3.2 Laboratory studies

3.2.1 Retention.

It is generally accepted that the retention of the polymeric fissure sealants currently available is largely due to mechanical interlocking between sealant tags and the system of pores in the etched enamel surface.

According to Low and von Fraunhofer, two sealant properties that are likely to influence its retention are dimensional changes following water resorption and transverse strength.[149] The ability of the tags to retain the sealant bulk depends largely on their adaptation to the walls of the enamel pores providing the necessary frictional resistance. Since each tag is maintained in a constant position by its associated pore in the enamel surface, changes in dimension of the sealant bulk would produce stresses at the point where the tags join the sealant bulk. The transverse strength of the material would give an indication of how much deflection or displacement the sealant tags are likely to be able to withstand before fracture occurs.

Three fissure sealants were investigated: *Nuva-Seal, Epoxylite 9075,* and *ESPE 71730*. Specimens were immersed in water at 37 $\pm$ 1^{o}C., and observed for three months at weekly intervals. All three fissure sealants expanded during the first six weeks. *Nuva Seal* and *Epoxylite 9075* continued to expand after the first six weeks, but achieved a stable dimension after about eight weeks. *ESPE 71730* began to shrink after approximately six weeks. The amount of expansion at the end of the month was 0.6 per cent for *Nuva Seal*, 1.6 per cent for *Epoxylite 9075* and 0.25 per cent for *ESPE 71730*. Transverse strength tests were conducted on a transverse loading jig on an Instron Universal Testing Machine, after 1 hour, 1 month and 3 months.

Nuva Seal had the highest flexural strength at all three test periods, and *Epoxylite 9075* the lowest (Table 23).

Table 23

Transverse strength

Fissure Sealant	Transverse strength (mean ± s.d. in kg cm^{-2}) At 1 h.	V(%)	At 1 mth.	V(%)	At 3 mths	V(%)
Nuva Seal	565.2 ± 51.3*	9.1	748.8 ± 24.5	3.3	714.0 ± 25.5	4.9
ESPE 71730	218.4 ± 24.5	11.2	484.8 ± 69.5	14.3	540.0 ± 76.1	14.1
Epolylite 9075	88.5 ± 6.2	7.0	84.8 + 6.7	7.9	78.0 ± 18.1	23.2

V, coefficient of variation. * Specimens deflected to 5.5mm without fracture.

Transverse strength of *Nuva Seal* at one hour was 76 per cent of its maximum value, which was reached at 1 month and decreased after that. After 1 hour, the transverse strength of *Espe 71730* was only 40 per cent of its maximum value which occurred at 3 months. *Epoxylite 9075* however, had reached its maximum transverse strength after 1 hour with its strength progressively decreasing over the next 3 months. The increase in strength of the 2 ultraviolet polymerised materials was attributed to continuing polymerization within the bulk of the material after the initial set. Decrease in strength of *Epoxylite 9075* was probably due to water absorption.

Dimensional changes occurring in the sealant can result in weakening or fracture at the bases of sealant tags, which might render the sealant more suscepitble to any dislodging forces during mastication and would probably partly account for the low rate of sealant retention in clinical trials.[149]

Tensile strength measurements are commonly used to assess the bond strength between an adhesive resin and enamel. In 1974, Williams et al reported the results of an experiment measuring the tensile bond strengths between different fissure sealants and enamel.[230] The materials used were three types of polymeric fissure sealants: *Nuva Seal, Epoxylite*

9075 and *ESPE 717;* a dental cement: Poly F and a glass ionomer cement, Aspa. Acrylic buttons were attached to the etched enamel surface of premolars, cured with the different materials in situ and immersed in water. Bond strengths were tested after immersing the specimens for 7 days and after 6 months at 37°C. Table 24 gives the figures of the forces required to separate the buttons from the enamel surface of the teeth.

Table 24

Separating Force (kg/cm^{-2})

Sealant	7 days	6 months
Epoxylite 9075	42.3 ± 23.3	16.1 ± 6.9
Nuva Seal	25.7 ± 11.2	34.6 ± 14.7
Espe 717	22.5 ± 9.8	12.2 ± 3.8
Aspa	16.0 ± 6.1	21.9 ± 10.0
Poly F	8.1 ± 3.0	13.0 ± 3.8

Nuva Seal had the most satisfactory bond strength to tooth enamel, both after 7 days and after storage in water for 6 months.[230]

Breakspere et al listed four situations which may arise if a sealant film is pulled away from the enamel surface:[40]

1. film and tags are pulled away completely.
2. the film is sheared off from the tags, leaving the tags embedded in the enamel surface.
3. cohesive failure occurs in the bulk of the film.
4. failure occurs in the enamel substrate.

Process 1 would occur if the surface forces at the polymer-enamel interface are less than the cohesive strength of the polymer. Process 2 and 3 are closely related, with a greater possibility of fracture occurring at the base of the tags, since the greatest stresses arise in this area. Process 4 can probably be a result of weakening of the enamel structure during the acid-etching process.

They also investigated adhesive bond strengths between sealants and enamel in various environments and also some mechanical properties. The fissure sealants used were *Nuva Seal, Epoxylite 9075* and *Elmex*.[40]

These were compared with other materials of different chemical characteristics, such as: Methyl-2-cyanoacrylate *(Eastman 910 Adhesive)*, Polymethyl methacrylate *(Croform, Davis, Schottlander & Davis)*, Zinc polycarboxylate *(Durelon, Espe GmbH)*, Nitrocellulose and Polytetrafluorethylene. The adhesives were applied to prepared ground surfaces of molar teeth and bond strength was measured with an Instron Universal Testing Machine. Compressive strength, tensile strength, hardness and abrasion resistance of the materials were also measured. Table 25 shows tabulation of the average adhesive bond strengths.

Average bond strengths recorded after immersing the teeth for 3 days in water are in the column headed "Wet". Etching the enamel before applying the polymers increased bond strength, whereas treatment with water decreased it. The values of the mechanical properties are presented in Table 26, only for the materials from which a suitable specimen could be obtained. No direct relationship exists between hardness of the polymers and their abrasion resistance.[40]

Williams et al evaluated the microhardness, water solubility and water absorption of fissure sealants, as an indication of the physical and possible chemical changes occurring in the materials, to assess their long-term suitability in the mouth.[229] The materials investigated were: *Nuva Seal, Espe 717, Aspa glass ionomer cement,* and *Poly F cement*. Five specimens of each material were prepared and six indentations made and measured at intervals of 1 hour, 1 month, 2 months, 3 months and 6 months.

Table 25

Adhesion of fissure sealants to tooth enamel

Polymer	Adhesive strength* ($N/m^2 \times 10^6$) Enamel not etched	Dry	Wet†	Decrease in adhesive strength on immersion in water	Improvement of adhesive strength on etching (%)
Nuva Seal	3.9 ± 0.3	10.8 ± 0.9	3.3 ± 0.3	69	175
Elmex	5.0 ± 0.4	5.7 ± 0.5	2.5 ± 0.2	57	14
Epoxylite 9075	3.7 ± 0.3	9.4 ± 0.8	3.9 ± 0.3	58	152
Zinc polycarboxylate	4.3 ± 0.4	9.4 ± 0.8	5.8 ± 0.5	39	118
Polymethyl methacrylate	6.8 ± 0.6	12.6 ± 1.0	7.7 ± 0.6	39	87
Methyl-2-cyanoacrylate	12.3 ± 1.0	20.4 ± 1.6	10.6 ± 0.9	48	65
Nitrocellulose	1.0 ± 0.1	0.8 ± 0.1	0.6 ± 0.05	21	-20
PTFE	0	0	-	-	-

† After three days' immersion in water at 298K.
* Each value is the mean ± s.d. of 14 separate determinations, 1.0 $N/m^2 = 1.02 \times 10^{-5}$ kg/cm^2.

Table 26

Mechanical properties of fissure sealants

Polymer	Compressive strength ($N/m^2 \times 10^6$)	Tensile strength ($N/m^2 \times 10^6$)	Hardness in^{-5} (cm^{-7})	Abrasion resistance (rev/0.025in)
Nuva Seal	102.9	28.9	98 (2.49)	1210
Epoxylite	63.2	25.9	104 (2.64)	805
Zinc polycarboxylate	50.9	12.7	96 (2.44)	670
Polymethyl mechacrylate	71.1	24.5	124 (3.15)	1260

Table 27

Mean microhardness values (kg/mm^2)

Material	1 hour	1 month	3 months	6 months
ASPA	114.66*	105.32	93.80	77.14
Poly F	59.05	60.47	64.47	84.02
Epoxylite 9075	26.85*	17.74	14.14	14.00
Nuva Seal	12.06	15.85	17.85	19.43
ESPE 717	12.48	15.05	17.44	15.42

* Figures for 24 hours

Table 28

Water solubility ($mg/mm^2 \times 10^{-2}$)

Material	1 month	3 months	6 months
ASPA	0.0917	0.0958	0.1595
Poly F	No results,	all specimens	fractured
Epoxylite 9075	0.1135	0.1323	0.1323
Nuva Seal	0.1225	0.1323	0.1427
ESPE 717	0.0436	0.0716	0.0569

Table 29

Water absorption ($mg/mm^2 \times 10^{-2}$)

Material	1 month	3 months	6 months
ASPA	0.7567	0.8183	0.9186
Poly F	No results, solubility specimens disintegrated during drying phase		
Epoxylite 9075	0.1885	0.2160	0.2019
Nuva Seal	0.1625	0.2148	0.1765
ESPE 717	0.1385	0.1535	0.1452

The figures for *Epoxylite 9075* and *Aspa* were obtained at 24 hours because of the initial resilience of the material making it difficult to obtain a clear value. (Table 27).

The microhardness of *Nuva Seal* increased progressively over 6 months, probably due to continuing polymerization reaction within the material. *Espe 717* showed an increase up to 3 months which decreased at the end of 6 months to the same value found at 1 month. Hardness of *Epoxylite 9075* was about the same at 2 and 6 months. *Poly F* showed an increase in hardness while *Aspa* exhibited progressive decrease over the 6 months.

For water solubility tests, specimens were weighed and immersed in water at 37 $\pm$ 1°C. After 1 month, 3 months and 6 months, the specimens were removed, dried in a dessicator and weighed again. Progressive increase in the net weight loss was found for *Nuva Seal* and *Aspa*. *Espe* showed a continuing weight loss up to 3 months. (Table 28)

For water absorption tests, specimens of each material were also immersed in water at 37 $\pm$ 1°C, the water being changed weekly. After 1 month, 3 months and 6 months, the specimens were removed from the water, excess surface water wiped off and weighed. It was also necessary to take account of the material lost by dissolution. The water absorption of *Nuva Seal* increased up until 3 months and then started to decline, as seen in Table 29, maybe because water ingress had reached a steady state. there being a possibility that the water was incorporated in some form within the material. Water absorption of *Espe 717* was lower than for *Nuva Seal*, reflecting the differing natures of the side chains of the materials. *Epoxylite 9075* has a similar water absorption figure as *Nuva Seal* at 3 months, and *Aspa* showed a big absorption value.[229]

Water sorption of the resin is possibly a significant factor in retention. Water may weaken or soften the resin by causing it to swell or by lubricating it internally. In vivo, tags might be expected to lose strength in proportion to their ability to absorb water.[115]

3.2.2 Depth of penetration

Ideally, a pit and fissure sealant should completely fill the pit and fissures and extend onto the enamel of the cuspal inclined planes without disturbing occlusal harmony.

Lee and Swarz, applying a polyurethane resin to 215 human extracted teeth found that the resin penetrated to the base of all fissures.[92]

Wright and Beck, however, using 2 ultraviolet light polymerized Bis-Gma resins and a chemically polymerized Bis-Gma resin, reported that in the depths of narrow fissures where the fissural width was less than 60-100mm. the resin did not penetrate into the total depth and a plug of debris was always observed beneath the sealant.[94] It seems that in such cases the sealant was simply forming a bridge across the fissural orifice between the cuspal inclined planes. Depending on the size of the orifice and the support offered by the cuspal inclined planes, a predisposition to potential weakness of the sealant may exist and its loss would re-expose the fissure. Also, wear will often result in complete loss of the sealant.

Powell and Craig investigated the frequency of complete penetration of Bis-Gma resin fissure sealants into wide and constricted fissures by means of photomicrographs.[181] Crowns of 260 sound upper premolars were used, The occlusal fissures were cleaned as well as possible by scraping with a fine probe. The teeth were divided into two groups; one group was coated with *Nuva Seal*, the other group with *Epoxylite 9075*. Each crown was then sectioned bucco-lingually, four sections were cut from each crown making a total of 1,040 sections. Three hundred and ninety had wide fissures and 650 had constricted fissures. It was found that 334 of the 390 wide fissures examined were completely filled with the sealants, whereas only 28 of the 650 constricted fissures were completely filled.[181]

The penetration of sealants into the pits and fissures depends upon:[203]

a. the geometric configuration of the fissure;

b. the presence of material deposits within the fissures;

c. the physical and chemical properties of the sealants themselves.

a. The geometric configuration of pits and fissures in any tooth may vary from a shallow, wide V form to a narrow, constrictive form which sometimes has a bulbous termination. All three types may be found in one tooth. Eko divided the pits and fissures into three kinds, according to their shapes, groove type, middle type and fissure type.[73] Shallow and wide fissures were often completely penetrated by the sealants. Deciduous teeth show fewer pits and fewer deep constrictive fissures, usually exhibiting a shallow, wide or narrow V configuration.[82]

b. Deep, narrow fissures were often filled with material which seemed to make resin penetration difficult and which remained, despite careful prophylaxis.[83,97] Taylor and Gwinnett tried the effect of different prophylactic procedures in resin penetration in permanent premolars and molars.[216] The teeth were divided into 4 groups: The first group was cleaned with a water slurry of pumice and a gently rotating rubber cup, the second group with a zirconium silicate paste and a gently rotating rubber cup, the third group with a water slurry of pumice and a gently rotating bristle brush, whereas the fourth group received a prophylaxis with zirconium silicate and a bristle brush.

