LABORATORY AND CLINICAL INVESTIGATIONS INTO THE DIAGNOSIS AND MANAGEMENT OF FISSURE CARIES USING FISSURE SEALANT, GLASS IONOMER (POLYALKENOATE) CEMENT AND COMPOSITE RESIN

Gordon Brian Gray,
M.Sc. (Medical Science)(Glasgow), B.D.S.(Glasgow)

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Dental Hospital & School.
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ABSTRACT.

This thesis comprises a series inter-related studies designed to elucidate aspects of the diagnosis and management of fissure caries using "sealant restorations".

In a preliminary study, the use of the probe in addition to visual inspection did not improve the validity of the decisions to leave untreated, fissure seal or investigate fissures in a group of extracted teeth. A group of Community Dental Officers participated in a large survey/field trial in which they recorded details of 569 investigative cavities prepared in fissures. They were asked to predict the size of the lesion. As the size of the lesion increased, the accuracy of the prediction reduced and was not improved in operators using the probe. Caries lesions were most frequently underestimated in right mandibular first molars and both mandibular second molar teeth. The restorations in the field trial were assessed after 6 months, 1 year and 2 years. Sealant restorations were placed predominantly in first permanent molar teeth. The figures for complete retention of fissure sealant after 6, 12 and 24 months were: 56, 42 and 34% for therapeutic fissure sealants; 25, 17 and 9% for intra-enamel composite sealant restoration; 21, 12 and 13.8% for glass ionomer sealant restorations and 28, 19 and 18% for laminate sealant restorations. It was estimated that at the end of the two year field trial over 85% of restorations would survive a further one to two years and 37% would survive for more than two years. Eighty-seven to ninety-two percent of restorations required either no treatment of minimal additions of further fissure sealant. Improved retention of sealant was found with increasing age of patient at the time of restoration placement and with reduced size of restoration surface. Loss of fissure sealant from the surface of the restorative materials was noted more frequently than from the adjacent fissures of the occlusal surfaces of molar teeth.

In vitro studies designed to investigate means of optimising shear bond strength of fissure sealant to restorative materials showed that when the base resin systems in the composite and fissure sealant are different, the mean shear bond strengths are significantly reduced. A significant increase in shear bond strength was noted, with both light and self cured fissure sealant, when Scotchbond Dual Cure was applied to the glass ionomer cement surface.

A hospital based clinical trial with strict protocols was carried out to demonstrate the optimum performance of 150 sealant restorations. No restorations were lost and in the small type 2 restorations (n=15), 100% retention of fissure sealant was noted. In the larger type 4 restorations, complete fissure sealant retention was observed in 67% of teeth (n=97). The presence of small composite restorations did not adversely affect fissure sealant retention. Fissure sealant retention to glass ionomer cement restorations was significantly less ($P<0.05$).

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Declaration

This work was undertaken in the Department of Adult Dental Care, University of Glasgow Dental Hospital and School and also in the Community Dental Services of Lanarkshire and Greater Glasgow Health Boards. The material contained within this thesis is entirely original.

Some of the techniques used in the thesis are modifications of previously published work while some are original techniques developed for the study. The application of the techniques described in the work, however, were undertaken by the author.

Part of the work of this study have been published.

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Chapter
1

The Diagnosis and Clinical Management of Pit and Fissure Caries.

Chapter 1.

1.1 Changes in the Clinical Presentation of Dental Caries.

1.1.1. Changes in caries prevalence during the last century.

In the latter half of the nineteenth century the caries rate in the U.K. increased dramatically. Nikiforuk (1985) reported the mean caries prevalence to have risen from 18% to 66% for first permanent molars: the reason for this change - and a similar observation for second permanent molars - was considered to be the three fold increase in sugar consumption during this period.

In a review of the literature, Sheiham (1984) described a peak in caries prevalence during the mid 1950's. This was subsequently followed by a gradual decline in caries prevalence throughout the developed industrial countries. He attributed this decline in part to reduced sugar consumption, but the acceleration in the fall in caries rates since the early 1980's is due in no small measure to the widespread use of fluoride containing toothpastes.

Wilska (1947) established the first direct relationship between the amount of sugar consumed and the prevalence of dental caries. More than 20 kilograms of sugar was consumed per person per year and resulted in 98% of the adult population having some caries experience. In the Vipeholm study, Gustafsson *et al* (1954) demonstrated that it was not the total consumption of sugar but the frequency of intake that was the most important factor determining the caries rate.

Sheiham (1991) discussed the reasons for reducing "free" sugar consumption to below 15 kilograms per person per year. The dose-response relationship between caries and sucrose consumption forms a sigmoid curve, where low levels of sucrose consumption [10kg.per anum] lead to low caries incidence. Increasing the consumption of sugar results in a greater incidence of dental disease. Takeuchi (1962) reported a plateauing of the dose-response curve over an upper limit of 38kgs of sugar per year; further increases in sugar consumption over this limit did not lead to a further increase in dental caries. The gradient of the dose-response curve is greater when the frequency of sugar intake is increased (Newbrun 1982) and it has been argued the curve will shift to the right and rise less steeply when a source of fluoride is available.

Over the past two decades, the prevalence of dental caries has fallen markedly in most countries in Europe (Marthaler *et al* 1988, Steiner *et al* 1989 & Renson 1989) and the United States of America (Brunelle & Carlos 1982). The reduction in caries is generally attributed to the increasing availability of fluoridated toothpastes (Glass 1982 & Holm 1990). For example, declining caries prevalence in Scottish schoolchildren has been reported during the decade from 1970 to 1980. The greatest decrease in caries prevalence in Scotland was 44 per cent - this reduction was recorded in the four fluoridated areas. Around Glasgow and Lanarkshire, which have a lower socio-economic grouping, a 28 per cent reduction was achieved (Stephen et al 1987). By contrast, Anderson *et al* (1981) reported a reduction in caries incidence in England of between 32 and 57 per cent. This study compared dental health data from a group of 12 year old school children with that from a similar matched group 10 years previously.

1.1.2 Prevalence of caries-free children.

The scale of the problem in the management of caries in children in the 1950s and 1960s is demonstrated by the reports of Millar (1953) and Jackson (1965) who observed that 50% of molars became carious within the first year following eruption. Hargreaves & Chester (1973) observed that 80% became carious within two years of eruption and Bergman & Anneroth (1972) reported that by the age of 10 years, 90% of pits and fissures became carious.

The dramatic change in caries prevalence in children is reflected in the 2 to 5 fold increase in the number of children who were completely caries free (Naylor 1982). Thirty per cent of 11 year old British children were found to be caries free in 1983 compared with only 10% in 1973 (OPCS Monitor 1983). The comparable figure for 11 year old children in the USA was 34 per cent in 1980 (Miller *et al* U.S. Dept of Health & Human Services 1981).

Anderson (1982) revisited an area of England which he had surveyed 15 years previously. Interestingly, he reported a large increase in the number of children who were completely caries free. Twenty per cent of five year old children were caries free in 1964, while an improvement of only 6% was recorded after a further ten years. In 1980, a dramatic change was demonstrated when 49% of five year old children were found to be completely free from dental caries.

1.1.3. Caries reduction in the adult population.

The reduction of caries prevalence has been described not only in children but also in the adult population. Elderton (1985a) has shown a 32% reduction in the number of teeth restored in adults in the 16-29 year old age group during the period 1965 to 1981. Not all of this reduction can be related to declining caries incidence since a change in prescribing patterns has also been suggested.

1.1.4 Changes in carious sites affected.

The reduction in caries prevalence has been associated with a change in the nature of the remaining lesions. A decline in the number of smooth surface carious lesions has been noted because of the protection afforded to these surfaces by fluoride. Reduction in caries by fluorides affects some tooth sites more than others: reductions are larger on proximal surfaces and smooth surfaces than on pits and fissures (Ashley *et al* 1977; Jackson *et al* 1985).

Earlier work by Knutsun (1948) reported smooth surface caries accounted for 31% of all lesions in a group of 2,016 Minnesota school children. These findings were recorded at baseline during a trial where 2, 4 or 6 fluoride applications were made to one side of the dentition - the other side serving as a control.

Miller *et al* (1981) observed a 50% reduction in caries affecting approximal surfaces as a result of fluoridation. Eighty four per cent of all new carious surfaces were reported as arising in pits and fissures. Bohannan *et al* (1984) and Ripa *et al* (1988) also confirmed the reported rise in the proportion of pit and fissure caries.

Stamm (1984) observed that carious lesions in children under the age of twelve occur virtually exclusively in first permanent molar teeth. Thereafter, lesions in second permanent molars become increasingly prevalent. Van Palenstein *et al* (1989) confirmed that the first permanent molar contributed predominantly to the caries incidence. The occlusal surfaces of teeth in the permanent dentition account for only 12.5% of all available surfaces yet this surface receives 60% of all new restorations placed (Wendt *et al* 1988).

Pitts (1991) studied caries incidence and treatment received by a group of 1568 five, eight, twelve and fifteen year old Scottish school-children over a five year period from 1983. He observed that 15% did not attend for treatment over the five year period. Sixty three point three per cent of restorations were placed in permanent molar teeth - 38% in first molar and 25.5% in second molar teeth. Fifty five per cent of amalgam restorations placed were single surface and, surprisingly, 39% of all restorations placed in permanent teeth were replacement restorations. However, this report does not differentiate between true replacement restorations i.e. removal of a restoration and subsequent restoration placement in an unfilled section of the fissure pattern of a restored tooth.

1.1.5 Influence of fluoride.

Ainsworth (1933) observed a relationship between reduced caries prevalence and the presence of fluoride in the water supply. When fluoride levels were measured (Churchill 1931) and found to be high, white and brown markings of the teeth were described. McKay (1933) related the presence of high fluoride levels to these markings and described the phenomenon as enamel mottling. He had originally observed this phenomenon in Colorado, U.S.A. in 1916, although similar descriptions had also come from Naples in Europe (Eager 1902).

Under controlled conditions, fluoridation of the water supply has been shown to reduce the caries experience by approximately 50%. A similar reduction in the number of first permanent molar extractions was also recorded. The need for approximal restorations in maxillary incisors has been virtually eliminated in areas with water fluoridation (Murray 1976).

The effect of continuous residence and social class on caries experience in a group of 15 year old children from three areas of the North-East of England was discussed by Murray *et al* (1991). It was demonstrated that continuous residence in the naturally fluoridated area of Hartlepool produced a 32% lower DMF value (Decayed, Missing & Filled) than could be achieved in the artificially fluoridated city of Newcastle. When the low fluoride area of Middlesbrough was compared to Newcastle, it was observed that the DMF was 18% higher and, like Newcastle, there appeared to be a trend towards more caries in the lower social groups. The naturally fluoridated area of Hartlepool, however, showed no correlation between caries incidence and social group.

When Carmichael *et al* (1980) examined the deciduous dentition in a group of 644 five year old children from the fluoridated city of Newcastle and its non-fluoridated rural areas, he observed that there was no social class trend in the number of caries free children in the artificially fluoridated area. In the lower social group, caries experience in the non fluoridated area was 71% higher than in the fluoridated area. The authors concluded that fluoridation had its greatest effect in the lower social classes where there is a higher incidence of approximal caries.

Rock *et al* (1981) compared the caries experience of two groups of school children in Birmingham (where the water supply has been fluoridated) and Wolverhampton (where the water supply contains a low level of fluoride). They reported on the delayed onset of caries in first molars in the fluoridated area. The delay was significant compared to the rapid development of post eruption caries found by other workers. Thylstrup and Fejerskov (1986) analysed data from children who had been exposed to water fluoridation before tooth eruption and also a group not exposed until after eruption of the dentition. They considered that the group exposed to fluoride after tooth eruption showed disappointing results. They postulated that this was due to the short length of time the teeth had been exposed and concluded:

> "the importance of the pre-eruptive ingestion of fluoride for caries inhibition is only of borderline significance relative to the much more important post-eruptive effects".

Lovius & Goose (1969) reported that molars formed in fluoridated communities were both smaller and had shallower pits and fissures - a feature which would naturally be of benefit in the reduction of pit and fissure caries. Backer-Dirks (1966 & 1967) reported caries reduction to be greater on smooth surfaces. This was re-confirmed by Groenveld *et al* (1988). A study by Ripa *et al* (1988) noted an increasing proportion of caries occurring in pit and fissure surfaces. It would seem therefore that altered tooth morphology could not explain completely the increasing proportion of pit and fissure lesions.

Renson (1989) postulated that the observed caries reduction (even in areas where there had been no fluoridation of the water supply) might be linked to the increasing use of fluoride containing dentifrices, the market share of which was only 4% in 1970 but rose significantly to reach a 95% share in the British market by 1977.

It was considered previously that fluoridated dentifrices exhibited only a topical effect (Hill *et al* 1973). However, enamel mottling was noted by Ericsson and Forsman (1969) in children whose only exposure to fluoride was from toothpaste.

Barnhart *et al* (1974) demonstrated that varying amounts of fluoride were ingested by children of differing ages: 34.9% was ingested by children between the ages of 2 and 4 years compared to 2.9% by adults aged 20 to 35 years. More recently, Ekstrand *et al* (1983) showed fluoride ingestion from the gastro-intestinal tract could be rapidly and easily achieved. They demonstrated that twice daily brushing with a fluoride toothpaste exposed the child to 2 milligrams of fluoride, one third of which was likely to be swallowed to provide the optimal daily intake of fluoride ion.

The problem of fluorosis - due to ingestion of fluoride from toothpastes - was addressed by Newbrun (1986) when he reported that the incidence of fluorosis could be increased by 150% if dentifrices containing 2,500 ppm. fluoride became widely available without prescription. Stephen et al (1989) concluded that over their three year clinical trial, designed to measure the efficacy of fluoride containing dentifrices with differing fluoride concentrations:

> "every additional 500 ppm over and above 1000 ppm F would provide a cumulative 6% reduction in caries increment."

Marthaler (1973) has argued that caries reduction is greater than that explainable in terms of anti caries affect due to fluoride dentifrices which would be in the order of 20-30% only.

von der Fehr and Moller (1978) showed that it was not only the fluoride ion, but also the abrasive elements in the toothpaste, that were important in caries reduction. Di-calcium phosphate can react with the fluoride moiety to reduce its activity. Silica is now added as the abrasive to overcome this problem.

The suggestion that ingested fluoride could alter fissure patterns making it more difficult to diagnose occlusal caries was considered by Sawle and Andlaw in 1982. His interpretation of the data indicated that this was not the case.

1.1.6. **Occult caries.**

Recently, there has been recognition of the so called "occult lesion" in which extensive dentinal caries is present under what appears clinically to be a sound enamel surface (Ball 1986, Paterson *et al* 1991). Millman (1984) expressed concern on the validity of epidemiological data which did not use radiographic evidence to identify such lesions.

Diffuse radiolucencies in dentine below intact occlusal enamel has become a worrying and evidently wide-spread phenomenon that has prompted a number of dental practitioners to voice their anxiety in letters appearing in the dental literature (Millman 1984, Ball 1986, Page 1986, Lewin 1985, Stean 1982).

Occult caries has been related to the presence of fluoride enriched enamel that could resist acid attack from both the tooth surface and also from below the intact enamel. Sawle and Andlaw (1988) compared the data from two clinical trials carried out in 1974 and 1982. The later data from 1982 showed 32.2% of occlusal carious lesions in molars were diagnosed radiographically whereas eight years earlier only 10.3% of such lesions were diagnosed from radiographs. These data support the view that the increased use of fluoridated dentifrices makes it more difficult to clinically diagnose pit and fissure lesions.

Occult caries does not appear to be an entirely new phenomenon. A publication by Hyatt in 1931 shows a radiographic illustration of:

> "how deeply decay may progress at the base of a pit or fissure without giving any external evidence of its presence".

1.2. Diagnosis of Fissure Caries.

1.2.1 Histology and chemistry of fissure caries.

The initial lesion of pit and fissure caries occurs bilaterally on the walls of the fissure (Mortimer 1964). The caries process is initially a surface demineralisation which is followed by sub-surface loss of calcified tooth structure until the dentine is reached - the surface layer of enamel remaining relatively intact (Gray 1966).

The products of micro-organism metabolism are responsible for the demineralisation of the tooth structure. Demineralisation has been shown not to be a process of continued and gradual progression but to be intermittent with periods of alternating remineralisation (Silverstone 1977). Saliva represents an excellent remineralising solution especially when it is charged with the fluoride ion (Silverstone 1971).

The early white spot lesion can be arrested if the balance is tipped in favour of remineralisation (Kidd 1984). Koulourides *et al* (1980) reported that *in vivo* research showed that not only could the early white spot lesion be remineralised but that the arrested lesion was *more* resistant to further demineralisation. They termed this phenomenon "cariogenic priming". Clinical evidence of this was provided by Joyston-Bechal and Kidd (1981) who observed that white spot lesions in premolar teeth of young patients were more resistant to acid attack than neighbouring sound enamel. Histological evidence of remineralising lines were shown at the advancing front both superficially and within the lesion (Kidd 1983). Silverstone *et al* (1981) showed that a lesion could arrest even if only the surface zone remineralised.

1.2.2. Detection of Fissure Caries: Preparation of the teeth and the detection of fissure caries by visual inspection alone.

The importance of lighting, cleanliness of the teeth and examiner concentration was emphasised by Jackson (1950) who set out a routine procedure for caries diagnosis designed to reduce error.

The site of the lesion on the side walls of the fissure prevents direct inspection. However, detection of fissure caries by simple inspection has been considered by a number of authors. According to König (1966) the extent and intensity of the surface discolouration in a fissure is approximately proportional to the histological changes in the dentine underlying the enamel. Steep cuspal incline angles appear to be associated with the development of fissure caries (König 1963) although Rotgans *et al* (1979) was unable to demonstrate any relationship in a population where the caries prevalence was low. The correlation between the presence of dentine caries and diagnosis by inspection using a blunt probe has been demonstrated to be "fair" (Downer and O'Mullane 1975). On 15% of occasions, teeth clinically diagnosed as having fissure caries were found to be caries-free on histological sectioning.

A purely visual examination depends on demineralised enamel scattering light differently compared to surrounding sound enamel. Brinkman *et al* (1988) developed an optical instrument to measure quantitatively the intensity of scattered light. This allowed measurement of mineral loss in smooth surface lesions. The optical needle consisted of two bundles of fibres to deliver and collect the scattered light.

Bjelkhagen *et al* (1982) photographed the difference in luminescence between intact and carious enamel. He illuminated the smooth surfaces of teeth with light from an argon laser and photographed the reflected light. A filter was placed in front of the camera to eliminate all light with wavelengths less than 540nm. He showed that this technique was useful for the detection of occlusal lesions not otherwise detected by clinical examination alone.

Neilson and Pitts (1991) described the positive correlation between free smooth surface caries and pit and fissure lesions. One thousand one hundred and fifty one 13 year old subjects with at least one free smooth surface lesion (40% of the total sample group) were followed over a three year period. The authors demonstrated that where patients had decalcified smooth surface lesions that could be easily observed on clinical examination, a similar situation was likely to exist on the unseen walls of the fissures. They recommended patients in this category undergo radiographic assessment.

1.2.3 Use of the probe in detection of fissure caries.

Early texts advocated the use of sharp probes to diagnose fissure caries. Thus Parfitt and Herbert (1955) observed:

> "with the occlusal surface of molars, experience shows that unless a fine sharp point can be made to stick into a fissure there is a very small chance of caries being present."

As recently as 1970 Pickard noted that:

> "caries starting in an anatomical pit or fissure is best appreciated by a certain 'stickiness' on probing".

Recent survey data in a group of Scottish general practitioners (Paterson *et al* 1990) showed that 30-50% still used stickiness to the probe as the main method of diagnosis of pit and fissure lesions. Weerheijm *et al* (1989) recommended the use of light, mirror and probe as the principal diagnostic tools for detection of occlusal caries. They did, however, observe that there was no ideal method of detecting the presence and extent of pit and fissure caries.

Sognnaes (1940) observed that the accurate diagnosis of caries involved rather more than the use of the probe. He based this conclusion on a study in which he examined a series of children in 4 successive stages:

a. Mirror and probe alone.
b. Drying the teeth before use of the mirror and probe.
c. Cleaning and drying the teeth before use of mirror and probe.
d. Mirror and probe examination after cleaning and drying plus radiographs.

He noted that after drying of the teeth 20.8% more lesions were detected. Cleaning before drying produced a further increase of 9.7% in the number of detected lesions. Unfortunately, in the tabulated results the lesions were not classified by type i.e. into smooth surface and pit and fissure lesions.

The importance of using standardised probes was recognised by Miller and Atkinson (1951) who developed replaceable machine made probe tips in order to ensure that inaccuracies did not arise as a result of the distortion in shape and reduction in length of instruments following repeated sharpening.

The relationship between "stickiness" on probing and the shape and size of the probe tip and the fissure being examined was commented upon by Parfitt (1954). He observed that some deep and narrow fissures gripped the probe tip when no caries was present while in other instances caries in dentine was far advanced before stickiness was apparent.

A more extensive investigation of the value of the probe in the diagnosis of fissure caries was carried out by Miller and Hobson (1956). In a preliminary study, three clinicians examined a group of 30 children on two separate occasions. At the first visit, a standard probe was used and at the second examination, a probe with replaceable tips was employed. They concluded that the probe with replaceable tips provided a more reliable and reproducible form of diagnosis. A further more extensive study followed in which a series of lower molars were examined in detail by one of three dental surgeons using replaceable probe tips which were discarded after the examination of 7 patients. Radiographs were taken and read by an independent examiner. Data from this initial examination led to the conclusion that in this study, radiographs rarely allowed a diagnosis of occlusal caries before it was clinically obvious. In follow up examinations, carried out at 6 monthly intervals, two standards of caries were defined:

i) Caries - "Sticky". A probe with light pressure in a pit or fissure required a definite pull for removal.

ii) Caries - requiring filling.

A total of 380 "sticky" fissures were observed of which well over half were detected within 12 months of eruption of the tooth. Over a 41 month follow up period 70% of these sticky fissures became carious. It must be emphasised that this result was achieved with strictly defined criteria for the examination of the patient using standardised probe tips which were replaced after every 7 cases.

The possibility that probing of fissures to diagnose caries may produce damage to the enamel surfaces was investigated by Ekstrand *et al* (1987). Their study was carried out using 10 young adults who were scheduled to have their newly erupted wisdom teeth extracted. One tooth in each patient was selected at random and clinically examined with a new dental probe which was applied at several angles to all pits and fissures. The results demonstrated that the use of probes may produce irreversible traumatic defects in demineralized areas in occlusal fissures which would favour the progression of the carious lesion.

van der Laan-van Dorp and Exterkate (1986) discovered during *in vitro* testing that the use of probes resulted in a greater rate of caries progression. Their work was carried out using incipient artificially induced carious lesions in fissures. These lesions were created in extracted bovine incisors by preparing a fissure along the labial surface using a diamond disc. A gel containing phosphoric acid was then used to decalcify designated areas of the fissure surfaces. More rapid involvement of the underlying dentine occurred after probing the fissures.

Bergman and Linden (1969) reported that the use of the dental explorer on arrested caries could irreversibly damage fissure surfaces and transfer cariogenic micro-organisms to non-infected pits and fissures.

A study by Lussi (1991) discussed the differences in fissure caries diagnosis *in vitro* with and without the use of a dental explorer. Sixteen general dental practitioners and eighteen hospital dentists were asked to examine specified areas on 61 extracted molar and premolar teeth - only ten of the hospital dentists were allowed to use a probe while the other participants relied on visual inspection alone. Twelve examiners were asked to repeat the exercise a week later to assess reproducibility. Teeth were then sectioned for histological examination.

The sensitivity and specificity of caries diagnosis was not significantly different between the two groups of examiners. Reproducibility was found to be highly significant but the author concluded:

> "Correct diagnosis of fissure caries seems to be quite difficult, be it by visual technique only or with the additional help of an explorer."

1.2.4 Use of radiographs in the detection of fissure caries.

X-rays were first discovered by Wilhelm Conrad Roentgen in 1895 according to Whaites (1992). The potential for caries diagnosis was reported by Bodecker and Bodecker (1912). The first x-ray machine for dental use did not appear until 1917 and nine years later, the bitewing film was described. In 1934, Anderson *et al* documented the first clinical trial which made use of radiographic techniques.

As carious lesions absorb less radiation than the surrounding sound mineralised dental tissues, they appear darker on roentgenographic film. Assessment is only a semi-quantitative measurement and is therefore open to error.