A few teeth were also soaked in a sodium hypochlorite solution for 12 hours. Even with the use of the sodium hypochlorite solution, debris was still present in the deep fissures. All sealants exhibited a similar degree of penetration. Careless application of the sealant may also result in air entrapment beneath the resin, with incomplete penetration.[216]

In all instances, only the inclined cuspal planes were clean, whereas the pit and fissure entrance often remained occluded with debris, resulting in an incomplete penetration of the resin.

c. According to Fan et al, the rate of sealant penetration is a function of the crevice dimension of a fissure and the penetrativity of the sealant.[75] Penetrativity can be expressed in terms of a Penetration Coefficient (PC), which is a function of the properties of the sealant: surface tension, viscosity and contact angle on the capillary wall. An experiment with *Nuva Seal* showed that the PC of *Nuva Seal* was highly temperature-dependent. PC at 37°C was 2.5 times that at 25°C, which was mostly due to a decrease in the viscosity of the sealant at a higher temperature.[75]

A study to determine the effect of PC on the rate of flow of a fissure sealant into the pits and fissures was conducted by Apostolidis et al.[5] Experimental sealants were formulated in order of decreasing penetrativity using Bis-Gma resin and methyl methacrylate monomer, and applied on extracted permanent molars.

The range of PC was 0.07 to 1.31 cm/sec. among the polymer dilutions. It was found that PC with higher values were associated with better penetration, indicating that the PC was strongly associated with polymer penetration into the fissures of teeth.[5]

3.2.3 Microleakage.

Success of pit and fissure sealants depends upon the efficacy of the resin to seal these vulnerable areas and to maintain the seal for a prolonged period. If complete sealing is not achieved, or the seal is lost, even over a small area, the potential for the sealant to act as an anticariogenic agent is jeopardised.[201] Since it has been shown that other restorative materials leak at the tooth restoration interface, sealants may also exhibit microleakage at their margins. Several investigations have been conducted on the sealing ability of the sealants. Rudolph tested 2 commercially available pit and fissure sealants, *Nuva Seal* and *Epoxylite 9075* and another experimental Bis-Gma resin.[201] Sealing ability was measured on the basis of the ability of the fissure sealant applied on extracted human molars, to preclude the passage of ^{45}Ca. The specimens were stored in water up to three months and subjected to thermal cycling.

There were four instances of leakage among the *Nuva Seal* specimens 1 case of leakage with *Epoxylite 9075* and none with the experimental sealant. It was pointed out, however, that application of the sealant in vivo is more difficult than application in vitro and the teeth were not subjected to mechanical stress and occlusal wear.

Dennison et al, using an improved neutron activation method and dysprosium nitrate as a tracer to study *Nuva Seal, Epoxylite 9075* and an experimental α- cyanoacrylate resin on permanent molars, reached a similar conclusion.[63]

Another report on microleakage of sealants, determined by dye penetration and zero resistance current measurement studies, was given by Williams et al.[228] The materials consisted of *Espe 717* and *71729 Nuva Seal, Epoxylite 9075* and 2 cements, *Poly F* and *Aspa*. After the sealants were applied to premolars, the specimens were 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.

Nuva Seal appeared to be the most resistant to dye penetration. In the initial 2-week period of immersion, there was some degree of penetration at the interface. The authors attributed this to the leaking out of low molecular weight entities and viscous fluid, combining with the enamel at the sealant/enamel interface, sealing it against the ingress of solution. *Espe 717* and *Epoxylite 9075* exhibited more erratic leakage behaviour.

The differences between these two materials and *Nuva Seal* can be due to differences in the method of polymerization or the molecular constitution. *Aspa* and *Poly F* were very permeable in water owing to the hydrophilic nature of the polyacrylate matrix with carboxylate group which allows penetration of water through the cement mass. A zero resistance ammeter technique was used to measure the galvanic currents 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.[228]

Powell et al did a study in vitro and in vivo, using *Nuva Seal*.[183] For the in vitro study, the sealant was applied to the etched surfaces of 52 extracted premolars and molars. Twenty six of the teeth were used as an initial sample and prepared for production of autoradiographs. The other 26 teeth were immersed in physiologic saline solution and incubated for three months at 37^{o}C.

Sixty three teeth were selected as the in vivo sample. All the teeth were sealed in vivo, 10 of them were directly extracted as controls, the others were extracted over a period of 4 months for orthodontic treatment. The teeth were soaked in ^{45}Ca isotope solution for two hours.

Of the initial sample, eight teeth (31 per cent) exhibited leakage, while after incubation for three months, leakage was seen in 10 (39 per cent) of the teeth in vitro. Over the four months, leakage occurred in 40 per cent of the control teeth and in 48 per cent of the test teeth in vivo, with no correlation between the leakage patterns and the time of service in the mouth. Leakage occurred in 75 per cent of the upper premolars and in 43 per cent of the lower premolars. Twelve of the 16 teeth (75 per cent) of the teeth that were in occlusion at the time they were sealed showed leakage which is probably caused by the occlusal forces.

The authors were of the opinion that even though a high percentage of the specimens showed leakage, the same penetrations may not be possible for larger molecules. So that, even though leakage occurs, food particles and plaque cannot gain access to the pit and fissure areas as long as the sealant remained intact on the tooth surface.[183]

Pink et al investigated bacterial penetration around a fissure sealant in vitro.[179] Freshly extracted caries free human molars were prepared by cutting 3-4mm. off the root apex and opening into the pulp chamber. After *Nuva Seal* was applied according to the directions of the manufacturer, the teeth were sealed into petrie dishes with an epoxy resin. The apparatus was sterilized in ethylene oxide and a paper point was placed from the apex to the base of the sealant. The pulp chamber was filled with cotton pellets and the apex closed with epoxy resin. Sterile trypticase soy broth was pipetted into the upper compartment of the petrie plate.

After innoculation with either streptococcus mutans or C. histolyticum, the samples were incubated for 2, 4, 6 and 8 days at 37^{o}C. Bacterial penetration was assessed by a cloudy appearance after the paper point was aseptically deposited in a test tube and verified by a gram stain and organism identification. Forty two out of 68 samples (61.8 per cent) exhibited some bacterial penetration between the sealant and the enamel interface, which means that in this study, *Nuva Seal* does not seal out bacteria in all instances.[179] This observation was similar to that reported by Mednick et al.[159]

Another microleakage study was done by Powell and Craig, using sodium carbonate -^{14}C, D-glucose-^{14}C and sucrose-^{14}C as tracers to investigate leakage occurring in 120 sound freshly extracted contralateral pairs of upper premolars sealed with *Nuva Seal* and *Epoxylite 9075*.[182]

Different pairs of teeth were subjected to one of the following treatments:

-thermal cycling - 200 cycles (4^oC to 60^oC.)

-aging 3 months at 37^oC

-aging 6 months at 37^oC

-control - 24 hours at 37^oC.

Thereafter the teeth were immersed in the appropriate isotope for 48 hours at 20^oC and sectioned. Autoradiographs were prepared and showed that tracer penetration along the entire tooth-resin interface occurred in 53.3 per cent of the *Nuva Seal* sealed teeth and in 38.3 per cent of the *Epoxylite* sealed teeth. Slight penetration was observed in 21.7 per cent of the *Nuva Seal* specimens and in 22.5 per cent of the *Epoxylite 9075* specimens and no tracer penetration in 25 per cent and 39.2 per cent of teeth treated with *Nuva Seal* and *Epoxylite 9075* respectively. Thermal cycling tended to increase the incidence of microleakage while aging tended to decrease it.[102]

Jensen and Handelman applied 6 different fissure sealants: *Concise Enamel Bond System, Delton, Epoxylite 9075, Kerr Pit and Fissure Sealant, Nuva Seal* and an experimental filled sealant to 48 caries free third molars.[124] After a week's storage in water, the specimens were thermal cycled at 1 minute intervals for 2 hours at 60 ± 3^oC. and 8 ± 3^oC. and then immersed in a 0.25 per cent aqueous solution of basic fuchsin for 24 hours.

Of the 48 specimens, the 8 teeth covered with *Epoxylite 9075* suffered the most. Two 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.[124]

These findings differed with the study of Speiser and Segat, who studied the sealing properties in vitro of *Delton, Nuva Seal, Epoxylite 9075, Kerr Pit and Fissure Sealant,* and *Concise White Pit and Fissure*

Sealant on 175 extracted mandibular and maxillary premolars and molars.[211] The specimens were thermal cycled in dye baths of 0.5 per cent basic fuchsin alternately between 10°C. and 70°C for 600 one-minute intervals. *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 of the resin groups.[211]

3.2.4 Sealant wear.

After a while in the oral cavity, the sealant layer becomes thinner and wears away due to occlusal and masticatory forces. Roberts et al investigated the wear of three commercial pit and fissure sealants, *filled Kerr Pit and Fissure Sealant, Delton Pit and Fissure Sealant, Nuva Seal*.[191] Samples of each sealant 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, the addition of 40 per cent quartz to the *Kerr Pit and Fissure Sealant* increased its resistance to penetration and dramatically altered the extent of surface damage done by the diamond transversing its surface, with it having the lowest value and *Nuva Seal* having the highest value of surface failure.[191]

The quantitative wear of sealants in vivo was assessed by Jensen et al, using a tooth replica technique.[125] *Nuva Seal* or an experimental filled sealant was applied on 32 caries free premolars and molars. Pre- and post-sealant impressions were obtained with an elastic impression material. Silver copings were made by electroplating the vinyl-epoxy dyes of the immediate post-sealant impressions. New impressions and new dyes were made at the 7 and 16 months recall visits.

Impression material was placed in the coping prior to placement of the pre-sealant dyes to determine the amount of sealant applied. The amount of sealant lost was determined in the same way, using the recall dyes and their respective copings. The amount of filled sealant applied was greater than the amount of unfilled sealant applied, a volume difference of 30 per cent in the molars. It was found that the greatest sealant loss occurred within the first seven months, with an average sealant loss of about 80 per cent for the molars and 65 per cent for the premolars. Although more sealant was applied to the molar teeth initially, it was lost at a more rapid rate. The two types of sealants appeared to wear equally.[125]

Merrill et al also used resin dyes to follow the wear and attrition of sealants in vivo.[164] The dyes were prepared from impressions and sectioned at fixed positions. Comparisons of the changes in occlusal silhouette as a function of time permitted evaluation of the sealants in places where total displacement had not occurred.

4. THE USE OF FISSURE SEALANTS IN DENTAL HEALTH SERVICES (INCLUDING PRIVATE PRACTICE)

4.1 Criteria for selection.

The utilisation of fissure sealing can be done under two conditions: 1. in a private practice,
2. in a public health programme.

1. In a private practice, fissure sealing can be easily integrated into the daily routine along with topical fluoride treatments. The dentist is sometimes forced to decide whether to seal a tooth or wait for a possible carious lesion to develop. According to Silverstone this is actually comparing a preventive regimen with a restorative approach.[204]

Observations have shown that sealant therapy is not indicated for all teeth.[105] According to Ripa, the selection of teeth for treatment should be done on an individual basis and determined by such factors as:[190]

a. The caries susceptibility of the individual occlusal surfaces;
b. The general caries activity in the mouth;
c. The length of time the tooth has remained caries free;
d. The patient's preventive regime.

a. Not every tooth has the same susceptibility to caries. A two-year study has been done on the occlusal caries incidence of permanent premolars and molars in Rochester, New York.[190] (Figure 7.). All selected teeth had been judged clinically sound. During the two years, there was a gradual increase in occlusal caries in the first premolars (21.2 per cent carious) and second premolars (31.1 per cent carious), whereas the caries incidence of the molars had risen sharply, with caries in 75.2 per cent of first molars and 84.5 per cent in second molars.

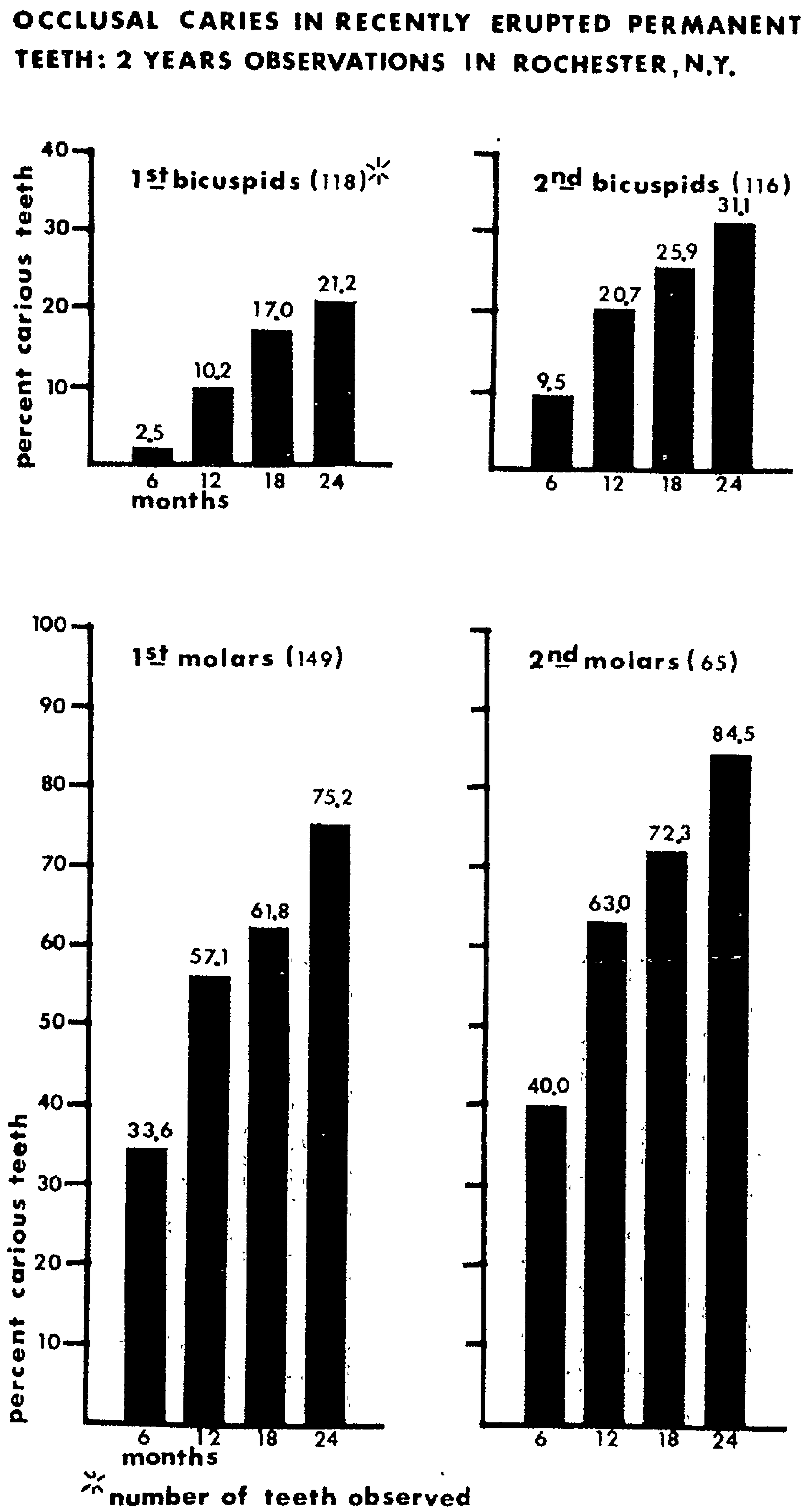

Figure 7: Two years' occlusal caries incidence of permanent premolars and molars.