The use of intra-oral radiography is invaluable for the diagnosis of approximal carious lesions. This led Backer-Dirks *et al* (1951) to abandon clinical examination and rely entirely on radiographic evaluation. This was considered to provide a higher degree of intra- and inter- examiner agreement. Similar high degrees of consistency were not reported, however, when this situation was applied to the diagnosis of fissure caries (Miller and Hobson 1956).

The use of intra oral radiography as a diagnostic tool to determine the presence of pit and fissure caries has been the subject of much debate.

Galagan and Vermillion (1956) reported the diagnosis of occlusal caries by radiographic means to be a clinical rarity while Wuehrmann *et al* (1969) suggested:

> "The diligent use of a mirror and explorer will ordinarily detect occlusal caries before it becomes observable radiographically".

King and Shaw (1979) were able to detect 96% of fissure caries from a clinical examination alone while the use of bitewing radiographs recorded the presence of only 33% of these lesions. Wenzel *et al* (1991) demonstrated that only half of the caries lesions present in histological sections was detectable radiographically. However, more recently the use of the bitewing radiograph in the detection of occlusal caries has become more common. Weerheijm *et al* (1989) concluded that bitewing radiographs could constitute a valuable addition to the individual clinical examination and advocated the use of bitewing radiographs for adolescent patients on fluoride supplements.

Creanor et al (1990) examined bitewing radiographs in a 2623 subjects aged between 14-15 years who were taking part in an anti-caries dentifrice trial in the West of Scotland. They reported that in 12.1% of the lower molars and 3.1% of upper molars which were judged to be clinically sound, radiographic evidence of dentine caries could be shown. They considered that their data provided further support for the view that increased use of fluoride resulted in maintained integrity of occlusal enamel overlying the spreading dentine lesion.

Paterson *et al* (1991) observed that while the bitewing radiograph was of little value in the detection of the early occlusal lesion - because of the fissure morphology - it was an important method of screening for occult lesions. The concept of a change in the features of the occlusal lesion leading to increased diagnostic difficulty has also been discussed by Sawle and Andlaw (1988).

In one of the few recent clinical studies designed to determine if the nature of occlusal caries was changing, Weerheijm *et al* (1989) looked in detail at 26 molar and premolar teeth with virtually intact enamel, from 10 patients aged between 11 and 18 years. Twenty of these had caries extending into the dentine. In 2 teeth, despite an apparently totally intact enamel surface, extensive dentine lesions were demonstrated. The authors concluded that the mirror, light and probe must remain the principal diagnostic tools supported by the bitewing radiograph in individual cases.

1.2.5 Other methods of fissure caries detection.

The presence of demineralised enamel fissures can be used in two further methods of caries detection.

a/ A method of electronically detecting caries was first described by Pincus in 1951. Detection using this method can be explained by increased conductivity of the tooth structures when microscopic voids, created by the initial caries process, become filled with saliva. The resistance of the tooth structure to the passage of a small battery generated current could be used as a diagnostic aid. The technique was improved by Mayuzami *et al* (1964) and White *et al* (1978).

A report by Rock and Kidd (1988) compared *in vivo* electronic detection with histological evidence of caries following extraction of the tooth for orthodontic reasons. Their results showed that the apparatus had a specificity of 85%: meaning that on only 15% of occasions did the machine not indicate a sound tooth. On 70% of occasions the machine correctly indicated the presence of fissure caries (sensitivity). Rock and Kidd concluded that as the apparatus could detect natural developmental areas of hypomineralisation as described by Gwinnet (1966), it could be used to monitor the effect of a caries control programme on the arrest of early carious lesions.

Previous work with this diagnostic system compared results with those obtained where sharp dental explorers were used (White *et al* 1981). This method has been shown to be inaccurate.

b/ The wetting of the enamel surface by dyes was first reported by Jansen and Visser (1950) who found that although sound enamel would take up dye with time, a carious lesion with its increased porosity would allow dye uptake more readily. More reactive calcium ions bond with carboxylic and sulphonic acid side groups on the dye. Brooke *et al* (1972), Owen and Rawls (1972) and Rawls and Owen (1978) showed that only a few minutes exposure was required for staining of carious enamel to occur. Sullivan (1954) reported the stained lesion to contrast with the white background of the tooth surface, thus improving the operator's diagnostic ability.

Hardwick and Manley (1952) showed the value of the technique as:

> " an indicator of incipient caries which had not progressed to the stage where clinical manifestations occur".

Calcium ions released from a lesion may form chelates with dyes. 8-hydroxyquinoline was reported by Konikoff and Lyles (1969) to chelate with these calcium ions and to subsequently fluoresce when excited by application of ultra-violet light. Many of the indicators and solvents used have commercial applications for industry. However, they were toxic, flammable and unsuitable for use in clinical dentistry. Their clinical use as a diagnostic system has not found universal favour - the dyes used having been found to stain plaque in pits and fissures, therefore making the detection of incipient lesions impossible. They have also been shown to react with the enamel and therefore have the major disadvantage of not being easily removed following detection.

Transillumination is a relatively old procedure, but the use of fibre-optics has allowed the illuminating energy to be more easily utilised in all areas of the mouth (Friedman and Marcus 1970). FOTI (Fibre Optic Trans Illumination) has been shown to be less sensitive than bitewing radiography in the detection of early carious lesions on approximal surfaces (Mitropoulous 1980). However, once the lesions have progressed into the underlying dentine, Nyvad *et al* (1980) have described the technique as being almost as reliable as bitewing radiography. This technique, however, is non invasive and free from the possible health hazards of ionising radiation.

Dooland and Smales (1982) reported indifferent results in detection of occlusal lesions when low intensity transillumination and high intensity fibre-optic systems were used to inspect 397 molar teeth in primary school children attending a School for Dental Therapists in South Australia. The high intensity light appeared to perform better than a low intensity model. Deep narrow fissures blocked the transmission of light more effectively than wide shallow fissure systems. In all cases the tooth required to be reasonably dry. Only four additional lesions were found that had not been previously diagnosed by clinical inspection.

Stephen *et al* (1987) found that fibre optic transillumination could result in the over diagnosis of approximal lesions due to the presence of flaws in the enamel. The use of FOTI in the posterior dentition was of some benefit only if radiographs were not available. In such instances diagnosis of approximal caries was improved by 48%.

1.2.6 Clinical management of fissure caries.

A review of the assessment and clinical management of early caries was presented by Elderton (1985b). He noted that there were no objective tests which would allow the diagnosis of active caries in a fissure and observed that clinicians had to rely on their subjective judgement of any hard tissue changes. The earlier work of Miller and Hobson (1956) was cited as evidence that early lesions manifested by "stickiness" in fissures did not all proceed to large dentinal lesions.

In Elderton's view, the management of pit and fissure lesions differed from that of smooth surface lesions in that it was inappropriate to adopt any type of "wait and watch" approach. When caries could be demonstrated in dentine, an invasive approach had to be adopted and a glass ionomer, composite resin or amalgam restoration placed.

1.3 The validity of diagnosis of fissure caries lesions by groups of Clinical Community Dental Officers and General Dental Practitioners: Comparison of an *in vitro* model and *in vivo* results.

1.3.1 INTRODUCTION

Diagnostic difficulties

As caries prevalence falls in the population and the proportion of pit and fissure caries rises, there must be greater emphasis placed on the correct diagnosis of Class I caries lesions. The traditional use of the dental probe in fissure caries diagnosis has been questioned and it has been suggested that a non invasive visual technique should replace it to avoid the danger of enhancing the incipient lesion.

Other non invasive techniques e.g. Fibre **O**ptic **T**ransIllumination and the measurement of the electrical resistance of the tooth have been investigated, but none has been universally adopted.

Radiography of the posterior teeth has a high sensitivity in the diagnosis of approximal caries but its use in the detection of occlusal lesions has been investigated and found lacking with the exception of the diagnosis of occult lesions.

Problems associated with diagnostic difficulties.

Diagnosis of pit and fissure caries therefore must account for a considerable part of the daily diagnostic routine of most dentists. Dental Health Educators and most of the general public (Levine 1985 and Todd *et al* 1982) believe that a regular dental examination plays an important part in preventing dental disease. Accurate diagnosis is essential in providing our patients with the best possible care but it has been reported that there is a problem identifying which teeth require placement of restorations (Elderton & Nuttall 1983, Merrett & Elderton 1984 and Elderton 1984). Kay *et al* (1988) and Weerheijm (1989) demonstrated that the detection of small occlusal lesions was difficult.

Restorative decisions taken by practitioners now influence the dental health on a population basis. When the prevalence of dental caries was very high, caries swamped the dental indices. Nowadays, the filled component of the dental health indices make the greatest impact.

1.3.2 Aims of the current study.

In the present study a group of Community Dental Officers and General Dental Practitioners practising in the Greater Glasgow and Lanarkshire Health Board areas were asked:

1. To list their treatment decisions for 35 extracted molar teeth - initially without radiographs.

2. To record any modification to those decisions that they considered appropriate after review of the radiographs of these teeth.

3. To record their clinical treatment decisions taken in a large field trial designed to assess the performance of sealant restorations in the management of fissure caries.

1.3.3 MATERIALS AND METHODS.

Tooth selection.

Thirty-five human molar teeth with no smooth surface caries were selected for inclusion in the trial. Storage of the molar teeth in a saline solution prior to the investigation did not exceed six months. The teeth were mounted in numbered acrylic blocks and cleaned with a pumice slurry. A clinical photograph and radiograph were taken of each tooth. They were kept moist throughout the trial period. The teeth were selected after careful visual examination so that balanced numbers of clinically obvious sound teeth, teeth with evidence of decalcification in the fissure pattern and teeth with cavitation were included in the sample.

Participating operators.

Twenty five dentists participated in the investigation: 12 General Dental Practitioners and 13 Clinical Community Dental Officers. The dentists were asked to examine the occlusal, buccal and palatal pits and fissures of the sample teeth using a standard operating lamp. They were allowed to use compressed air for drying the tooth surfaces and note was taken of the method of diagnosis used i.e. visual inspection alone or visual inspection in combination with tactile probing.

Treatment decisions.

Each dentist was asked to make a treatment decision which could include:

* investigation of the fissure and placement of a restoration;
* fissure sealing the pits and fissures;
* performing no treatment.

Decisions were based on the assumption that the specimen was a first permanent molar and came from a 12 year old with a good attendance record and with a moderate caries experience i.e. having two other restorations in the mouth and there being two other caries lesions present in other teeth. After the initial treatment decision, the dentists were provided with radiographs of the tooth specimens and asked to note any change in treatment decision based on the new evidence.

Validating criteria.

Once all the operators had inspected the teeth, the samples were serially sectioned perpendicular to the surface with a diamond disc and water spray coolant and the sections were again photographed. The sectioned teeth were examined under magnification of 10X to determine if caries was present in dentine or enamel based on the serial sections. Decalcification of the side walls of the fissure was scored as an enamel lesion while spread of the decalcification at the enamel-dentine junction was scored as a dentine lesion.

The sectioned tooth was considered to be the validating criteria against which the evaluation of the treatment decisions made by the two operator groups was made.

Sensitivity and specificity values were calculated for each operator (Krasse 1988) and, in addition, the number of correct treatment decisions were noted. The results were analysed for differences between the two operator groups and for differences between vision and probe users and those operators who diagnosed using a visual inspection routine alone.

1.3.4 RESULTS.

Treatment decisions for each molar tooth sample.

In Figures 1.1 and 1.2 the treatment decisions made for each of the molar tooth samples are shown graphically. The samples marked with an asterisks are those which were considered to be free from dentinal caries when serially sectioned and examined under a magnification of 10X. In Figure 1.1, tooth number 11 would have been restored by 56% of the dentists yet was found to be free from caries when sectioned. Conversely, tooth number 15 was found to have dentine caries yet would have been investigated by only 24% of the operators. Figure 1.2 shows the frequency of treatment decisions after the operators were able to assess radiographs of the extracted molar teeth. Eight more operators (32%) would have investigated tooth numbers 52 and six more operators (24%) would have intervened in tooth number 4. These molars both had established dentine caries.

Influence of the specialty in which the operator worked.

Table 1.1 indicates the number of teeth each operator considered should be investigated and the total number of correct decisions decided after the examination of the sectioned tooth. When statistically evaluated using Kruskal Wallis test, no significant difference was found between the CDO's and the GDP's on the number of decisions on teeth requiring investigation. Similarly, using Wilcoxon's Signed Rank test no significant difference was found between the decisions taken with and without examination of a radiograph. The decisions not to investigate included those occasions where fissure sealing was advocated. This non-invasive procedure was considered correct if there was no caries lesion in dentine.

Sensitivity and specificity values.

The sensitivity and specificity for each operator is presented in Table 1.2 Most operators diagnosed with greater specificity than sensitivity. 73.7% of the probe users had higher specificity than sensitivity while the validity of those operators who diagnosed by a visual inspection alone was 79.5% and that of the operators using a visual and tactile method was 80.1%. When radiographs were used in the diagnosis, 8 of the 25 operators (32%) had their sensitivity lowered and 5 dentists (20%) had specificity values reduced.

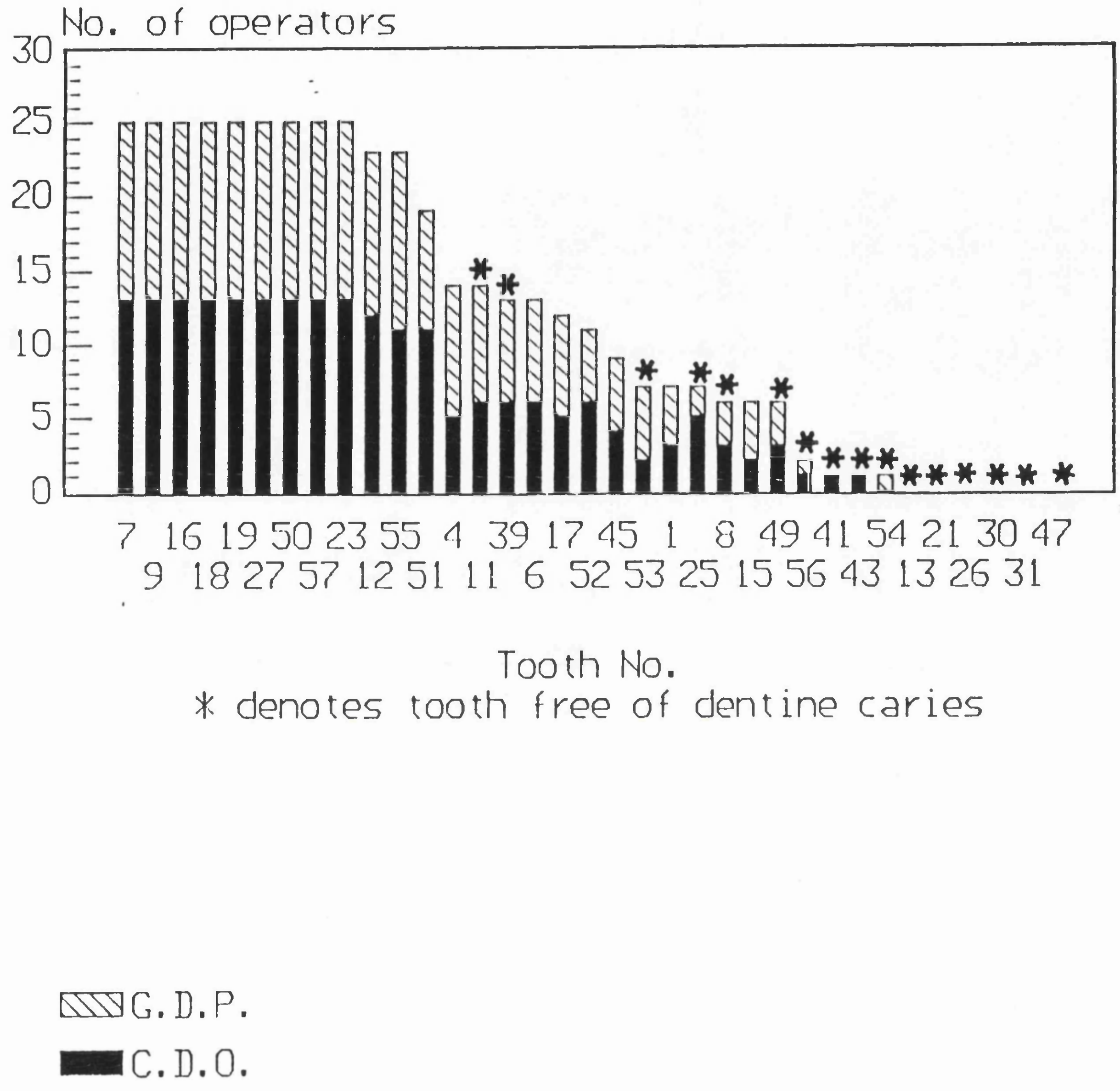


Figure 1.1 **Frequency of treatment decisions taken by the two groups of operators to investigate each of the 35 teeth. No radiographic assessment was employed.**

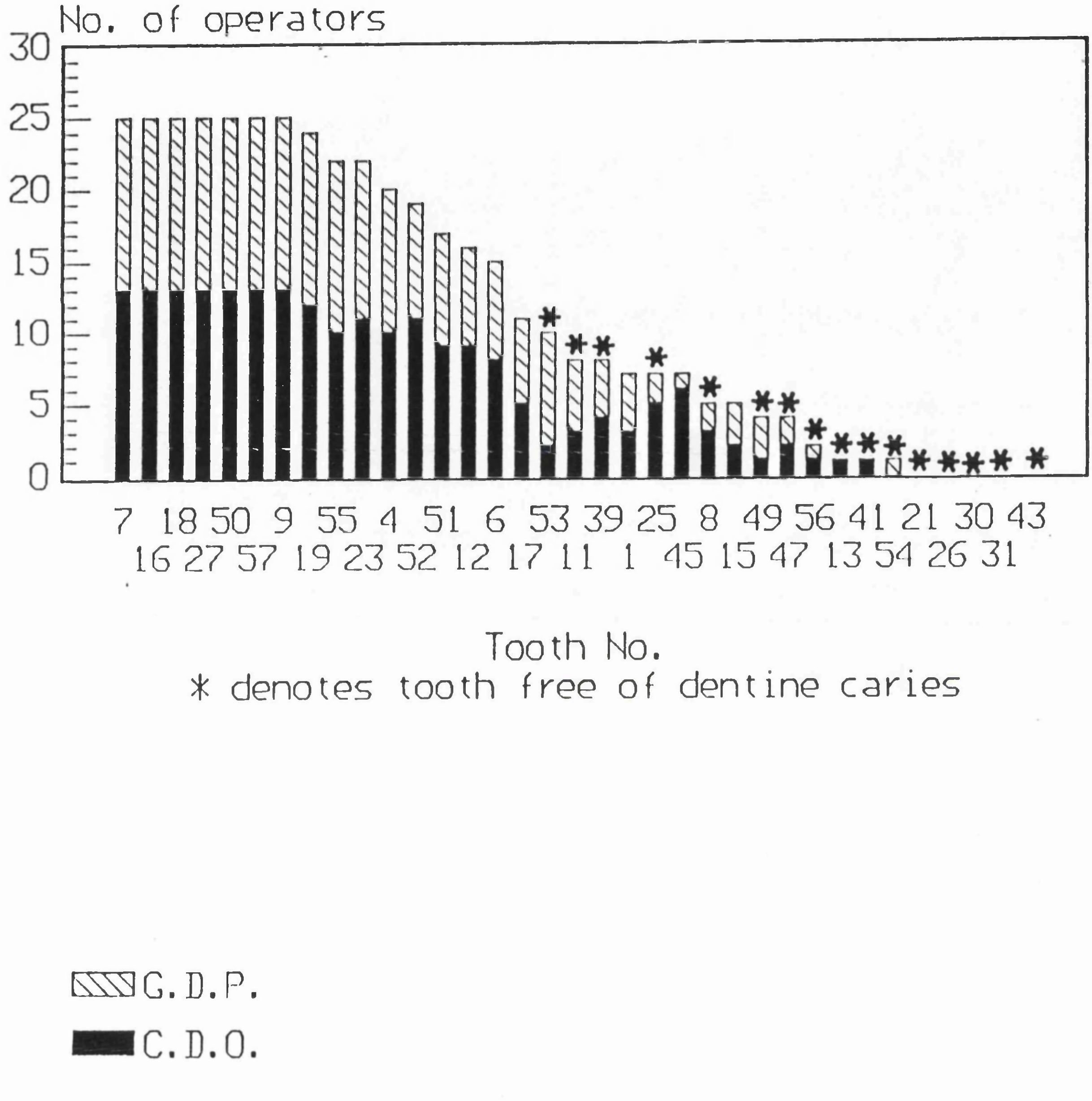


Figure 1.2 **Frequency of treatment decisions taken by the two groups of operators to investigate each of the 35 teeth. Radiographs were assessed before a treatment decision was reached.**

		without radiographs			with radiographs		
Operator Number	Diag. Method	Investig. decisions Max 35	Non-invig decisions Max 35	Total correct decisions Max 35	Invest decisions Max 35	Non-inv deci-sions Max 35	Total correct decisions Max 35
1	V+P	19	16	31	20	15	32
2	V+P	11	24	27	12	23	28
3	V+P	10	25	26	12	23	28
4	V+P	22	13	26	24	11	28
5	V+P	12	23	28	13	22	29
6	V	26	9	28	26	9	28
7	V+P	17	18	27	12	23	28
8	V	14	21	26	17	18	25
9	V+P	16	19	28	19	16	30
10	V+P	13	22	29	15	20	31
11	V	17	18	27	19	16	24
12	V+P	11	24	27	10	25	26
13	V+P	22	13	28	20	15	28
14	V	19	16	29	19	16	29
15	V+P	20	15	30	20	15	30
16	V+P	14	21	27	13	22	28
17	V+P	18	17	28	17	18	29
18	V+P	13	22	29	12	23	28
19	V	20	15	30	20	15	30
20	V+P	16	19	30	14	21	28
21	V+P	18	17	28	16	19	26
22	V+P	14	21	28	14	21	25
23	V	21	14	27	19	16	27
24	V+P	24	11	28	23	12	29
25	V+P	16	19	28	20	15	28

Operators 1 - 13 Clinical Community Dental Officers

Operators 14 - 25 General Dental Practitioners

V = Visual Inspection

V + P = Visual Inspection and Probe

Table 1.1 Total and number of correct treatment decisions taken by each dentist.

Operator Number	Sensitivity without	Sensitivity with	Specificity without	Specificity with
	radiographs		radiographs	
1 V+P	89.5	94.7	87.5	87.5
2 V+P	57.9	63.2	100	100
3 V+P	52.6	63.2	100	100
4 V+P	84.2	94.7	62.5	62.5
5 V+P	63.1	68.4	100	100
6 V	100	100	56.2	56.2
7 V+P	73.8	57.9	81.2	93.7
8 V	73.7	78.9	100	87.5
9 V+P	73.7	84.2	87.5	81.2
10 V+P	68.4	78.9	100	100
11 V	73.7	47.4	81.2	37.5
12 V+P	57.9	52.6	100	100
13 V+P	89.5	84.2	68.7	75.0
(Ave)	**(73.7**	**74.5)**	**(86.5**	**83.2)**
14 V	84.2	84.2	81.2	81.2
15 V+P	89.5	89.5	81.2	81.2
16 V+P	68.4	68.4	93.7	100
17 V+P	78.9	78.9	81.2	87.5
18 V+P	68.4	63.2	100	100
19 V	89.5	89.5	81.2	81.2
20 V+P	78.9	68.4	93.7	93.7
21 V+P	78.9	68.4	81.2	81.2
22 V+P	68.4	63.2	93.7	87.5
23 V	84.2	78.9	68.7	75.0
24 V+P	94.7	94.7	62.5	68.7
25 V+P	73.7	84.2	87.5	75.0
(Ave)	**(79.8**	**77.6)**	**(83.8**	**84.3)**
Overall Means:	**76.6**	**76.0**	**85.2**	**83.7**

1 - 13 Clinical Community Dental Officers

14 - 25 General Dental Practitioners

V = Visual Inspection
V + P = Visual Inspection and Probe

Table 1.2 Validity of dentists' treatment decisions in terms of sensitivity and specificity with and without the use of radiographs.

1.3.5 DISCUSSION

Differences between diagnostic methods.