The pattern of caries attack in different tooth types needs to be considered too, as an additional criteria for sealing.[91] It is known that the initial caries attack in a particular tooth type occurs most commonly on the occlusal surface and seldom on the proximal surface, at least not until some years later, then fissure sealing is likely to be of benefit. But if caries in a particular tooth type occurs most frequently in a proximal surface, then there would be little point in sealing the occlusal surfaces of these teeth, as they would often need an occluso-proximal restoration anyway.

A tooth with shallow, well-coalesced pits and fissures is less likely to develop caries than a tooth with narrow and deep fissures. Some dentists have elected to seal all occlusal surfaces, regardless of their liability to decay; others prefer to seal only those surfaces which they consider highly susceptible.

b. In every population there are individuals who are caries free or highly resistant towards caries. Such patients do not require fissure sealants, as natural protection appears to exist in these cases. Therefore, the previous occlusal caries experience is a determining factor in the dentists' decision to use a sealant.[227]

If a child has several occlusal carious lesions it is a good precaution to seal the other teeth. But if there are many interproximal cavities as well, sealants should only be used on non-carious teeth if additional efforts are made to prevent interproximal decay.

c. Recently erupted teeth, especially molars, should be sealed as soon as possible since these teeth are known to be susceptible to decay. That means that 6 to 8 year old children should be the priority group for fissure sealing.[46] If the tooth has been in the mouth for a long time and is still sound, the chances of it developing decay are minimal and such teeth need not be sealed.

In mature adults, whose vulnerable teeth have already been lost or restored, there is little point in applying fissure sealants because the remaining sound teeth are already naturally resistant. This has also been pointed out by Eden, who did a clinical evaluation on the effects of *Nuva Seal* used for naval personnel 18 to 23 years of age.[70] For 719 treated pairs, the net gain was only 7 occlusal surfaces and the percent effectiveness was 37 per cent.

d. Occlusal sealing is suited for use as a component of a multiple caries preventive approach. As previously mentioned, the effectiveness of a sealant is greatly reduced if a sealed tooth develops a proximal cavity and has to be restored with an occluso-proximal restoration. Therefore, topical fluoride applications, proper oral hygiene procedures and proper diet are important measures which should be carried out in conjunction with the application of sealants.

The cost of fissure sealing is determined by the dentist, based upon internal office economics, and the fee paid by the patients. Suggested re-examination for sealed teeth is 6 months, which corresponds with the usual recall schedule. The cost of the initial application plus subsequent re-applications if sealant is lost, may conceivably be greater than if the teeth had received occlusal restorations. However, if the teeth can be spared from ever developing dental decay the caries free status achieved may well be worth the extra cost.

2. In a public health programme, a lot of considerations need to be taken into account if fissure sealants are to be used. The results of clinical trials conducted in field situations were not as good as the results from studies where the sealing was done in a dental office. This was because dental offices are usually constructed to provide good working environments, where application of the sealant needing a meticulous technique could be done as ideally as possible. Public health programmes, on the other hand, must often be conducted under less ideal conditions.

In a dental office sealant application is usually done by the dentist. In a public health programme however, delegation to dental therapists is desirable to provide maximum delivery of dental services. Whether they may be legally engaged in applying sealants depends upon the dental practice Acts of individual States and countries. In the State of New York for instance, the Dental Practice Act prohibits the placement of pit and fissure sealants by dental hygienists.[146] But, according to a questionnaire held in January 1974 in the United States to assess the attitudes of practising dentists towards some expanded functions for dental hygienists, over 80 per cent indicated that they would allow dental hygienists to apply sealants.[146]

In February 1974, the A.D.A. Council on Dental Materials and Devices made a few statements, among which two are of particular importance:[220]

1. "The procedure of placement of pit and fissure sealants is considered safe when used by properly (maximally) trained auxiliary personnel under the direct supervision of a dentist".

2. "The decision to use and the placement of such products should continue at present to be the responsibility of the profession".

Another consideration in the use of pit and fissure sealants in a public health programme is whether the programme will be held in a non-fluoridated or fluoridated community. An analysis of data derived from the pattern of treatment for first permanent molars in New Zealand school children from non-fluoridated and fluoridated areas was carried out by Roder.[198] Two hundred children from each area were examined.

In the non-fluoridated communities, occlusal restorations were required in 93.6 per cent of the children at a mean age of 7.29 years and 62.6 per cent needed this care prior to the eighth birthday. There was no appreciable difference between quadrants or sexes.

Seventy one point six per cent needed a mesial restoration with occlusal extension at the mean age of 9.1 years and 21.1 per cent needed a distal restoration with an occlusal extension at the mean age of 10.56 years, so that the mean age at which occlusal surfaces first needed care was almost 2 years before the comparable age for the mesial surfaces and over 3 years for the distal surfaces. Therefore, over 60 per cent of the teeth were first restored with an occlusal filling and subsequently with an occluso-proximal filling after almost 2½ years. It can be hypothesised that if the occlusal surface of these teeth were sealed soon after eruption, one round of operative treatment would be eliminated for many children.

In the fluoridated community, there was a distinction made between boys and girls, where 79.3 per cent from 100 boys required occlusal restorations at a mean age of 8.9 years, and 85.3 per cent of 100 girls at an age of 8.46 years, whereas 22.5 per cent of the boys and 29.5 per cent of the girls needed this care before their eighth birthday. Overall, 37.8 per cent needed mesial restorations with an occlusal extension at the mean age of 10.09 years, and a distal restoration with occlusal extension was needed in only 2.9 per cent at 10.35 years. So that in a fluoridated community, almost half (44 per cent) needed treatment occlusally, but not occluso-proximally. Over 25 per cent of the teeth which had an occlusal filling were consequently filled with an occluso-proximal filling after a mean period of almost 3 years. According to these figures, the need for occlusal fillings of first molars is reduced appreciably by the use of fissure sealants.[198]

The cost of fissure sealant application in a public health programme is an important factor to consider and must be weighed against the benefits to be derived and compared with the possible results achieved if alternative preventive methods are used.

Leake and Martinello had calculated the cost-benefit ratio of the use of a fissure sealant in a public health programme in 1971.[135] (See Chapter 3 1. page 86.

The cost-effectiveness of applying *Nuva Seal* on one upper and one lower permanent molar in children aged 6-8 years in East Lancashire was calculated by Higson.[103]

The individual cost of the *Nuva Seal* lamp was about 200 pounds but assuming fairly continuous use, the cost per application was negligible. Likewise, the costs of materials used in the sealing process and in the provision of fillings were small per unit and can be ignored. Professional time was the greatest cost involved, and a useful measure of cost-effectiveness was obtained by calculating this factor. The average time taken to give a prophylaxis and apply the sealant was 15 minutes per child, or 7.5 minutes per tooth (2 molars, upper and lower). Thus the cost of application was:
7.5 minutes of dentist's time + 7.5 minutes of dental auxiliary's time =

7.5 units of time.

The average time taken to complete an amalgam filling, including the administration of a local anaesthetic was:
15 minutes of dentist's time + 15 minutes of assistant's time =

15 units of time.

After two years 45 children were available for re-examination. The number of sealed teeth which became carious was 37, the number of carious control teeth was 48.

The number of fillings saved over the 2 year period =

48 - 37 = 11.

Cost of fillings saved=11 x 15 = 165 units of time.

Cost of sealant applications to 90 teeth =

90 x 7.5 units = 674 units of time.

Cost effectiveness = 165/675 = 0.24.

This means that in order to achieve a cost-effectiveness of 1.0, a saving of 675/15, that is, 45 fillings would be needed. This would represent an almost complete elimination of caries in the sealed teeth.[103]

Burt had made a tentative analysis of the efficiency of allocating resources to fissure sealing, rather than to restorative procedures in a public dental programme during a 2 year trial in London.[44] He compared the time taken for sealing and placing the restoration, in order to reach the objective; that is, no clinically detectable lesions in initially sound permanent teeth after 2 years.

The time taken for respective operations, hence salary costs, is an important factor. Other factors are the cost of training the operator and the assistant, the cost of equipment and materials used and the cost of clinical facilities. In a school dental service, personnel training costs, dental equipment, salaries and facilities are the same under either alternative (so that the time factor has to be considered in the analysis). The average time required for restorative treatment was taken for 2 sources, one was from stop-watch observations of a dentist working with one chairside assistant; the other was from one dentist working with 2 chairside assistants.

The sealants were placed by a dentist working with one chairside assistant. Two hundred and thirty four pairs of teeth in 118 children were sealed with *Nuva Seal* without a previous prophylaxis. The mean time to apply the sealant to one tooth was 5.3 minutes, to two teeth 4.6 minutes, to three teeth 35 minutes and to 4 teeth 3 minutes, a mean of 4.2 minutes per tooth and 8.5 minutes. Once teeth are isolated and dried it has taken only relatively little time extra to seal additional teeth. The overall time for sealing 234 teeth was 999 minutes.

After two years, 56 of the control teeth needed one surface filling, with an average time per procedure of 10.4 - 11.9 minutes per procedure and 5 teeth needed a two-surface filling, with an average time of 15.7 - 16.7 minutes per filling, so that the total time required to fill 61 teeth was 660.9 - 749.9 minutes. This means that the time required for treating the control teeth which became carious was still from 24.9 per cent to 33.8 per cent less than the time required to apply the sealant.[44]

Another report on cost-effectiveness of sealants as an alternative to conventional restorations was done by Leverett et al.[145] Non carious and carious first permanent molars with no proximal lesions on one side of the mouth in study subjects were sealed with *Nuva Seal*, whereas carious occlusal surfaces of the first permanent molars on the 130 subjects have been followed for three treatment series and 360 subjects for two treatment series.

Although sealant placement reduced caries increment by about 75 per cent, the cost of initial placement and replacement of sealant was more than the cost of conventional restoration with amalgam. When the sealant was placed over a carious lesion instead of a restoration with amalgam, the initial placement was cost-effective, but not enough data were available to determine resealing costs. The authors were of the opinion that selective placements and better retention of sealants was necessary to improve the cost-effectiveness of the procedure.[145]

Diagnosis and criteria of carious teeth for the selective use of fissure sealants.

Many investigators had encountered difficulties in accurately deciding whether or not caries was present in a fissure, using visual and tactile methods. There was often a variation in diagnosis made by different examiners and by the same examiner.

Findings have indicated that when a probe inserted with light pressure in a pit and fissure becomes "stuck" and required a definite pull for removal, there was some degree of caries present in 70 per cent of the cases. In other words, 70 per cent of the "sticky" fissures had carious lesions.[166] In the other cases, a probe catching in the fissure may be only due to the physical characteristics of the fissure.[200]

However, Rock argued that the weakness in the identification of early occlusal caries on the evidence of a probe lies in the fact that it is not so certain that absence of "stickiness" means that the depth of the fissures are sound. In a deep narrow fissure, which may widen further down and extend almost to the dentine, the probe may fail to enter and caries could be present. With radiographs, from 5 per cent to 51 per cent more lesions could be detected.[194]

In some circumstances, debris and organic material in the fissures will take up stain and usually appear brown, which is not necessarily indicative of caries formation.

The scoring of teeth for caries varies with different investigators, for example:

a) 0 = unstained, explorer doesn't catch.
   1 = stained pit or fissure, but explorer doesn't catch.
   2 = stained or unstained, explorer catches something, but without sticking or penetration.
   These teeth were considered caries free.[34]

b) Caries free (code 0): unstained fissure, explorer can't be admitted.
   (code 1): fissure stained or probe catches in fissure with moderate pressure.
   Caries (code 2): visually obvious caries, or softness detectable with explorer at the base of a stained fissure.

   Sealant was applied to teeth classified as 0 or 1, but not to those graded 2.[46]

c) 1 = caries free, no stain and no areas easily caught by explorer.
   2 = caries free, stained but no pitted areas.
   3 = caries free, pitted areas, demonstrable with explorer, may or may not also be stained.
   4 = objectively demonstrable caries or site filled.

c) 5 = objectively demonstrable caries on mesial or distal surface of tooth.

6 = tooth unerupted or exfoliated.

Teeth with score 4-6 were excluded from the study.[193]

d) 0 = definite fissure - relatively smooth with no stain.

1 = definite fissure - relatively smooth with stain.

2 = definite fissure - light catch of explorer with no stain.

3 = definite fissure - light catch of explorer with stain.

4 = definite fissure - catch supports the end of the explorer.

Teeth rated 0, 1, 2 or 3 and no proximal decay were included.[135]

e) C0 = no sign of caries.

C1 = thin known line at base of fissure, no breakdown of visible changes in walls or fissure.

C2 = one or both of the following:

thick brown line at base of fissure, white change in walls of fissure.

No breakdown of enamel.

C3 = breakdown in walls of fissure, with break in enamel or shadow or opacity beneath enamel of less than 1.5mm. measured across the fissure.

C0 and C1 were considered caries free. C2 and above were scored as carious.[103]

If there is any doubt about the presence or absence of caries, Ulverstad suggested that the fissure be opened with a thin diamond bur to allow for a closer inspection. In cases where a small carious lesion is found, the caries can be removed, the cavity lined with a base if necessary and a combined cavity filling and sealant can be placed.[225]

According to Moeller, with the caries progression pattern and the caries progression rate in mind, the proper age groups for receiving pit and fissure sealants are the following:[167]

1. 3 years (all primary molars erupted)
2. 6 years (first permanent molars erupted)
3. 9-10 years, may be (premolars erupted)
4. 11-12 years (second permanent molars erupted).

Each age group is checked once every 6 months after the sealant has been placed.[167]

4.2 Materials and methods

As already mentioned, there are two kinds of fissure sealants according to the method used to induce polymerization; chemically polymerized fissure sealants and ultraviolet polymerized fissure sealants. Various brands of Bis-Gma sealants are commercially available, with different methods of handling, but only four examples will be given here.

A. *Nuva Seal.*

The *Nuva Seal* set consists of a kit containing individual bottles of resin, bottles of catalyst, conditioning solutions, cleaning solutions, brushes and wood splints, and the *Nuva Lite.*

Method of application:

1. The tooth surface to be sealed is cleaned with a prophylactic paste, using a bristle brush. It is then thoroughly rinsed with a water spray. An explorer tine is used to dislodge particles of prophylaxis paste from the orifice of the pits and fissures.

2. After the tooth is dried and isolated with rubber dam or cotton rolls, a cotton pellet held by tweezers and saturated with the conditioning solution is gently moved over the enamel surface up to the tips of the cusps and the edges of the marginal ridges. This will take approximately 1 minute if the tooth has not been exposed to fluoride treatment before, but can be 2-2½ minutes on teeth with optimal fluoride exposure.

3. After etching of the enamel, the conditioning solution is then thoroughly rinsed off with the water spray. Care should be taken that the water does not contain oil.

4. If a rubber dam is not used, new cotton rolls are immediately inserted to isolate the tooth from saliva contamination and tongue movements. The surface is dried with warm compressed air for approximately 10 seconds. The etched surface should have a uniform

dull, whitish, satiny appearance. If patches of shiny surface are observed, the conditioning solution should be applied for an additional 60 seconds or until the desired surface appearance is achieved.

5. *Nuva Seal* is prepared by adding 1 drop of catalyst to 1 ml. of resin in its individual bottle and mixing thoroughly. It is then applied with a camel hair brush. The sealant should be gently applied onto the surface to avoid bubble formation at the enamel interface and in the body of the sealant. It should fill all fossae, bridging the gap between the inclined cuspal planes and form a featheredge with the cuspal ridges.

6. The sealant is then polymerized by exposure to the *Nuva Lite* for 10-15 seconds. The end of the quartz rod is moved slightly over the surface, so that all parts of the sealant are exposed to the ultraviolet light.

7. The degree of hardening can be checked with the point of an explorer. Following polymerization, a very thin layer of air inhibited unpolymerized sealant remains on the surface which should be wiped off with a cotton roll. The occlusion is then checked. Slight occlusal interference usually adjusts itself in a few hours. Of course, several teeth can be treated in one sitting, usually in one quadrant.

B. *Nuva Cote*.

Nuva Cote has been produced to take the place of *Nuva Seal*, with better properties. It is lightly filled so that its abrasion resistance is higher than the unfilled sealants, and is easier to detect on recall examinations. Preparation of the tooth surface is the same as with *Nuva Seal*. However, *Nuva Cote* is pre-activated/ initiated, so that there is no need for mixing.

C. *Epoxylite 9075.*

Epoxylite 9075 is the chemically polymerized fissure sealant frequently used in clinical and laboratory trials. The kit contains bottles of resin part A, resin part B, cleanser, primer, a vial of activator powder and applicator syringes.

Method of application.

1. Prior to first use of the sealant, the entire contents of the activator vial is emptied in to the bottle with resin part A. This is shaken for approximately 3-5 minutes until the activator is completely dissolved. The colour-coded syringes are filled with resin part A, resin part B and the primer.

2. The tooth is celaned with a brush and pumice, and rinsed.

3. After drying and isolating the tooth is dried. A cotton pellet with *epoxylite fissure cleanser* is dabbed onto the occlusal surface of the tooth for 30 seconds up to 2 minutes.

4. The cleanser is rinsed away, and the etched tooth is carefully dried with a stream of warm air.

5. Two or three drops of fissure primer are applied by syringe. The primer has a low viscosity, spreads over the entire occlusal surface and displaces any water that may remain in the pits and fissures. The tooth is dried again.

6. One or two drops of resin part A is applied by means of syringe to the tooth surface. An equivalent amount of resin part B is then applied on top of the first sealer. Interdiffusion of the two resins produces polymerization directly on the tooth surface, which usually takes about two minutes. Excess unpolymerized sealant should be wiped away with a cotton pellet and the hardened surface checked with an explorer.

7. To facilitate detection of the sealant on recall, the sealant has a dye incorporated which fluoresces under ultraviolet light. A Dental Examination Light which emits ultraviolet light was designed for this purpose.

D. *Delton*.

Delton is a relatively new product from Johnson and Johnson which shows promise and is easy to apply. The kit contains bottles of universal resin, catalyst and etching liquid, a special applicator with disposable nozzles, mixing pads and mixing spatulas. (Figure 8 and 9)

Method of application.

1. The tooth is cleaned as usual, isolated, and etched with the etching liquid and dried.

2. One or more drops of universal resin, depending on the amount needed, is put onto the mixing pad. An equal amount of catalyst is added and the mixture is stirred for 15 seconds.

3. The applicator is filled and the sealant is applied directly on to the tooth.

Figure 10 shows a freshly sealed tooth. The surface of the resin is normally quite smooth when checked with an explorer. An occasional catch may be noted, which is due to air bubbles that may be present at the surface prior to polymerization.

When the resin hardens, the surface of the bubble may break, leaving a small depression. Small depressions can be ignored, whereas larger ones are filled by quickly adding or re-applying a dab of sealant over them. The transition from the sealant surface to the enamel surface should be imperceptible.

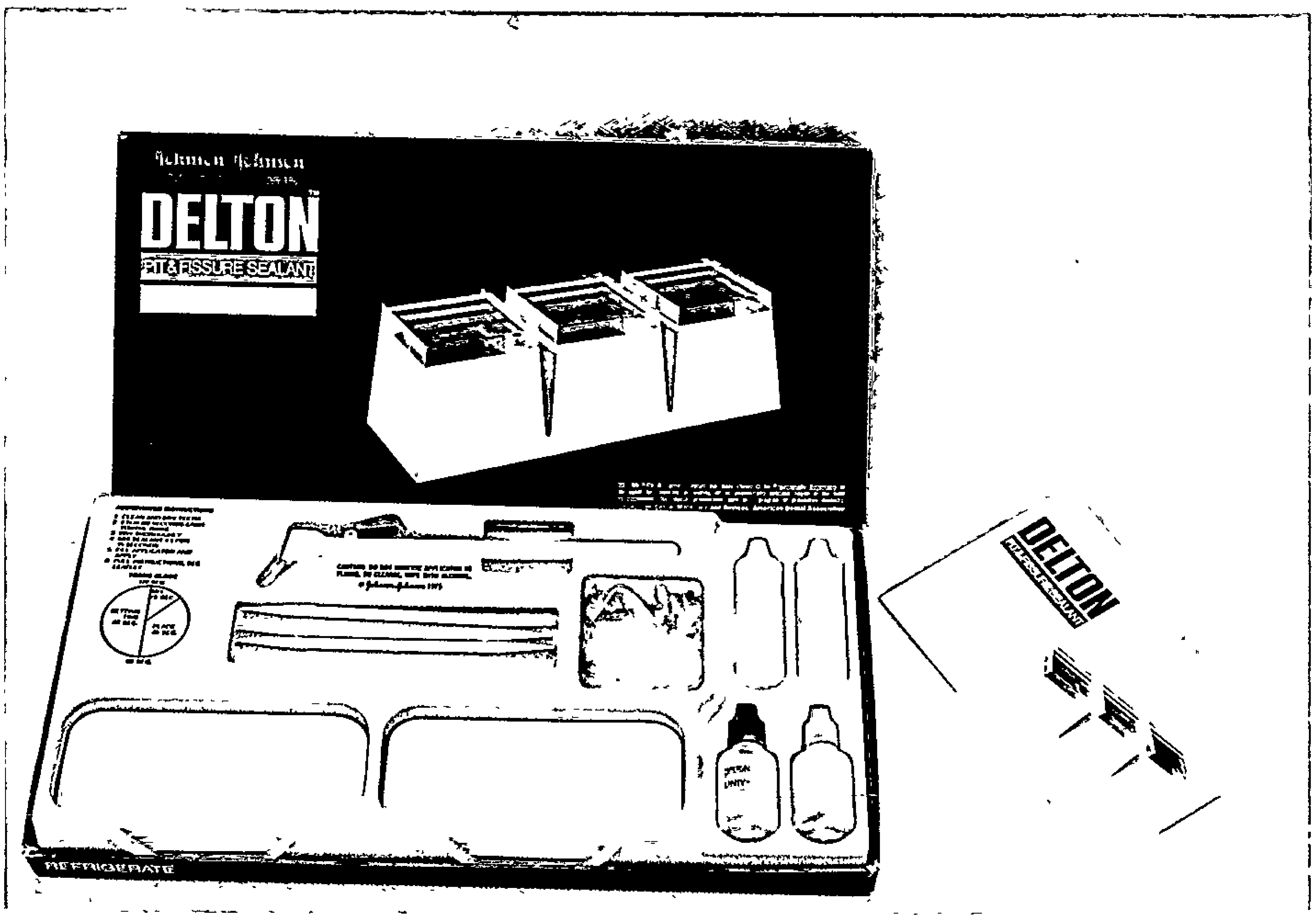

Figure 8: *Delton* kit.

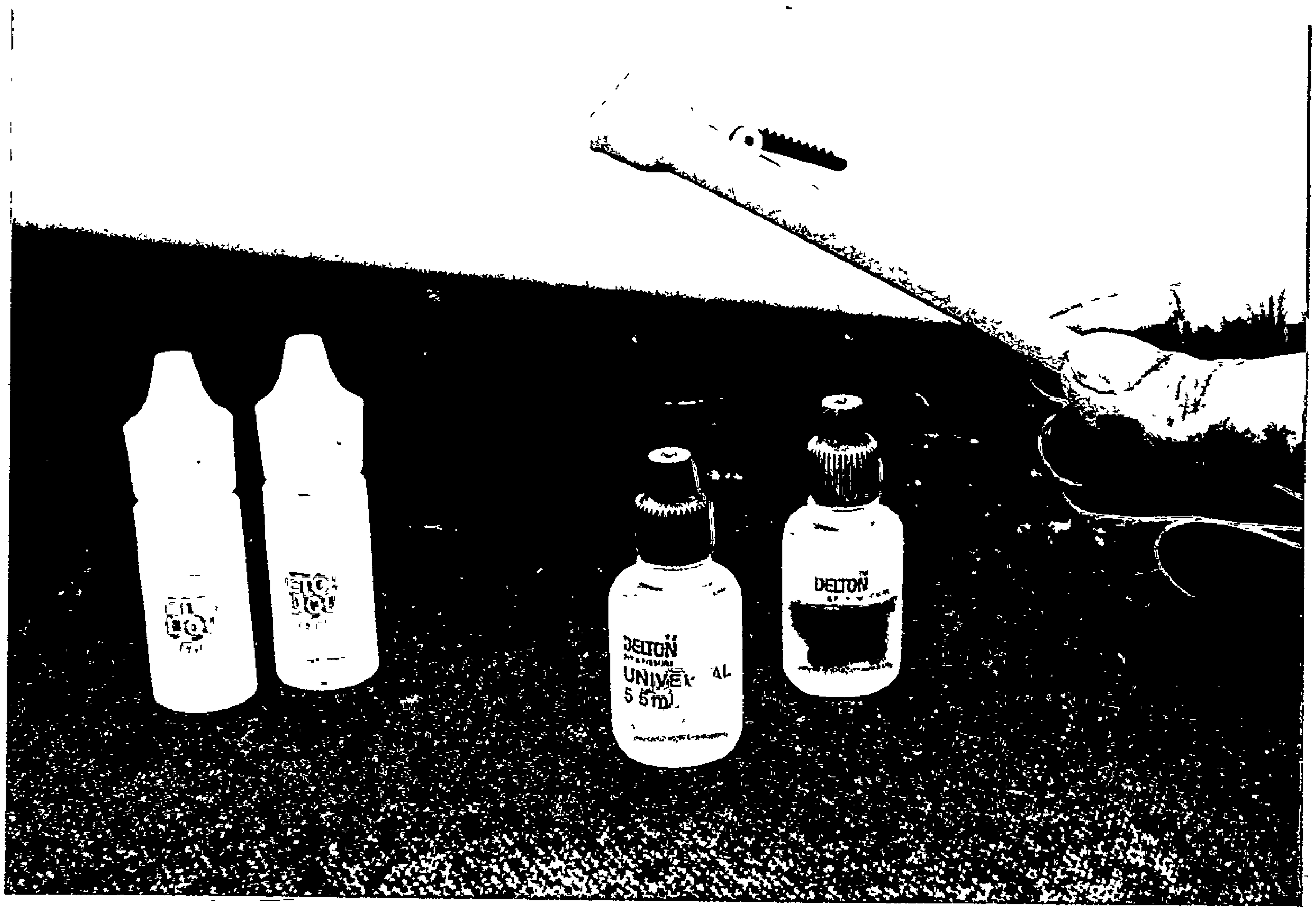

Figure 9: *Delton* etching liquid, universal resin, catalyst and applicator.