There has been considerable discussion within the profession about the best diagnostic technique for pit and fissure caries. A number of literature reports illustrate some of the difficulties. Probing of pit and fissure surfaces has been shown to enhance the breakdown of the enamel surface in early lesions favouring their progress (Ekstrand *et al* 1987). The use of the dental explorer has been shown to introduce cariogenic bacteria into the fissure system (Bergman and Linden 1969). Although Lussi (1991) observed that the use of the dental probe produced a higher specificity than those using vision alone as a diagnostic method, he reported this to be statistically insignificant. He argued that operators using the dental explorer would be more likely to correctly diagnose sound teeth. In his view, this was due to the explorer failing to stick in the fissures of sound teeth. The relationship between "stickiness" on probing and the shape and size of the probe tip and the fissure being examined was commented upon by Parfitt as long ago as 1954. Parfitt observed that some deep and narrow fissures gripped the probe tip when no caries was present while in other instances caries in dentine was far advanced before stickiness was apparent.

Difficulties in diagnosing occlusal caries may be caused by the remineralisation of the fissures in the presence of fluoride. Caries can then extend into dentine with an intact enamel surface (Sawle and Andlaw 1988 & Weerheijm 1989). With increased use of fluoridated toothpastes, Sawle and Andlaw (1988) demonstrate radiographically that there was an increased number of clinically undiagnosed caries lesions. Drying of the teeth was reported to be vital in demonstrating opacities around fissures (Lussi 1991) yet this is difficult in the conditions of a paediatric clinical practice.

Differences among operator groups.

Kay *et al* (1988) used an *in vitro* method similar to that used in the first part of the current study to compare treatment decisions taken by dentist from different hospital departments. They suggested that variation between dentists arose from personal idiosyncrasies rather than from any influences of the speciality of the dentist. In the present investigation, the results from groups of dentists working as General Dental Practitioners and Clinical Community Dental Officers were compared. No differences were found in either sensitivity or specificity, but the group of Clinical Community Dental Officers advocated more fissure sealants be placed than did the General Dental

Practitioners. Kay *et al* (1988) also observed that as the prevalence of caries falls so does the predictive power of a screening test. They recommended that questionable lesions should be placed on routine review or preferably should be fissure sealed. Handelman (1976) concluded that pit and fissure sealants could safely be used without cavity preparation in the management of occlusal caries because there was a reported reduction in the viable bacterial count of fissure caries under intact fissure sealant (Jeronimus *et al* 1975). Theilade *et al* (1977) attributed this effect to the close hermetic seal obtained between the resins used for sealing and the etched enamel surface. When the integrity of the seal was tested by Jensen and Handelman (1978) using radioactive isotopes, it was discovered that no movement of fluid or ions took place. Long term performance of fissure sealants have been reported with complete retention of sealant after 10 years ranging from 42 to 80% (Simonsen 1987 & Wendt and Koch 1988). Simonsen (1987) reported that only 15.6% of sealed surfaces had developed caries or been restored after 10 years.

Sensitivity and specificity values.

In the studies by Kay *et al* (1988) and Lussi (1991) it was demonstrated that the operators had higher specificity than sensitivity. Similar observations were made in the present study, with the overall specificity similar to that achieved by Lussi (1991) - 88% compared to 83%. This means 88% of the sound teeth were correctly diagnosed while the remaining 12% were misinterpreted. The consequences of this is the needless filling of sound teeth and committing them to a "repeat restorative cycle" where they may have a lifetime of repair and extension (Elderton 1977). The sensitivity in this investigation was higher than that achieved by either Kay *et al* (1988) or Lussi (1991). Seventy-four percent of the sample molar teeth were correctly identified as requiring placement of fillings. This means 26% of carious molars were left with caries untreated, i.e. the dentists were under - diagnosing rather than over - diagnosing. As routine dental examination is regarded by patients as an important method of preventing dental disease (Todd *et al* 1982) it is important not to place restorations in sound teeth. The Inquiry into Unnecessary Dental Treatment (1985) indicated that it was preferable to have a screening method that allowed some carious lesions to go unfilled rather than risking filling sound teeth.

In the current study the differences between the specificity and sensitivity values obtained by operators using a visual inspection alone and those also using the probe were not statistically significant. In view of the report by Ekstrand *et al* (1987) of potential damage to the enamel surfaces on the fissure walls, it would appear prudent to discontinue use of the probe in diagnosis of fissure caries since it produces no improvement in diagnostic accuracy. Elderton (1983 & 1984) and Merrett and Elderton (1984) suggested the diagnostic methods used did not influence the ability to diagnose fissure caries.

Visual inspection of pits and fissure on the occlusal surface of extracted molar teeth was not an entirely reliable diagnostic method for caries: the molar in sample 11 was caries free yet would have been investigated by 56% of the operators involved; when the tooth in sample 15 was serially sectioned it was found to contain dentinal caries which only 24% of the dentists would have elected to restore. Although there was unanimous decision to investigate nine of the sample teeth, there were differing views as to which teeth required restoration with the remainder of the sample.

In the *in vitro* situation, the use of a visual inspection method of caries diagnosis is equivalent to the traditional method of diagnosis using the dental explorer.

1.4 The Prediction of the Extent of Caries in Pit and Fissure Lesions in a Field Trial in the West of Scotland.

1.4.1 INTRODUCTION

Changes in caries prevalence.

A number of letters to dental journals have observed the difficulty in accurately diagnosing fissure caries. The reason underlying this was termed the "fluoride syndrome" where fluoride enriched surface enamel resisted breakdown until the underlying dentine caries was extensive and advanced: a condition known as "occult caries".

Some studies have examined patients using different diagnostic techniques and compared the results with either radiographs or the extracted teeth which were serially sectioned and examined (e.g. Ekstrand *et al* 1987) . The possibility of damage to the enamel surface caused by probing fissures has been demonstrated. Currently many authorities advocate a non invasive inspection of the cleaned and dried tooth surface. The results from the previous study indicated no difference in the sensitivity and specificity values for operators using:

* visual inspection alone
* visual inspection plus the probe

In addition, when bitewing radiographs were studied during the caries diagnosis examination in section 1.3, no improvement in the accuracy of the diagnosis was observed. In the current study, the same two groups of operators were used.

The aim of the current study.

It would appear that there may be increasing difficulty with the detection of active caries in pits and fissures. The majority of reports to date have concerned either *in vitro* studies using extracted teeth or very small numbers of patients being treated under closely supervised conditions. There does not appear to be any data available from practitioners providing a routine care service for children and young adults.

A large field trial designed to evaluate the performance of sealant restorations in the management of fissure caries has been carried out. These restorations were placed by Commmunity Clinical Dental Officers (CDOs) and General Dental Practitioners (GDPs) in the West of Scotland, using their normal methods of diagnosis and techniques for the placement of the restorations. They were placed in occlusal, buccal and palatal pits and fissures of molar and premolar teeth in the permanent dentition. All of the operators had used the Scottish Office Distance Learning Programme "Trends in the Management of Fissure Caries" (1989). This argued the case for the preventive management of fissure lesions. Diagnosis of caries was based on an assessment of the overall caries risk, followed by careful inspection of the cleaned, dried tooth and of bitewing radiographs. The application of fissure sealant was advocated for stained and decalcified fissures without evidence of cavitation or dentine caries on a radiograph. Where an active lesion was suspected the investigative cavity approach first advocated by Simonsen and Stallard (1977) in their description of the Preventive Resin Restoration was recommended. Where the lesion was limited to enamel, it was suggested that the cavity was restored with composite resin and fissure sealant. If the cavity extended into dentine but did not show significant lateral spread at the enamel - dentine junction, a combination of glass ionomer cement and fissure sealant was advocated. For the more extensive lesion with lateral spread resulting in the margins of the final restoration being in occlusion, a glass ionomer base and a posterior composite restoration, followed by sealing of the remaining fissures was described.

As each restoration was registered, participants recorded the extent of the lesion found in enamel and dentine and whether the cavity size was as predicted, larger or smaller than expected.

1.4.3 MATERIALS AND METHODS.

A field trial of sealant restorations.

The field trial was based upon 14 CDOs working for the Greater Glasgow and Lanarkshire Health Boards and 19 GDPs from Greater Glasgow, Lanarkshire and Ayrshire & Arran Health Board Family Practitioner Lists. All the participants were volunteers: no attempt was made to select the participants.

Participating operators monitored their use of the sealant restoration technique through the use of a specially designed registration card system. This recorded the details of the tooth and clinical findings during the operative procedure. Operators were asked to record if the cavity extended into dentine or remained within enamel. In addition, the size of the completed cavity was compared with that estimated by the operator before the restorative procedure commenced.

Sealant Restorations were classified using the nomenclature adopted in "Trends in the Management of Fissure Caries". Cavity size and type of sealant restoration selection criteria are shown in Table 1.3

In type 2 - 4 lesions, the extent of caries was determined after the preparation of an investigative cavity (designed to remove the caries only) with a small bur.

At the outset of the trial all the participants were interviewed to determine the clinical techniques routinely used for the diagnosis of pit and fissure caries.

All of the participants recognised the importance of cleansing and drying the teeth before examination. All were using adequate operating lights. Blunt ended epidemiological probes were not available to the participants.

Type	Indication	Materials Suggested
1	Stained/decalcified fissures.	Fissure Sealant applied.
2	Lesion limited to enamel after biopsy.	Composite resin + Fissure Sealant.
3	Biopsy shows caries just into dentine.	Glass Ionomer cement + Fissure Sealant.
4	Biopsy shows extensive caries in dentine.	Glass ionomer cement base + Composite resin + Fissure Sealant.

Table 1.3 Types of lesion / Sealant Restoration used in pit and fissure caries.

1.4.3 RESULTS.

Distribution of Teeth.

Figure 1.3 shows the distribution by tooth of the 1052 Sealant Restorations placed in the field trial. As would be expected in the 6 to 14 age group, the restorations have been placed predominantly in first permanent molar teeth, with the majority of the remainder placed in second molars.

Distribution of sealant restoration types.

Figure 1.4 shows the distribution of the types of restoration. Type 1 restorations (i.e. Fissure Sealant alone placed over stained and decalcified fissures) did not involve any cavity preparation and therefore are excluded from the subsequent data.

The methods of diagnosis used by the participants are presented in Table 1.4. Six of the 14 CDOs (43%) did not routinely use bitewing radiography and eleven (79%) still routinely used the dental probe. One GDP did not use radiographs routinely and the probe was used in diagnosis by 84% of the group.

Figures 1.5 - 1.7 show the results of the cavity size prediction in the types 2, 3 and 4 restorations respectively. Accuracy in cavity size prediction was 58 -75% for the type 2 restorations (used where the lesions was limited to enamel).

With the larger type 4 restorations, (used where there was extensive dentine involvement), the accuracy of cavity size prediction fell to 28 - 41%. In the smaller restorations, the majority of the errors in cavity size prediction were that the cavity was smaller than expected. With the larger restorations, the opposite was true with 52 - 69% of the cavities being larger than expected.

Statistical comparison using the Chi-square test shows no significant difference between the accuracy of prediction of cavity size between the operators using the probe and those using only visual inspection for the types 2 and 4 restorations ($P > 0.05$). In type 3 cavities (i.e. lesions extending just into dentine), a visual inspection technique alone proved not only to be more accurate in correctly estimating cavity size but also to have fewer cavities larger than expected than either of the other two diagnostic techniques involving use of the probe ($P < 0.05$).

Figure 1.8 depicts the summated data for the types 2 to 4 restorations. This shows that the overall number of restorations where the cavity size was as predicted by the operators was approximately 50% (range 48 - 57%). There was no statistical difference in the accuracy of prediction achieved by the different diagnostic methods.