Figure 10: A freshly sealed tooth.

4.3 <u>Factors affecting the success/failure of fissure sealants</u>.

Fissure sealants to be effective must be retained in a good condition on the occlusal surfaces of the teeth for as long as possible. Therefore, success/failure of fissure sealants, besides lying in their inherent physical properties, depend also on strict adherence to certain requirements, the most important ones being:

1. Proper surface preparation:

(a) Prophylaxis.

The prophylaxis paste used should not contain a material which has an oil base or other organic matter which might be worked into the enamel surface and interfere with bonding.

(b) Acid etching.

The acid and its reaction products with enamel must be thoroughly removed by washing with a jet spray of water for about 10-15 seconds.[33] When using a colourless etching liquid, it is rather difficult to estimate the precise area of application and to ensure that no acid remains after the etching is finished. Also, occasionally there will be a thin film of dental plaque left which, if not completely removed, will affect the bond. Therefore an etching agent was developed which enables the operator to determine the area over which the acid has been placed, because it shows a bright yellow-green appearance.[114] After a while the colour becomes blue and finally dark violet. The green to blue change signifies the occurrence of a reaction. The violet colour indicates that the etch is complete. When the solution is washed away with water, any residual acid or any remaining plaque will give a blue or bright purple colour to the tooth surface, which has to be removed.[114] Washing also eliminates loosely bound debris and is more likely to assure microspaces in the enamel for penetration of the sealant. At this point, contact with saliva should be avoided since the conditioned enamel readily absorbs salivary constituents that may reduce the free surface energy and render it less favourable for bonding.[199]

Natural oil from the skin represents a source of contamination too. Touching the prepared enamel surface after etching is therefore contraindicated. In the event that contamination does occur accidentally, the process should be started again from the beginning. The enamel should be properly etched, characterised by a uniform, dull, frosty white appearance.

(c) Drying the enamel surface.

The tooth should be properly isolated during and after etching, so as to maintain a completely dry field. A stream of warm compressed air that does not cool the enamel surface and favour moisture condensation can be used. Care should be taken that the air line does not contain water or oil. To check the presence of moisture, the air can be blown onto a mirror to see if there is any condensation. It is possible to install a filter capable of removing moisture and oil in the line. In partially erupted molars, where soft tissue is slightly covering part of the tooth, strands of cotton can be placed in the sulcus, displacing the soft tissue from the ridge of the tooth.[112]

2. Proper mixing and application of the sealant:

The sealant is applied immediately after the enamel surface has been dried, evenly spread into the pits and fissures to minimize internal and surface bubbling that usually leaves voids and constitutes weak parts in the sealant. These defects can be the cause of partial or perhaps later on, total loss of the sealant.[212]

For the chemically polymerized sealants which need mixing, the mixing should be done properly and applied as quickly as possible to the occlusal surface. Once the mix begins to gel, it will not wet the enamel surface or penetrate into the pores, so that the adhesive bond will be greatly reduced.

Breakspere reported the results of varying the time of etching, the method of application, the viscosity of the sealant and the effect of moisture on the tooth surface in vitro.[41] The sealant used was *Nuva Seal*. The presence of tags on the underside of the sealant in contact with the enamel was investigated. The underlying enamel was dissolved with 50 per cent HCl, the back of the sealant was shadowed and observed in the scanning electron microscope.

(a) Effect of time of etching.

Sections of the occlusal surfaces of human molars were etched for one, two or three minutes. The sealant was brushed into the etched enamel surface for 30 seconds and then polymerized. There was an increase in the length of the tags, with an increase in the time of etching.

(b) Effect of method of application.

A molar tooth was divided into 4 quadrants and etched. One was used as control, the other three being treated with sealant applied by:

- brushing with a small brush for 30 seconds,
- dabbing onto the enamel surface for 30 seconds, using a cotton wool swab,
- applying a drop on the surface and leaving it for 30 seconds.

It was found that the largest number of tags were obtained by brushing the sealant into the etched enamel surface.

(c) Effect of viscosity.

A selection of monomer solutions of different viscosities was prepared by mixing finely ground polymerized *Nuva Seal* with the monomer in varying solutions. Each solution was applied by the different methods used to test the method of application. When the sealant was brushed into the etched enamel surface, no difference was found in the number and length of the tags using the different solutions.

(d) Effect of moisture on the enamel surface.

Four quadrants of an occlusal surface of the same tooth were etched for one minute. One was dried in the usual manner, the other three were wetted with distilled water and the surface moisture removed with absorbent paper. The sealant was also brushed into, or left as a drop on the dampened enamel surface. In all cases, the depth of penetration into the enamel of the tags were less than that found in dry etched enamel and the large number of small tags usually detected were missing.[41]

Hinding and Buonocore investigated the effect of a substitute etching solution and an aged sealant on sealant retention in premolars and molars.[105] The solution used was 57.3 per cent orthophosphoric acid, 25.7 per cent water, 9.7 per cent aluminium hydrate and a 7.3 per cent by weight aqueous solution of dissolved zinc oxide. The sealant, probably *Nuva Seal*, was aged experimentally and partially polymerized to increase its viscosity and to simulate the effect of storage in the dental office.

After two years, sealant retention for the teeth etched with the experimental solution and the aged sealant was found to be 32.4 per cent compared with 88.9 per cent retention found in teeth etched with 50 per cent orthophosphoric acid to which 7 per cent zinc oxide has been added and sealed with fresh sealant.[105]

3. Adequate ultraviolet intensity

For the ultraviolet polymerized sealants, the intensity of the ultraviolet light used must be sufficient to induce complete polymerization, not only in the mass of the sealant, but also in the tags which have formed. High intensities were found to produce a more rapid set and greater final hardness.

Various investigators have reported a considerable variation in the ultraviolet light intensity in a sample of light sources, as well as ultraviolet light variations in the quartz rod of individual lamps.[224,237]

Reduction in the output of the ultraviolet lights, resulting in inadequate polymerization, can be the cause of reduced tensile bond strength, which was proven by tensile bond strength tests using an old and a new bulb with different output.[237]

Young et al investigated the performance of ultraviolet light sources, in the polymerization of fissure sealants.[236] The ultraviolet lights examined were 7 *Nuva Lite* units, commonly used with the *Nuva Seal* sealant, and 1 *Quartz-Lite* or *Alpha Lite* , which is used with the *Alpha-Seal* sealant. ~~The fissure sealant used was~~

In the *Nuva-Lite* ultraviolet radiation was produced by a 50W. medium pressure mercury arc lamp, conducted to the tooth along a fused quartz light guids. In the *Quartz Lite* ultraviolet radiation was from a 100W. super high pressure mercury discharge lamp directed to the tooth along a bundle of quartz fibre-optics. The fused quartz guide attached to the *Nuva Lite* has an active diameter of 2.5mm. and is portected by a metal sheath of 4.5mm. in diameter at its tip.

When the setting times of the resins were measured, it was found that they were strongly dependent on the intensity of the ultraviolet radiation applied. It was estimated that the *Nuva Seal* sealant must be illuminated with an intensity of 25 mW/Cm^2 if the resin was to set completely within 20 seconds in premolars, and an intensity of $16mW/Cm^2$ must be produced for the 30 seconds' exposure recommended by the manufacturers in the sealing of molars.

For the 7 *Nuva-Lites* studied, 5 could not completely polymerize the sealant within 20 seconds, and 2 of these 5 would not produce a complete set within 30 seconds. The average ultraviolet intensities of the *Nuva Lites'* outputs were from 9 to 50 mW/Cm^2. This variation was attributed to:

- the aging process, resulting in units which emitted considerable strongly visible light but only low levels of ultraviolet radiation. When new ultraviolet sources were fitted in two lights, a 100 per cent and 50 per cent improvement was observed.

- gradual accumulation of polymerized sealant on the tip of the quartz guide. After changing two of the lights, the output increased by 22 per cent and 57 per cent.
- angle of the bend in the quartz guide. One of the lights had its quartz guide replaced by another having a more gradual bend Increase in output was 55 per cent.

The *Quartz Lite* was found to produce an average intensity of 40 mW/Cm^2 over a circular area with a diameter of 3mm. but if the total ultraviolet outputs were calculated by multiplying the intensity by the area illuminated, it was found to emit only 2.8 mW compared to 7-39 mW from the *Nuva Lite*. Figure 11 shows the pattern of intensity distribution 1mm. below the tips of the *Nuva Lite* and *Quartz Lite*.

In the *Nuva Lite* the ultraviolet radiation was mainly concentrated in a horseshoe shaped band in the front half of the illuminated area. With the *Quartz Lite*, the intensity distribution was also asymmetrical. The intensity distribution of ultraviolet radiation by the two lights at 0, 2, 5, and 10mm. below the tips of their guides was also recorded (Figure 12).

The peak intensities decreased with increased distance from the guide tip. The peak intensities measured along the diameters at 0, 2, 5, and 10mm. below the tips of the *Nuva Lite* were 45, 40, 30 and 20 mW/Cm^2, respectively. With the *Quartz Lite*, the average intensity in the central area fell from about 50 mW/Cm^2 immediately below the tip to 20 mW/Cm^2, 10mm. below the tip.

Due to the results obtained in this investigation, the authors recommended that:

(a) the output of the *Nuva Lites* should be checked regularly;

(b) the exposure time should be increased for at least 45 seconds for each tooth;

(c) the guide is cleaned with chloroform after each patient;

(d) a quartz guide with a gradual bend be used in preference to one with a sharp bend.

(e) a low scanning procedure as close to the total tooth surface as possible is carried out.

(f) the surface should be checked very carefully with a probe after polymerization.[236]

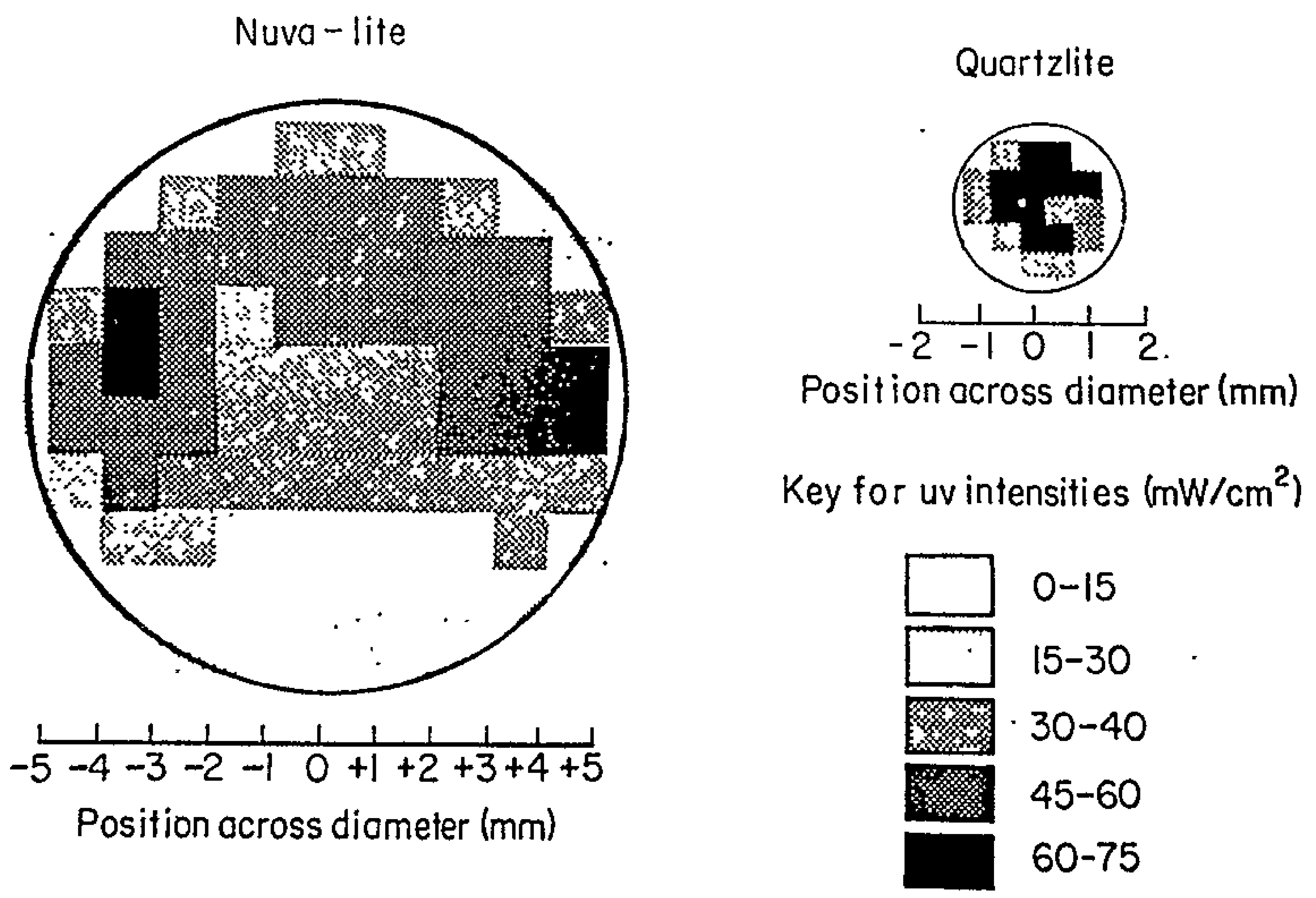

Figure 11: The distributions of uv radiation over planes 1mm. below and parallel to the tips of the guides of a *Nuva Lite* and *Quartzlite* are represented by squares with different degrees of shading. The circles denote the extent of the visible radiation with the top and bottom of the circles corresponding to the leading and trailing edges of the guides, respectively.