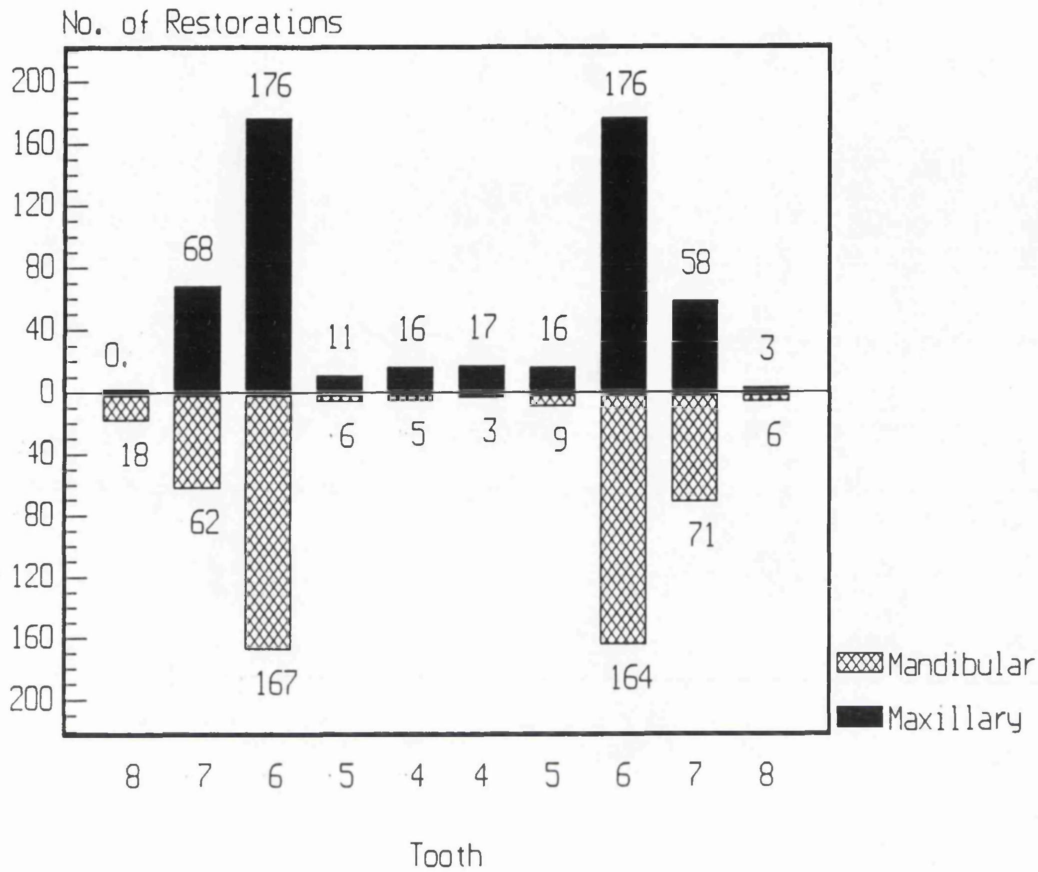


Figure 1.3 **Distribution of teeth restored by General Dental Practitioners and community Dental Officers. In total, 1052 sealant restorations were placed.**

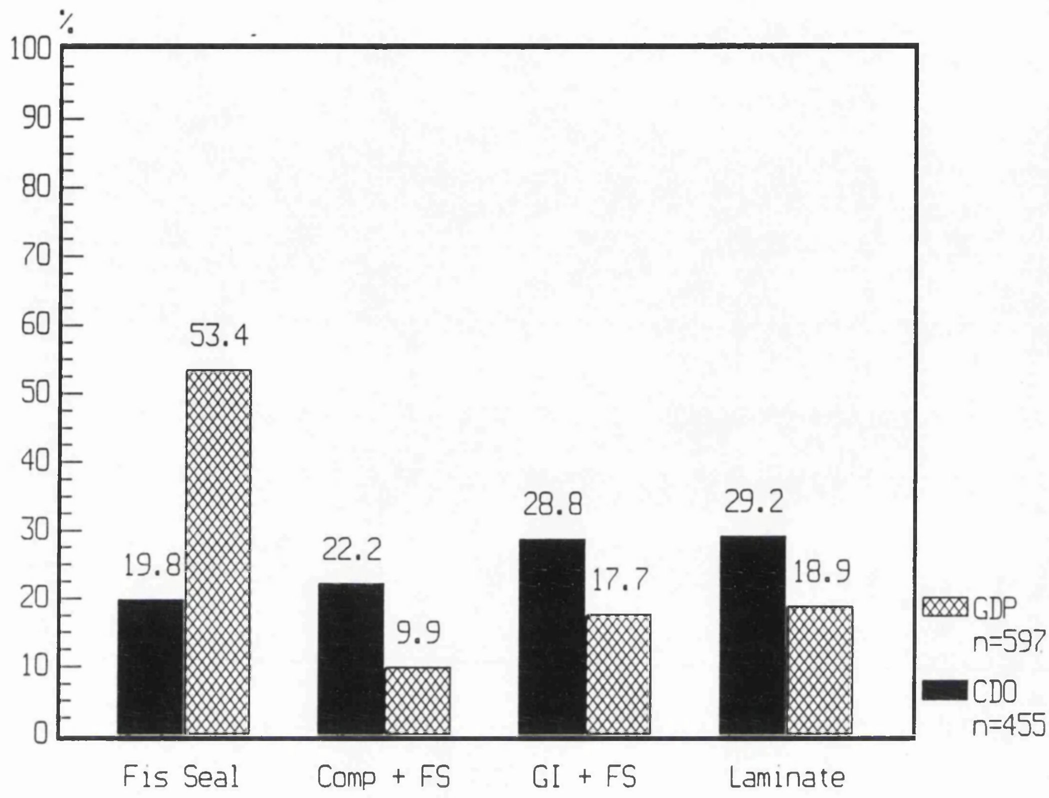
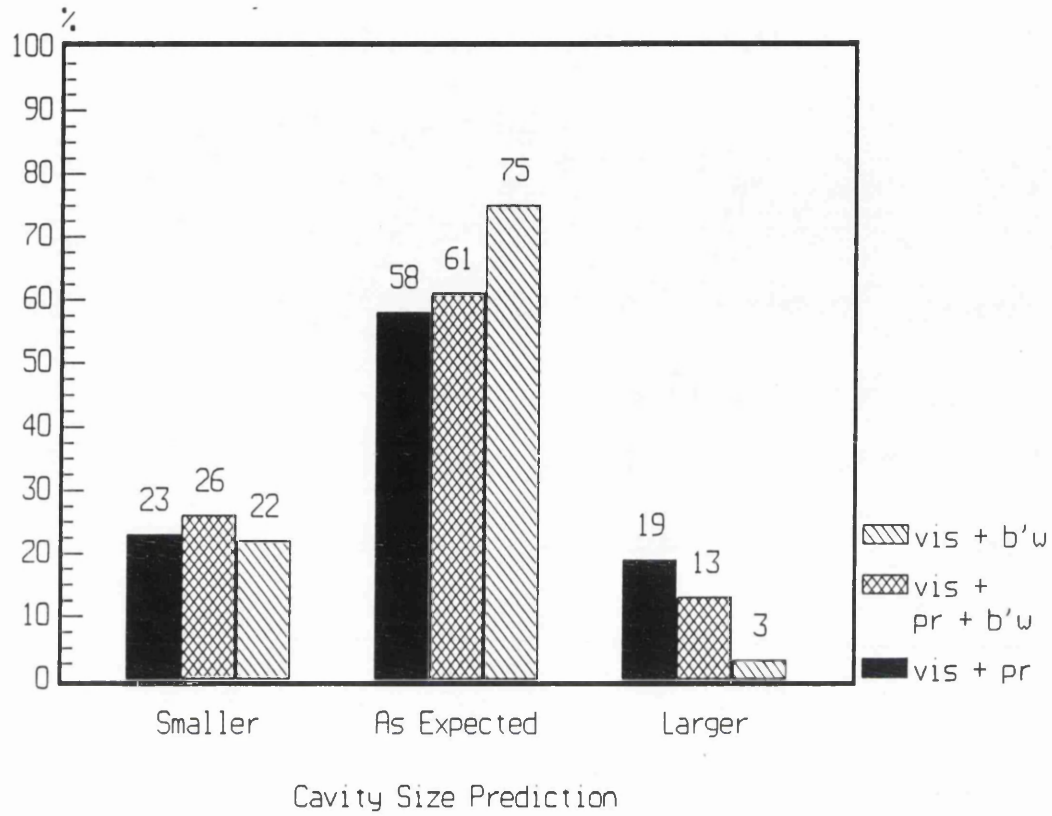


Figure 1.4 **Distribution of the 1052 sealant restorations placed by the two groups of operators. The enamel biopsy technique was employed during 46.6% of restorations placed by the General Dental Practitioners and during 80.2% of restorations provided by the staff in the community Dental Services.**

	Visual + Probe	Visual + Probe + Bitewing	Visual + Bitewing
Community Dental Officer	**6**	**5**	**3**
General Dental Practitioner	**1**	**15**	**3**
Totals	**7**	**20**	**6**

Table 1.4 Diagnostic methods used by the two groups of operators to detect fissure caries (n = 33).

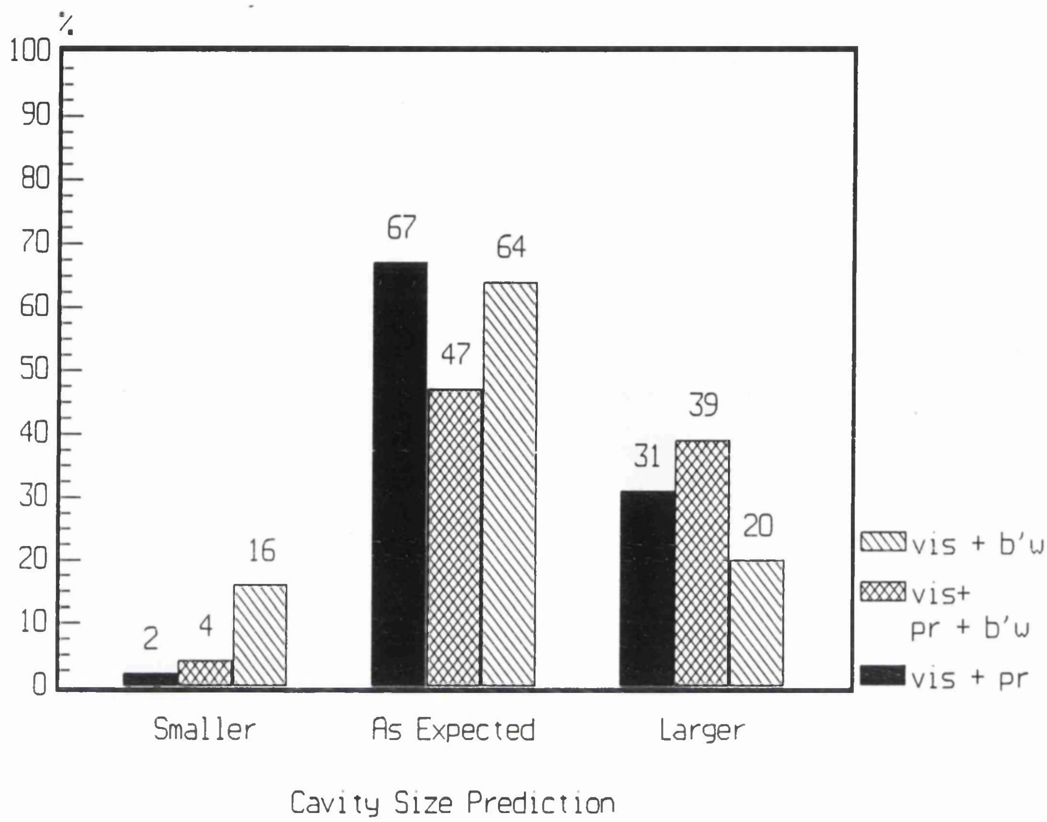


Statistical comparison.

Differences among diagnostic methods

$Chi^2 = 6.59$ $DF = 4$ $P > 0.05$

Figure 1.5 **Cavity size prediction by all operators for intra-enamel sealant restorations involving the use of composite resin and fissure sealant (n=160). Diagnosis is shown for operators using probe or visual inspection in combination with radiographs.**

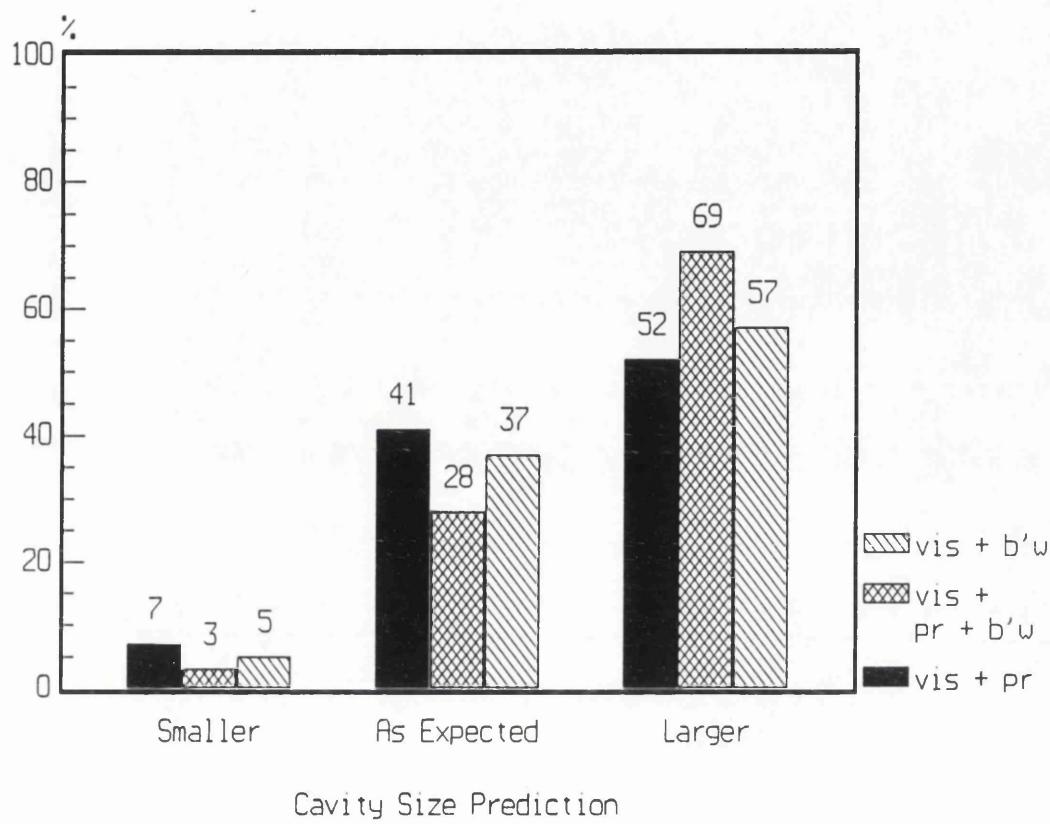


Statistical comparison.

Differences among diagnostic methods

$Chi^2 = 15.49$ DF = 4 $P > 0.05$

Figure 1.6 **Cavity size prediction by all operators for minimal dentine caries restored with sealant restorations involving the use of glass ionomer cement and fissure sealant (n=237).**
Diagnosis is shown for operators using probe or visual inspection in combination with radiographs.

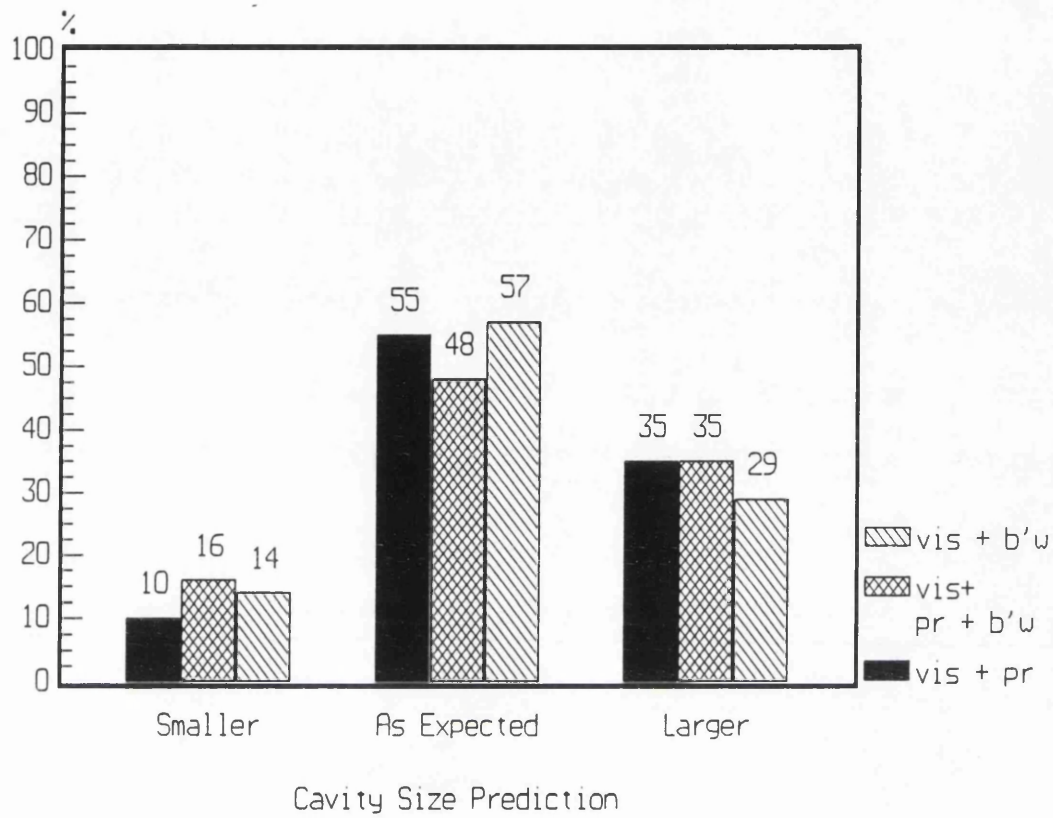


Statistical comparison.

Differences among diagnostic methods

$Chi^2 = 5.02 \quad DF = 4 \qquad P > 0.05$

Figure 1.7 Cavity size prediction by all operators for dentine caries restored with sealant restorations involving the use of glass ionomer cement, composite resin and fissure sealant (n=246). Diagnosis is shown for operators using probe or visual inspection in combination with radiographs.



<u>*Statistical comparison.*</u>

Differences among diagnostic methods

$Chi^2 = 3.84$ DF = 4 $P > 0.05$

Figure 1.8 Cavity size prediction by all operators for all carious cavities restored with sealant restorations involving the use of combinations of glass ionomer cement, composite resin and fissure sealant (n=643).

Sensitivity and specificity values were tabulated by cavity type and by diagnostic method of caries detection. Sensitivity values were generally higher in the group of operators who did not use the probe. With increasing cavity size, the specificity improved but the low value for all diagnostic methods reflects the generally poor accuracy with which the size of cavities was estimated (see Tables 1.5.1 and 1.5.2).

A comparison of the validity scores for the same group of participating operators is shown in Figure 1.9, where sensitivity and specificity values are shown for the *in vitro* estimation of cavity size (and treatment) and the current *in vivo* study. Lower values were observed in the *in vivo* estimation of cavity size.

In Table 1.6 the distribution of "larger than expected" lesions among the four quadrants is shown for the first and second molar teeth. There are significant differences in the number of accurately predicted large cavities in each quadrant. Accuracy of prediction of larger cavity size was significantly lower for the first molar in the lower right quadrant ($P < 0.01$). If accuracy of cavity size prediction is considered for second molar teeth, there is significantly less accuracy in size prediction in both mandibular second molars when compared to their maxillary counterparts ($P < 0.01$).

	Smaller			As Expected			Larger		
Type	V+P	V+P+B	V+B	V+P	V+P+B	V+B	V+P	V+P+B	V+B
2	12 (23%)	14 (26%)	10 (22%	30 (58%)	33 (61%)	31 (75%	10 (19%)	7 (13%)	1 (3%)
3	1 (1%)	11 (4%)	16 (16%	36 (67%)	37 (47%)	58 (64%	17 (31%)	30 (39%)	17 (20%
4	4 (7%)	1 (3%)	14 (5%)	24 (41%)	8 (28%)	35 (37%	31 (52%)	20 (69%)	61 (57%
All S.R.	17 (10%)	26 (16%)	40 (14%)	90 (55%)	78 (48%)	124 (57%)	58 (35%)	57 (35%)	79 (29%)

Statistical Comparisons.

Differences among the diagnostic methods used in:

Type 2 $Chi^2 = 6.59$ DF = 4 $P > 0.05$

*Type 3 $Chi^2 = 15.49$ DF = 4 $P < 0.01$ ***

Type 4 $Chi^2 = 5.02$ DF = 4 $P > 0.05$

All S.R. $Chi^2 = 3.84$ DF = 4 $P > 0.05$

At 5% level of significance differences existed between all combinations of diagnostic methods used in Type 3.

*V+P+B v V+B $Chi^2 = 8.21$ DF = 2 $P < 0.05$ **

non P v P users $Chi^2 = 9.12$ DF = 2 $P < 0.05$ *

V+P v V+P+B $Chi^2 = 7.84$ DF = 2 $P < 0.05$ *

Table 1.5.1 The distribution of cavity size expectation by diagnostic methods and cavity types.

	Sensitivity			Specificity		
Type	V+P	V+P+B	V+B	V+P	V+P+B	V+B
2	31.9%	35.1%	33.0%	59.2%	61.1%	79.6%
3	27.5%	28.2%	44.3%	80.4%	55.4%	64.1%
4	35.8%	11.9%	52.2%	73.3%	84.0%	42.7%
All S.R.	30.8%	26.9%	42.6%	72.9%	70%	57.0%

Table 1.5.2 The sensitivity and specificity of the diagnostic methods used by cavity types.

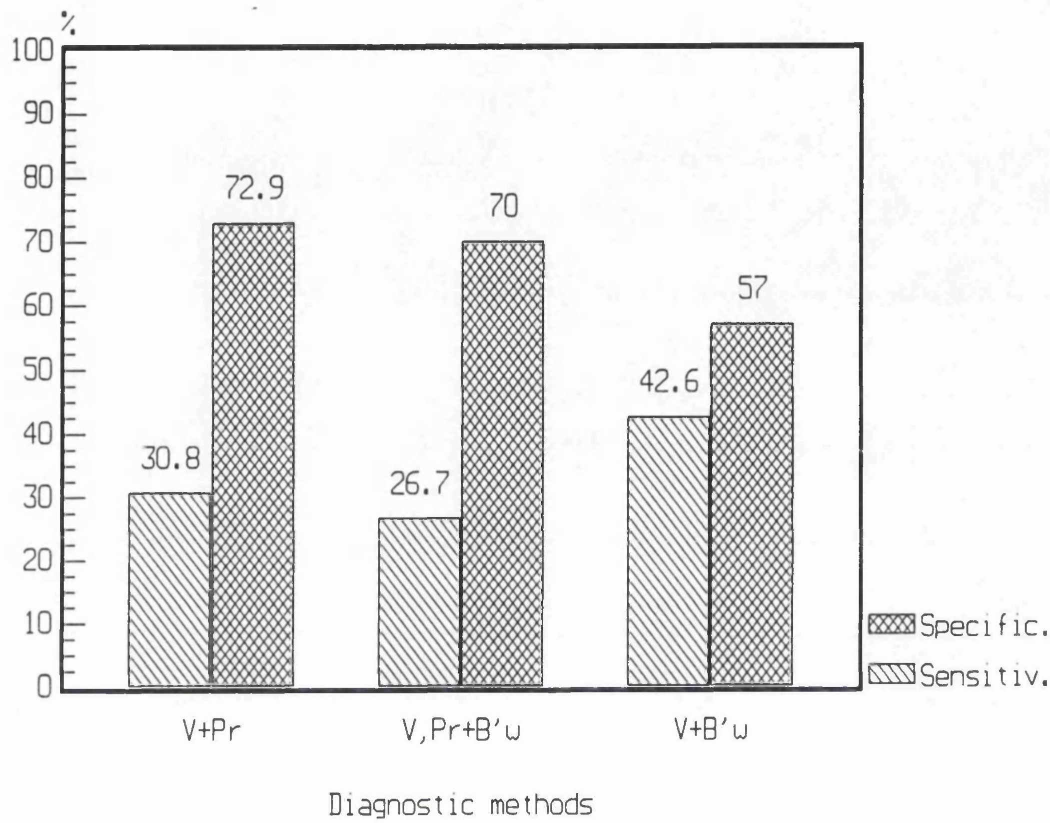


Figure 1.9 **Sensitivity and specificity values from *in vivo* estimation of cavity sizes.**

		First Molar Teeth Right	First Molar Teeth Left	Second Molar Teeth Right	Second Molar Teeth Left
Type 2 cavity. *Caries limited to enamel.*	Upper	3/21 (14%)	3/31 (10%)	2/5 (40%)	0/6 (0%)
	Lower	2/24 (17%)	1/24 (4.2%)	0/7 (0%)	3/10 (30%)
Type 3 cavity. *Caries just into dentine.*	Upper	14/48 (29%)	6/32 (19%)	2/12 (17%)	5/10 (50%)
	Lower	17/40 (43%)	7/28 (25%)	4/13 (31%)	6/16 (37%)
Type 4 cavity. *Extensive caries in dentine.*	Upper	20/32 (62%)	17/32 (53%)	3/14 (21%)	4/10 (40%)
	Lower	22/29 (76%)	18/41 (44%)	6/8 (75%)	14/21(67%)

Statistical Comparisons.