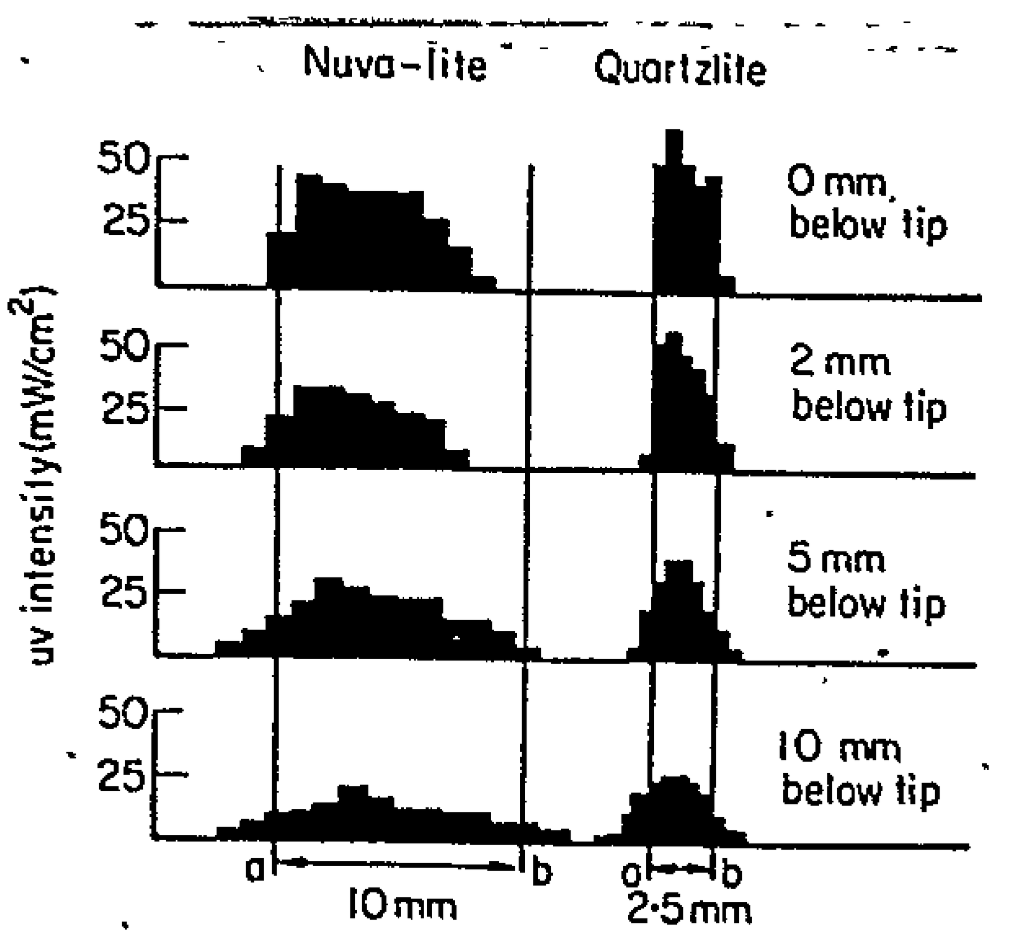

Figure 12: The intensity distribution of uv radiation across diameters of the circular areas illuminated by the *Nuva Lite* and *Quartz Lite* at 0, 2, 5, and 10 mm below the tips of their guides. The leading and trailing edges of the guides are represented by vertical lines marked a and b respectively.

4.4 Advantages and disadvantages of fissure sealants.

Advantages

(1) The use of fissure sealants can be recommended for a child whose susceptibility to caries is high at a time when satisfactory restorative treatment may be hampered by lack of co-operation. Application of the sealant requires no cutting of tooth substance, and is therefore a good way to introduce simple instrumentation to an apprehensive child.[174] It also means preservation of sound tooth structure, reducing the need for restorations.[60]

(2) The caries reduction obtained with fissure sealants varies widely, but is approximately 40-70 per cent after 3 years, 20-45 per cent after 4 years, and 15-40 per cent after 5 years for premolars, first and second molars.

(3) No harmful effects were observed by the use of Bis-Gma resins as sealants.[200] Rock et al investigated the reaction of the buccal mucosa in white rats, when unpolymerized sealant (*Nuva Seal* and *Alpha Seal*) was applied to one side of the mouth. The other side served as control. No difference was found in the structure of the mucosa on both sides. This suggests that there will be little risk of mucosal irritation if the resin is inadvertently spilt onto the oral mucosa during the sealing process.

(4) Fissure sealing can be fitted into a total programme of prevention.[78,200] In September 1972, a clinical study of 3 years' duration was undertaken to evaluate the effectiveness of well-established preventive measures in preventing oral disease in a community.[78] The subjects were children from schools in middle and lower sections of Buffalo. One thousand, five hundred and four children of sixth grade were selected, each of whom had been drinking fluoridated water. Three equally sized groups, consisting of two experimental groups (A, B) and a control group (c) were formed. The series of treatments received by these groups is shown in Table 30. Group C received only

Table 30

Treatment received by the three groups of subjects in the study

Procedures	A	B	C
Water fluoridation	+	+	+
Restorative care	+	+	+
Routine oral hygiene instruction	+	+	+
Topical fluoride	+	+	0
Sealant	+	+	0
Behavioural-motivational-organizational (BMO)	0	+	0

Table 31

Mean total DMFS scores - adjusted for baseline scores

	Treatment Group		
	A	B	C
12 mos.	5.27	5.31	5.43
24 mos.	6.81	6.85	7.87
36 mos.	7.69	7.54	8.90

Table 32

Mean DMFS - Occlusal scores, adjusted for baseline scores

	Treatment Group		
	A	B	C
12 mos.	3.19	3.30	3.40
24 mos.	4.26	4.28	5.08
36 mos.	4.70	4.74	5.79

routine oral hygiene instruction and referral for dental care when needed. They were given a prophylaxis at the beginning of each year.

Students in group A received treatment consisting of annual prophylaxis, application of topical fluorides, and application and re-application of sealant on the occlusal surface.

Group B received these same dental procedures and also basic instruction in peoper brushing and flossing techniques, along with a programme of activities aimed at motivating improved dental home care habits.

At the end of each year, the subjects were re-examined by standardised examiners. The mean total DMFS scores and mean DMFS occlusal scores can be seen in Tables 31 and 32.

After one year the mean DMFS occlusal scores for group A was less than for group C. The difference was between 0.028 and 0.392 at the 95 per cent confidence level. At the end of the second year group A and group B were each between 0.5 - 1.0 DMFS surfaces lower than group C. An effect of topical fluoride on smooth surface caries was not detected. After 3 years, group A and group B were each between 0.7 and 1.5 surfaces lower in DMFS occlusal scores than group C. Therefore, there was substantial evidence that the sealant reduced the incidence of caries on the occlusal surfaces.

Group A did not differ significantly from group B, so that the effect of the behavioural-motivational-organisational component of treatment was not seen.[78]

Disadvantages

(1) With the use of ultraviolet light-polymerized fissure sealants precautions need to be taken because of possible harmful effects of the ultraviolet lights. The ultraviolet portion of the electromagnetic spectrum which lies between 200 and 400 mm. has been considered for many years to be detrimental to life.[139]

Birdsell et al investigated the possible biological damage of ultraviolet radiation and found that three potential hazards must be considered: skin cancer, eye damage and the production of erythema by exposure to near violet radiation.[16]

Due to recent improvements in the manufacturing of ultraviolet lights, these potential hazards have been minimized. But it is still recommended that clinicians take appropriate measures to avoid these hazards, for example, wearing of safety glasses.

(2) Fissure sealing needs careful and proper application procedures which are often difficult to establish. The period of greatest risk for the pits and fissures of permanent first and second molars becoming carious is in the early years after tooth eruption. However, proper cleaning and complete isolation can be difficult to achieve, particularly on partially erupted teeth.

Bagramian et al in a clinical trial where all sound eligible teeth of more than 600 first and sixth grade children were sealed, noted a sealant loss of more than 50 per cent in both the first permanent molars in first graders and the second permanent molars in the sixth graders during the first six months.[283]

5. DISCUSSION

(1) It is clear that up until now the results of all of the various trials differ from one another, even if they have been carried out under similar conditions, using the same materials.

Apart from the inherent properties of the sealants themselves, this can be due to a variety of factors, amongst which the most important ones are:

i. the degree of careful attention given to details of the technique.

ii. the morphologic and structural difference of the teeth, and their place in the mouth.

iii. the degree of accuracy in assessing the retention of the sealant.

i. A well dried tooth after etching, without contamination of saliva appears to be an essential must in sealant application. Various investigators attributed early loss of the sealant to the difficulty of maintaining a dry field during application.[11,204]

ii. Results of different trials have indicated that sealants are more retentive on premolars than on molars.[45,189] This was attributed to the difference in morphology of premolars and molars, and to the pattern and different types of occlusion in the premolars and molars.[105]

Premolars are also easier to treat than molars because they are nearer to the front of the mouth, especially in the case of ultraviolet sealants where it is easier to hold the end of the ultraviolet gun at right angles to the occlusal surfaces of premolars than to the molars.[45,105] Retention is also better in permanent teeth compared to deciduous teeth.

Buonocore found that retention of the adhesive resin appeared to be best on those surfaces that had multiple crevices. Relatively smooth, saucer or cup-shaped surfaces with a single shallow pit or fissure appeared to be less retentive, which was associated with sealant loss from deciduous teeth.[33]

Sealant loss was also often detected on the distal part of the upper molars which is attributed to lack of moisture control.[188]

According to Going et al, some correlation exists between eruption patterns and retention of the sealant, as in the cases of the first and second permanent molars where an imposing distal flap of tissue can contaminate the etched enamel surface of the distal pits, resulting in poor retention of the sealant in these areas.[87]

iii. It was often found difficult to recognise sealant in pits and fissures after some time of wear. This can result in inter-examiner bias.

The methods of assessing sealant retention usually used are:

(a) Visual and probe examination.

Whilst the visual examination of relatively large amounts of sealant on the occlusal surface of a tooth usually presents little difficulty, after a few months in the oral cavity the diagnosis becomes less easy. This is largely due to the decrease of surface area of the sealant which usually occurs as a result of masticatory wear and because of poor optical contrast between the sealant and surrounding enamel. Therefore it becomes more and more difficult to see the remaining sealant until, eventually, considerable uncertainty arises as to whether the sealant is present or absent in the base of the fissures.

Before inspection the occlusal surfaces have to be washed and dried. The probe can be used to detect the change in occlusal surface contour. In those cases where substantial abrasion has taken place, gentle probing may fail to detect the presence of the sealant.

A method for better detection of the sealant is suggested by Douglas and Tranter, using an acid solution.[67] When an acid conditioner is applied to the tooth, the first stage is the removal of the salivary derived mucous films. After about 10 seconds, removal of mineral salts from the surface enamel starts. The sealant will not be affected by acid. Therefore, if the sealed tooth is treated with acid for 10 seconds, and then washed and dried, it will be much easier to detect the sealant because of the clear optical difference between residual sealants and the surrounding enamel.[67]

(b) Clinical photography.

Direct photography is useful in providing a permanent record of the sealant for subsequent evaluation but is rather difficult to carry out in the mouth. (Figure 13)

In a clinical trial conducted by Merrill et al, the direct clinical method of evaluation, using mirror and probe, resulted in a low level of agreement amongst three evaluators.[163] The concensus between evaluators 1 and 2 was 56 per cent; between evaluators 2 and 3 38 per cent, and 56 per cent between evaluators 1 and 3. Indirect evaluation of sealant retention, using photographic records, resulted in a higher degree of agreement.

A projected colour slide of the sealant at the time of insertion was constantly displayed on the left of a large screen, whereas the one representing the sealant after various periods of time was displayed on the right. With this method, the agreement among the three evaluators ranged from 95 to 98 per cent.[163]

To make detection of the sealant easier, various dyes have been incorporated in the sealants, e.g. fluorescent dye, red dye. Another way is the use of a lightly filled resin as the sealant.[207]

According to Ibsen, a lightly filled resin offers a number of advantages over the unfilled resin, including lower polymerization shrinkage and a lower coefficient of thermal expansion; higher hardness and increased abrasion resistance, also permitting easier initial inspection and re-inspection.[118]

(c) For the assessment of sealant retention and changes in sealant morphology in vivo, Davies et al introduced the impression and Stereoscan technique.[60]

A very fluid silicone (*Silflo, Flexico Products Ltd.*) was used to obtain an impression of every sealed tooth at each recall. This material flows easily over the occlusal surface and is able to repeoduce its details very well. Araldite models were cast, using 5ml. of Araldite Syrup CY212 (CIBA-ARL-Ltd., Druxford) mixed with 5ml. of Hardener Durcupan ACM mixture 964 and 0.5ml. of Accelerator DY064 for 30 minutes in a rotary mixer, incubated at 60°C for 10 minutes, vibrated into the impression and cured for 6 hours at 60°C. (Figure 14)

After painting the base of the models black to cut down the internal reflections, the models were photographed.

For examining in a scanning electron microscope, the casts were shadowed with gold paladium. In this way, changes in surface character and sealant area could be assessed accurately.[60] (Figure 15)

An accurate assessment of sealant retention cannot be made in sites with approximo-occlusal restorations at re-examination. If occlusal decay had developed or a simple occlusal filling was found on the follow-up examination, there was evidence that the sealant failed to confer protection.

Figure 13: Impressions of two sealed premolars at three successive recalls showing different extents of abrasion.

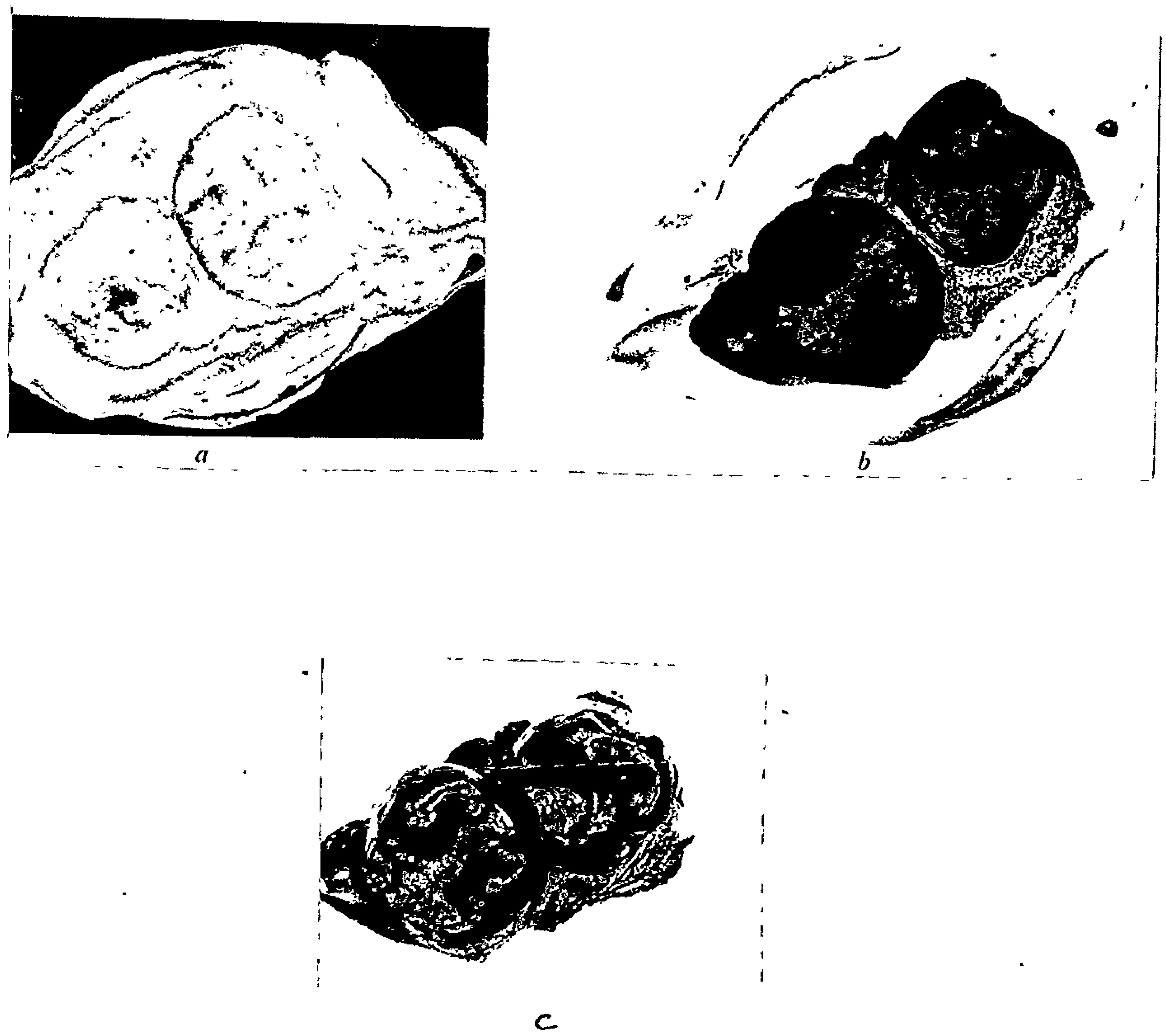

Figure 14: (a) Sil-Flo impression of a sealed tooth.
(b) Preparation of an *Araldite* model from the impression.
(c) *Araldite* model after coating the base with waterproof black ink.

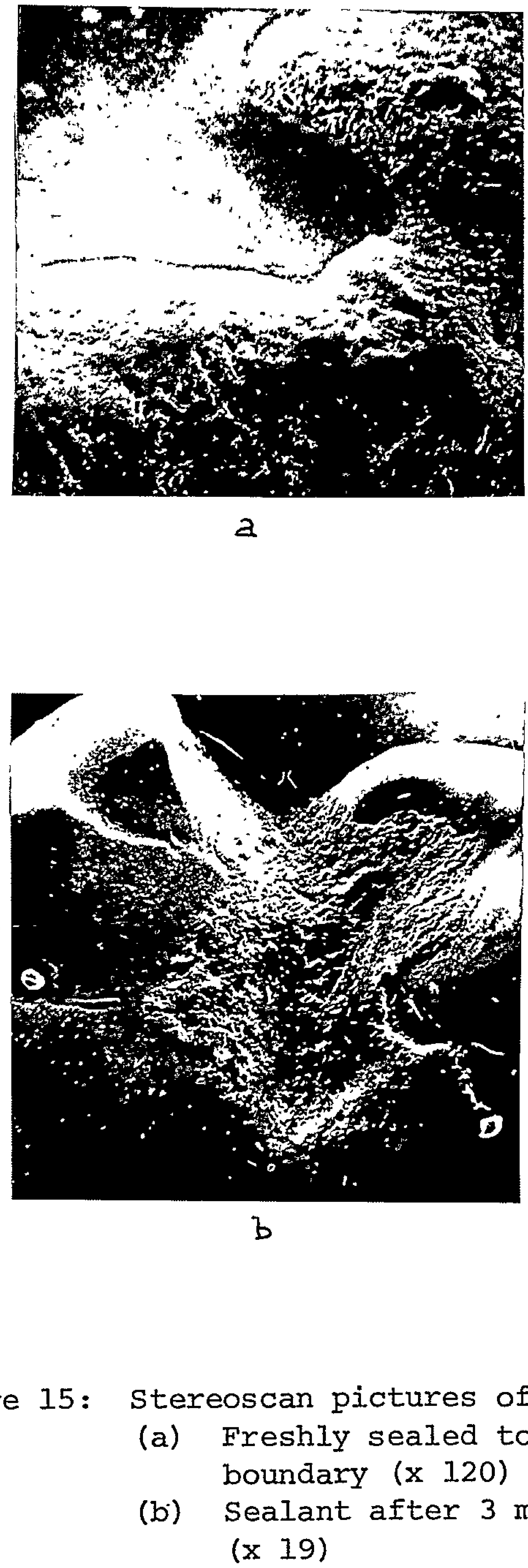

Figure 15: Stereoscan pictures of *Araldite* models.
(a) Freshly sealed tooth showing sealant boundary (x 120)
(b) Sealant after 3 months on premolar (x 19)

However, in teeth with an approximo-occlusal filling, it was impossible to determine if the sealant had been successful or unsuccessful. The occlusal surface may have been restored solely because of early intervention in the restorative treatment of approximal decay, or it may have been decayed itself.[107,108]

It has been hypothesised that previous knowledge of which occlusal sites had been sealed, has an effect on the scoring of these sites. If follow-up examinations were done blindly instead of non-blindly, the proportion of sites scored as sealant all present or sealant partly missing would possibly have been lower. However, in a comparison between blind and non-blind assessment of occlusal sealant retention 5 years after application reported by Horowitz and Poulsen, there was a 90.5 per cent complete agreement between non-blind and blind examinations in scoring the retention status of 893 occlusal sites.[111] There was only a slight tendency to classify more sites as having sealant present at non-blind examinations than at the blind examinations, 56.7 per cent and 55.1 per cent, respectively.

The percentage agreement was poorer for sites which were scored as caries-free (87.5 per cent) than for sites that were scored as decayed, missing or filled (99.1 per cent). It seems from this study that whether examinations are done blindly or non-blindly, is not so important in making accurate assessments of sealant retention.[111]

(2) It has been suggested that etching may damage the enamel and render it more liable to subsequent acid attacks and that the normal maturation of enamel may be disturbed by etching and sealing.

Various studies have shown that the effect of the conditioning acid is usually confined to the enamel of the inclined planes and the shallow fissures, whereas decay occurs in the depth of the pits and fissures.[96,216] If after etching the tooth is left unsealed, the characteristic etched pattern of the enamel disappears after exposure to the oral environment for as short as two days in vivo.[6,144] The surfaces become even and smooth, resembling non-etched enamel. In vitro studies using a scanning electron microscope have also shown that no distinction could be made between etched and unetched enamel following exposure to saliva or normal pumice prophylaxis.[104]

The treated enamel was apparently remineralised by the deposition of calcium phosphate salts, fluoride, and other trace elements present in the saliva and ingested. Therefore, other than the creation of a superficial etch, there appears to be no detrimental effect to tooth tissue from acid application.

The process of enamel maturation is controversial. Maturation of enamel is thought to be a posteruptive phenomenon, whereby resistance to caries seems to be increased as the tooth ages. It is used to indicate some sort of protective change in tooth composition through the acquisition of inorganic and organic constituents. However, there is no data available which specifically evaluates the effect of maturation on caries incidence.[27]

Other than fluoride, no specific factors have been proven to mature enamel and as has been mentioned before, occlusal pits and fissures are the least affected by fluoride therapy. Clinical trials have shown that control teeth which were allowed to mature normally acquired more decay in comparison with teeth treated with fissure sealants.

Bergman and Linden reported that fluid from the interior of the tooth is capable of being transported through the enamel, which would also contribute to the maturation process and may be part of the natural defense mechanisms of the tooth.[15]

(3) Confusion still exists as to the role of topical fluoride application in combination with fissure sealing. Buonocore considered the use of fluorides at various stages in the technique of fissure sealing:[27]

- before etching,
- after etching,
- after sealant application.

His opinion was that the use of a topical fluoride or fluoride paste might in fact be advantageous. Fluoride will penetrate into the pits and fissures and even though the occlusal surface is subsequently etched and washed, the fluoride may still be retained in those areas, be sealed in and become permanently fixed to provide continued protection against caries.

Fluoride should not be applied during or after etching, because its reaction products with enamel will block the microspaces, prevent resin penetration and also produce a less wettable surface. After sealing, a topical fluoride application will be of great benefit, because the etched areas of enamel not covered by the sealant will acquire considerable fluoride.

However, Low et al, in a series of experiments, found that *Nuva Seal* binds well with stannous fluoride treated enamel.[151,152] The tensile bond strength of *Nuva Seal* to enamel significantly increased when etched enamel was treated with freshly prepared 8 per cent stannous fluoride solution prior to *Nuva Seal* application in vitro. This was thought to be due to the possibility of the deposition of free stannous ions on the etched enamel surface. Tin is known to possess a high free energy so that the free stannous ion or the tin salt may therefore increase the free surface energy of the etched enamel and also its wettability. This might permit a rapid and effective filling of the system of pores by *Nuva Seal*, resulting in increased adhesion.[152]

In a later study it was found that the tensile bond strength of *Espe 71730, Alpha Seal* and *Epoxylite 9075* to enamel was reduced by treatment of the enamel with stannous fluoride.[150] Treatment of the etched enamel with acidulated phosphate fluoride reduced the bond strength of *Nuva Seal, Espe 71730, Alpha Seal* and *Epoxylite 9075*. Clinical studies to test the effectiveness of combined use of stannous fluoride and fissure sealants appear to be indicated.

(4) In the cases where the sealants do not completely penetrate to the base of pits and fissures, residual organic matter and debris, including bacterial aggregations, are unquestionably present in the depths of these incompletely filled sites.[216]

Theilade et al investigated the effect of sealing on the microflora in occlusal fissures.[217] Occlusal fissures from unerupted, third molars were implanted in the occlusal surface of pre-existing amalgam fillings in lower molars of dental students and were worn for 7 days to accumulate plaque.

Control fissures were then removed for bacterial study, experimental fissures were etched with 50 per cent phosphoric acid, sealed with *Nuva Seal* and removed either immediately or 2 weeks after sealing. Various selective media were used for the bacteria which were counted.

The anaerobic viable counts were much lower immediately after sealing compared to the controls, but there was only little difference between the anaerobic viable counts immediately after sealing and two weeks after sealing. The aerobic counts were lower than the anaerobic counts in control as well as sealed fissures. Some bacteria, such as Streptococcus sanguis and haemophilus were greatly reduced in numbers, while Streptococcus mutans and lactobacillus were affected very little.

Due to the fact that aciduric bacteria seems to survive best in sealed fissures, the authors felt that the phosphoric acid used for etching may, to a large extent, be responsible for the antibacterial effect of sealing, along with the resin, which especially in an unpolymerized state, is known to have toxic effects on mammalian cells.

It seems that as long as the sealant remains intact, the unknown metabolic activity of fissure plaque in situ are of much greater clinical importance than the number of microorganisms capable of multiplying upon subculture, so that knowledge of the availability of substrates in sealed fissures would be useful.

Even with leakage under sealants, as indicated by various investigators, it seems unlikely that nutrients would reach the fissure plaque through a sealant to any significant extent.

So that the caries preventive effect of fissure sealants may be due to a combination of decrease in the number of viable bacteria, and lack of sufficient fermentable carbohydrates for the remaining bacteria to accumulate acid in cariogenic concentrations.[95,217]

(5) Frequently, the clinical diagnosis of incipient carious lesions in posterior teeth is difficult, because of the depth, narrowness and complexity of the pits and fissures. According to Miller and Hobson, radiographs seldom show occlusal caries before the caries is clinically evident, so that radiographs are not reliable for the detection of early occlusal lesions.[166] As a result, such lesions may remain undetected and inadvertently, sealed with a sealant.

Questions have been raised concerning the fate of the sealed bacteria and the possible clinical course of the carious lesions.

Jeronimus et al conducted a study in vivo on permanent molars of 33 children with caries on the occlusal surface, extending into the dentine without clinically visible destruction of the occlusal enamel surface.[126] The teeth were divided into three groups, the incipient lesion group, moderate lesion group and deep lesion group, and sealed with *Nuva Seal, Epoxylite 9075* and *3M Caries Preventive Treatment*. Samples of carious dentine sealed in were removed from the tooth after 10 minutes, and at 2, 3 and 4 weeks after placement of the sealant.

In the cases of the sealed incipient lesions, the majority of samples taken immediately after sealing contained cultivable organisms but lesions sealed for the longer time periods under *Nuva Seal* and *Epoxylite 9075* showed predominantly negative cultures.

In the case of positive cultures with *Epoxylite 9075*, the sealant was found fractured or lost. The majority of *3M Caries Preventive Treatment* sealants were lost and in such instances cultivable organisms were found. With one exception, cultivable organisms were present in the moderately deep and deep carious lesions at all four time periods. The authors were of the opinion that the absolute diagnosis of incipient dental caries may not be of primary importance, however, in the case of deeper lesions, the microorganisms may remain alive and have the potential for advancing the carious process.[126]

A two year report of sealant effect on bacteria in dental caries is given by Handelman et al.[98] Sixty teeth sealed with an ultraviolet light polymerized sealant were sampled for bacteriologic examination one to two weeks and 1, 2, 4, 6, 12 and 24 months after the sealant had been placed with 29 teeth which were not sealed serving as controls. The criteria for selection of teeth in this study were a definite lesion in a pit or fissure which would catch and hold an explorer tip, with an otherwise intact enamel surface.

Radiographs were taken, those taken at base-examination and after 1 and 2 years evaluated. The major reduction in viable microorganisms occurred during the first two weeks, with a gradual reduction in total count thereafter. At the end of 1 and 2 years, there was about a 1000-fold and 2000-fold decrease, respectively, in the number of cultivable microorganisms from the dentine of sealed teeth compared with that of the control teeth. The radiographic findings indicated that there was no difference between radiographs taken before and after sealant placement, suggesting that there is no caries progression as long as the sealant is intact.[98]

Going et al investigated the viability of microorganisms in carious lesions covered 5 years with sealant.[85] They took bacteriological samples of 49 experimental and 21 control teeth and cultivated them on appropriate media for Streptococcus mutans, Streptococcus sanguis, Streptococcus salivarius and Lactobacilli. Sixteen of 18 test sites judged to have active caries in 1972 were found inactive in 1977; 10 of 12 sites judged to have suspected caries in 1972 were caries inactive in 1977. Results indicated that sealant treatment gave an apparent 89 per cent reversal from a caries active to a caries inactive state. Streptococcus mutans and Lactobacilli accounted for essentially the entire flora of 11 of the 24 sealed sites that had detectable bacteria.[85]

An evaluation of the clinical progress of caries under sealants was conducted by Mertz-Fairhurst et al.[160] In children with bilateral lesions in lower first permanent mandibular molars, the cavity on one side was sealed, while the cavity on the other side was left open and observed at 3 month intervals up to 12 months.

Cavity depth was measured by using a matrix constructed on a silver dye of each tooth. The matrix contained a tube which allowed the passage of a 0.5mm. in diameter wire, which was marked at a constant reference point.

A sonic device was used to gauge the force on the wire at approximately $2.5kg/mm^2$. Wire measurements were made at baseline and at 3 month intervals in the control cavity and at baseline and the final visit in the treated cavity. Bacterial samples were taken and cultivated, also standardised X-rays were taken.

The results indicated that the sealed cavities showed little or no change in depth in comparison with a 6-fold average increase in depth of the control cavities. There was an elimination or marked decrease in viable organisms under the sealants.[160] It was felt that there was a great possibility that many teeth sealed a year or two after eruption do contain pre-carious lesions, but in no clinical study has the sealing of these lesions caused any difficulty not has the use of sealants resulted in a higher incidence of caries during the trial.[118]

(6) Visual examination of sealed teeth will not detect all carious lesions that are present, although detection will be easier after the sealant has thinned due to wear. Once a tooth is coated with a sealant, it is no longer possible to verify a dark visual impression with an explorer to determine if it is stain or decay.

There is a possibility that sealed teeth with a dark stain at base line may be scored as caries under the sealant at the re-examination. This will be interpreted as possible caries initiation and the percent effectiveness of the sealant for "present" or "partly missing" categories will be low.

On the other hand, undetected developing caries under the sealant may result in an overstatement of sealant effectiveness.[86] As stated earlier, radiographs seldom show occlusal caries, before the caries is clinically evident. Mechanical removal is not a valid and practical method, nor is chemical removal of the sealant.

Takeuchi et al have tried to diagnose caries under sealants by electric conductivity measurements, supplemented by clinical judgements.[215] Electric conductivity tests were carried out on the first permanent molars before and after sealant placement. The electric resistance of the tooth immediately after sealing was astoundingly higher than that of the same tooth before sealing. In a few days however, the tooth's electric resistance decreased due to microscopic percolations between sealant and tooth substance. This decline stopped after a certain length of time, and after that kept the same value, which was still higher than the value before sealing. If the value became lower than the measurement error - 3 o, the teeth were electrically diagnosed as carious.[215]

(7) In the event of sealant loss, reapplication will be necessary. Sealant loss generally falls into two categories:[27]

a. loss soon after placement;

b. loss due to gradual abrasion.

When sealant is lost within a few weeks or a few months after placement, it is likely due to an improper/faulty application technique. So that re-etching will dissolve additional enamel and prepare the surface properly. With sealant loss as a result of abrasion, it is likely that there is still some sealant left. Most surfaces are retreated by applying a new layer directly over it. The re-treated by applying a new layer directly over it. The retention of the new layer will then depend a great deal on that of the underlying residual sealant, which is usually already weakened.[59] Therefore it is advisable to remove the residual sealant as much as possible, clean the surface by pumicing and etching and re-apply the sealant.

(8) Some authors were of the opinion that even in the event of sealant loss, the enamel surface was still protected due to remaining resin tags in the enamel, making it more resistant to acid decalcification, so that these areas might well be less susceptible to caries than the adjacent enamel.[104, 95, 205]

However, microscopic studies done by Wright and Beck about the appearance of sealants in fissures, have shown that an area of the base of all deep fissures about 100-200 μm in depth was devoid of tags.[234] And it is in these areas that caries usually progresses and not on the cuspal slopes where tags were found. But if the pits and fissures remain obturated even after the majority of sealant is lost, it is likely that they will remain so over long periods of time, and these teeth might well be less susceptible to caries.[234]

(9) The use of fissure sealants is ideally accompanied by the identification of those factors that will assist the dentist in choosing patients who are most likely to benefit from such treatment. Such factors are the number of carious lesions present, the state of oral hygiene, the patient's sugar intake, diet, eruption pattern of permanent teeth, heredity and family stability, and caries prediction tests may eventually serve as the criteria for screening potential success from probable failure.[86]

Once the significant factors have been identified, the procedures necessary for controlling dental caries, that will best suit the needs of the individual patient, can be selected.

For some, sealant therapy may be best; for others, fluoride therapy will be more beneficial, either alone or in combination with sealants.

SUMMARY AND CONCLUSIONS

6. SUMMARY AND CONCLUSIONS

1. Adhesive resins can be classified according to their clinical use as:
   - Adhesive resins used in restorative dentistry:
     acrylic resins
     composites.
   - Adhesive resins used in preventive dentistry:
     fissure sealants.
   - Adhesive resins used in orthodontic dentistry:
     orthodontic adhesives.

   They can be ultraviolet polymerized or chemically polymerized, and are available with a filler phase or without a filler phase.

2. The presence and morphology of pits and fissures greatly predispose posterior teeth to dental caries. These sites are ideal for the retention of food debris and bacteria and are almost impossible to clean thoroughly.

3. Sealants are mechanically retained materials which are used to seal pits and fissures, and to prevent the advent of caries in those areas. They can be grouped in two categories, according to their effect on the tooth surface:

   physical sealants, which are intended to fill and seal the pit and fissure entrances against the ingress of bacteria and bacterial substrate;

   chemical sealants, which contain fluoride salts as the active agents and can be considered as hybrids between fissure sealants and topical fluoride agents.

4. Several types of resin, unfilled and filled, have been employed as pit and fissure sealants, the principal ones being:
    a. α-2-cyanoacrylate sealants
    b. diacrylates.
    c. polyurethanes.

5. The bond between adhesive resins and the enamel of the tooth is mainly a mechanical bond. For optimal bonding to occur, the enamel surface needs to be cleaned by giving a prophylaxis and etching it with acid to:
    a. remove cuticular deposits, hypermineralized enamel, plaque and food debris.
    b. heighten the free surface energy of the enamel which favours wetting by the resins.
    c. create minute irregularities into which the resin may penetrate, resulting in mechanical interlocking.
    d. increase the surface across which adhesive forces may interact.

    Up until now, attempts have been unsuccessful to obtain satisfactory bonding between adhesive resins and dentine.

6. Adhesive resins, especially composites, are used for various clinical procedures, for example:
    a. restoration of cavities.
    b. repair of fractured incisors.
    c. sealing of cavity margins.
    d. covering enamel defects.
    e. rebuilding or reshaping of malformed teeth.
    f. temporary bridges or space maintainers.
    g. cementation of cast restorations.
    h. repair of cervical erosion.
    i. splinting of teeth.
    j. making resin replicas.
    k. making a dowel and core.
    l. bonding of orthodontic brackets.
    m. sealing of occlusal and approximal surfaces.
    n. treatment of fractures in oral surgery.

7. Clinical and laboratory studies have been carried out to test the effectiveness of fissure sealants in preventing caries. The points considered were:

   a. Retention: Complete retention varies between 30-90 per cent after 3 years, 20-60 per cent after 4 years and from 5-45 per cent after 5 years on posterior teeth, with a high frequency of retention on premolars and a much lower frequency of retention on the first and second permanent molars.

   b. Caries reduction: The caries reduction obtained varies between 40-70 per cent after 3 years, 20-45 per cent after four years, and 15-40 per cent after 5 years for the posterior teeth. It tends to be high for premolars and relatively low for first and second permanent molars.

   The degree of success or failure of fissure sealants and the varying results in retention and caries reduction obtained in clinical trials may be explained by:

   - differences in the sealant materials used;
   - the conditions under which the trials were conducted;
   - variations in tooth surface preparation and sealant application techniques;
   - morphological and structural differences of the treated teeth, their place in the mouth and length of time after eruption in the mouth;
   - examiner variability in assessing the degree of retention of the sealant and the caries status of the treated teeth.

   c. Depth of penetration: In deep and narrow fissures, it was found that the resin often did not penetrate to the base of the pits and fissures, and that microorganisms might be left in the deep fissures beneath the sealant.

d. <u>Microleakage</u>: There is laboratory evidence to suggest that fissure sealants do not provide an effective marginal seal in all instances and in view of this, further investigations need to be conducted to determine the viability of bacteria entrapped below fissure sealants. To date only a limited number of such studies have been carried out.

e. <u>Wear</u>: There is considerable wear of the fissure sealants, with varying wear patterns depending on the tooth site. It is yet to be determined when and how often a re-application of the sealant is necessary.

8. The effectiveness of fissure sealants in reducing pit and fissure caries is difficult to accurately determine. A number of problems still remain:

- in teeth which have the greatest risk of becoming carious, that is the newly erupted first and second permanent molars, fissure sealants are not as effective as in the premolars. The problem of determining the vulnerability or the actual caries status of a tooth makes proper selection of teeth to be sealed difficult.

- the cost-effectiveness of sealant treatment techniques is frequently questioned. The cost of initial application and subsequent re-application needed if sealant is lost might be greater than placing an occlusal restoration. But if the teeth can be spared from becoming carious, it may well be worth the extra cost.

- Meticulous application techniques are needed, which are difficult to carry out in large scale public health programmes.

The concept of treating the teeth with fissure sealants as part of an overall preventive programme is good, but they have not been as effective as was anticipated.

Further developments of fissure sealants should be made with emphasis on improvements in cost, ease of application, and durability in the oral environment.

APPENDIX I

Examples of composites

Chemically polymerized composites:

Material	Manufacturer	Type of resin
Adaptic	Johnson & Johnson, New Brunswick, N.Y.	Bis-Gma
Concise (Concise Enamel Bond System)	Minnesota Mining and Manufacturing Co., Minnesota.	Bis-Gma
Restodent	Lee Pharmaceuticals, South El Monte, California.	Bis-Gma
Shofu composite	Shofu Dental Mfg. Co. Ltd., Japan	Bis-Gma
Epoxylite	Lee Pharmaceuticals.	Bis-Gma
Cosmic	De Trey GmbH, Wiesbaden, Germany.	Bis-Gma
Enamelite	Lee Pharmaceuticals.	Bis-Gma
Optow	Optow Dental Manufacturing, Brooklyn New York.	Bis-Gma
Concise Syringe System composite	Minnesota Mining and Manufacturing Co., Minnesota	Bis-Gma
Palakav	Kulsen and Co., GmbH., Bad Homburg, West Germany.	PMMA
Polycap	Vivodent, Schaan, Liechtenstein	PMMA
Ultraviolet polymerized composites:		
Nuva-Fil	L.D. Caulk Co., Div. of Dentsply International, Inc.	Bis-Gma
Fotofil	Johnson & Johnson (Imperial Chemical Industries Limited.	Bis-Gma

APPENDIX II

Examples of fissure sealants

Chemically polymerized fissure sealants:

Material	Manufacturer	Type of resin
Delton	Johnson & Johnson Dental Products Co.	Bis-Gma
Concise Brand White Sealant	Minnesota Mining and Manufacturing Co. Minnesota.	Bis-Gma
Kerr Pit and Fissure Sealant	Kerr Manufacturing Co.	Bis-Gma
Epoxylite 9075	Lee Pharmaceuticals, South El Monte, California	Bis-Gma
3M Caries Prevent-ive Treatment	Minnesota Mining and Manufacturing Co. Minnesota	Bis-Gma

Ultraviolet polymerized fissure sealants:

Material	Manufacturer	Type of resin
Nuva Seal	L.D. Caulk Co., Div. of Dentsply International Inc., Milford, Delaware	Bix-Gma
Nuva Cote	idem	idem
Alphaseal	Amalgamated Dental Co., London, England	Polyurethane

APPENDIX III

Examples of acrylic and orthodontic resins

Chemically polymerized resins:

Material	Manufacturer	Type of resin
Sevitron	Amalgamated Dental Trade Distributors Ltd., London, England	PMMA
Pile-A	Shofu Dental Mfg. Co. Ltd., Japan	PMMA
Genie	Lee Pharmaceuticals, South El Monte, California.	PMMA
Bracket Bond	GAC International Inc., Farmingdale, N.Y.	PMMA
Unitek	Unitek Corporation, Monrovia, Calif.	PMMA
Orthomite	Rocky Mountain Dental Products Co., Denver, Colorado.	PMMA
Director	T.P. Laboratories Inc., La Porte, Indiana	PMMA
OIS Adhesive	Ortho International Services, Inc., San Fransisco, California	PMMA

Ultraviolet polymerized resins:

Nuva Tach	L.D. Caulk Co., Milford, Delaware	Bis-Gma

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