In type 4 cavities there were more larger than expected lesions in lower right first permanent molar than in the other permanent molar teeth.

$Chi^2=15.8$ $DF = 1$ $P < 0.01$ **

In type 4 cavities there were more larger than expected lesions in both mandibular second molars compared to maxillary second molar teeth.

$Chi^2=8.32$ $DF = 1$ $P < 0.01$ **

Other comparisons not significant.

Table 1.6 Frequency with which different cavity types were larger than expected when investigated using the enamel biopsy technique.

1.4.4 DISCUSSION

The operators and the collection of data.

The data in this study were obtained from operators working in the conditions of busy practices where the majority of routine treatment of fissure caries is carried out. It is encouraging to note that among the selected groups the use of fissure sealants alone to treat stained and decalcified fissures was a widely adopted practice.

All of the reported data was gathered on a self assessment basis i.e. participants were asked to record the extent of the lesions and how this compared with their preoperative prediction. It might have been expected that the participants would seek to present their diagnostic predictive skills in the best possible light, but the presented data do not support this view. The participants were volunteers and therefore the results must be viewed with caution because of the possibility of selection bias. However, the study reports data collected from practitioners working in normal dental practice rather than in the more strictly controlled conditions which are possible in an epidemiological study. The efficacy of the examination methods was evaluated by the participants' assessment of whether or not the caries was in dentine and whether the resultant cavity was larger or smaller than expected after the preparation of an investigative cavity.

Measurements of validity.

Two methods of validity can be used, sensitivity and specificity. In the context of the current study sensitivity is the extent to which the diagnostic method employed will reliably predict cavity size. Sensitivity and specificity values in excess of 85% are required for any test to be clinically acceptable (Kidd *et al* 1994). Operators not using the probe had a higher accuracy of cavity size estimation (specificity). It was interesting that in larger cavities to be restored with laminate restorations, the incorporation of a radiograph reduced the specificity in those operators using the probe. The data in Figure 1.8 indicate that use of radiographs underestimated the cavity size. This problem is well recognised.

Prediction in small cavities.

In the o44 Type 2 - 4 restorations in which an investigative cavity was prepared, it size was accurately predicted in 48 - 57% of cases (see Figure 1.8). Greater accuracy was achieved with the smaller cavities where 58 - 75% of the cavities were as expected. These cavities which were limited to enamel, comprised 24.8% of the cases where an investigative cavity was prepared. The commonest error in this group was to overestimate the cavity size (i.e. the cavity was smaller than expected). There is now good evidence that the application of fissure sealants to enamel lesions will result in the caries being arrested (Handelman *et al* 1976; Metz-Fairhurst *et al* 1986). It is therefore arguable that the decision to adopt an invasive technique in these cases represented an error in their management. However, discussion with the CDO's and GDP's revealed considerable fears about the failure of fissure sealants placed over active lesions in the conditions of general practice. The majority indicated a strong preference for the removal of decalcified and stained enamel from the fissure walls before the application of adhesive materials and/or fissure sealant.

Prediction in large cavity types.

The accuracy of cavity size prediction was much lower for the largest lesions with 52 - 69% of the cavities being larger than expected. This appears to support the view expressed by Sawle and Andlaw (1988) that fissure caries is becoming harder to diagnose.

Diagnostic methods and their accuracy.

It is perhaps surprising that a number of the CDO's were not using bitewing radiographs routinely to screen for caries. This reflected the fact that not all of the examinations are carried out in surgeries with radiographic facilities. Creanor *et al* (1990) examined bitewing radiographs in 2623 subjects aged between 14-15 years who were participating in anti caries dentifrice trial in the West of Scotland. They reported that in 12.1% of lower molars and 3.1% of upper molars which were judged to be clinically sound, there was radiographic evidence of caries in dentine. They considered that their data provided further support for the view that increased fluoride usage had resulted in the maintained integrity of the enamel over a spreading dentinal lesion.

The suggested regime for the use of bitewing radiographs, proposed by Pitts and Kidd (1992), would be advocated and it is suggested that this regime should be adopted to screen for clinically undetected occlusal dentine lesions in high risk teenage patients. Since it is clearly impossible not to look at the tooth being examined before applying the probe three examination regimes were therefore used by the participants:

1) Visual plus probe
2) Visual plus radiographs
3) Visual plus probe plus radiographs

No operator used visual examination alone to detect caries.

Differences among the diagnostic methods.

When the different diagnostic techniques were compared (see Figures 1.5 - 1.11; the data demonstrate that with a sample size of 644 cavities no significant differences were found in the accuracy of the prediction of cavity size whether the probe or visual inspection in combination with bitewing radiographs was used i.e. the use of the probe did not improve the accuracy of prediction of cavity size (sensitivity). If there is no diagnostic advantage and the danger of surface enamel damage as demonstrated by Ekstrand *et al* (1987) is considered then the use of the probe to detect fissure caries in practice should be discontinued.

Accuracy of cavity size prediction by tooth.

There is increased difficulty in accurate prediction of cavity size in the lower right first molar (see Table 1.6) compared with the other first molars. Rock *et al* (1990) noted differences in fissure sealant retention between the left and right hand side of the mouth and suggested that these could be related to right and left handed operators holding the curing light at slightly different angles on the different sides of the mouth. It is possible that differences in operator position between the left and right sides of the mouth could alter, for example, mirror angulation which could account for differences in accuracy in prediction of cavity size. The problem demonstrated with second molars compared to their maxillary counterparts probably reflects the more complex pattern commonly observed in mandibular second molars.

Problems with the diagnosis of fissure caries.

There is an urgent need for refinement in the diagnostic techniques for fissure caries. Elderton (1985b) has observed that a "wait and watch " approach in fissure lesions and if an active fissure lesion is suspected it must be investigated. The data in the current paper demonstrates how unsatisfactory current diagnostic methods are. In the light of these observations, diagnosis in clinical practice at present should comprise a combination of the assessment of overall caries risk, inspection of the clean and dried fissure under good lighting and finally examination of a bitewing radiograph. The investigative approach to intervention, where cavity preparation is limited to excision of caries should be adopted whenever there is doubt over the presence of caries in dentine.

Comparison of *in vitro* study with current *in vivo* study.

Although the use of an *in vitro* caries scoring system may have value as a teaching aid for undergraduate students and could be used for continuing education for dental practitioners, the results of the *in vitro* studies must be viewed with some caution. In section 1.3, the same group of dental operators achieved lower sensitivity values than in the current *in vivo* field trial. In the *in vitro* study, the participating operators were asked to estimate the cavity size and then were required to make a treatment decision (if any) for each of the sample molar teeth. In the current *in vivo* study, the same group of operators estimated the lesion size in teeth about to undergo clinical intervention. They then compared the estimated cavity size with the actual size of the caries lesion after an investigative cavity had been prepared.

In the *in vitro* study, the range of sensitivity scores was observed to be between 73.7% and 79.8%, depending upon the diagnostic method used. The comparable validity scores for the current *in vivo* study were 26.7% and 42.6% respectively (see Figure 1.9).

Estimation of the cavity size in the mouths of children is made more difficult by the problems of maintaining isolation and the frequent use of indirect vision, which are necessary at the posterior end of the dental arches, where illumination is also compromised.

1.5 CONCLUSIONS.

In vitro study.

1. No differences were demonstrated in the sensitivity and specificity of diagnoses achieved using visual inspection alone and visual inspection in combination with the probe.

2. No diagnostic differences detected between General Dental Practitioners (paid on an item of service basis) and the Community Dental Officers (paid a salary). Capitation had not been introduced as means of payment for general dental practitioners at the time this study was conducted.

3. The use of radiographs in addition to visual examination made no significant difference to the observed diagnostic accuracy.

4. In the *in vitro* study the presence of caries was under-diagnosed and the operators were not treating sound teeth unnecessarily.

In vivo study.

5. In a large field trial in the West of Scotland approximately 50% of lesions when investigated, were found to be of the size predicted by the operator.

6. The accuracy of prediction of cavity size decreased as cavity size became larger. In 50% of cases where there was found to be an extensive dentine lesion, the cavity was larger than the operator expected.

7. The use of the probe did not improve the accuracy of cavity size prediction in the conditions of clinical practice. In view of the literature reports of damage caused to the surface layer of enamel by the probe, its routine use in practice for the diagnosis of fissure caries should be discontinued.

8. In the *in vivo* study more errors in prediction of cavity size occurred in the lower right than in the other first molars and in both mandibular second molars than in their maxillary counterparts.

9. Operators who did not use the probe as part of their routine diagnostic regime for fissure caries had a higher sensitivity value particularly when dentine lesions were present.

10. In both studies in this chapter of the thesis, the conclusions from the *in vitro* and *in vivo* studies were similar when the same diagnostic methods were used. Although this may have major implications for teaching of undergraduate students and in the continuing education of graduates, the results of *in vitro* studies should be viewed with some caution as measures of validity are significantly greater in laboratory studies compared to that achieved in clinical trials.

Chapter

2

Comparison of the scoring of sealant restoration performance by Community Clinical Dental Officers and calibrated examiners.

2.1 INTODUCTION.

The scoring of restorations.

Sealant restorations are placed in two separate stages. In the first, glass ionomer cement, composite resin or a combination of glass ionomer cement and composite resin are placed to restore the discrete cavity prepared mechanically in a localised area of a pit or fissure surface. In the second, a pit and fissure sealant resin is applied over the surface of the restoration and into all the adjacent fissures. This takes the place of the original concept of "extension for prevention" (G.V.Black in Pickard, 1970).

The performance of sealant restorations may be measured by the degree of sealant retention and performance of the composite or glass ionomer cement filling. These features are used to provide evidence of the condition of the sealant restoration. These features may be classified into a system consisting of levels or grades characterised by the presence or absence of certain clinical signs.

For a clinical method of assessment to be useful in monitoring the performance of sealant restorations, it must be reliable and consistent when used by a number of operators, who may differ widely in their levels of experience. If it is not, difficulties may arise in the interpretation of the results of published work (Lindsay *et al* 1982) and in the data from self assessing field trials. A good level of agreement is necessary to provide a guide to the ultimate clinical performance.

A scoring system was devised by Cvar and Ryge (1971) and accepted by the United States Public Health Service (U.S.P.H.S.) which grades clinical evaluation of dental restorative materials (Criteria for the clinical evaluation of dental restorative materials, National Institutes of Health). The clinical performance of materials cannot be directly predicted for laboratory tests and, therefore, well-defined measures of clinical performance are required. Meaningful clinical information is available using rating scales. The assessors or observers must be well trained and the results of the training should be checked in some way (Marken 1966).
There has been a limited literature on the criteria used to review the performance of dental restorations but the problems of measuring wear *in vivo* on the surface of restorations has been recognised (Chadwick *et al* 1991) and is discussed in Chapter 4 Many of the techniques are labour intensive and require the use of complex equipment which may still measure wear only in specific areas avoiding others where catastrophic wear may have taken place.

During the collection of data from a field trial, it was important that the running of the dental clinic should not be disrupted by unnecessarily long and complicated data collection. It was for this reason that a simple, quick and accurate scoring method was devised. The U.S.P.H.S. system has been adopted in a modified form in this study. In addition, the extent and presence of the fissure sealant and further treatment requirements were considered according to set of criteria developed specifically for the study.

2.2 MATERIALS AND METHODS.

2.2.1 Practice scoring.

Before the initial six month review of the sealant restorations placed by the thirteen Community Clinical Dental Officers participating in the field trial, a training exercise in scoring or grading the performance of sealant restorations was initiated. Details relating to the setting up of the field study may be found in Chapter 3.

Twenty six extracted human molar teeth were embedded in numbered acrylic blocks. Sealant restorations were placed which involved the enamel biopsy technique. An equal number of sound and faulty restorations were placed. Faults included: missing restorations; wear on the surface of the glass ionomer or composite resin filling; staining around all or some of the restoration periphery; presence of secondary caries and areas of missing fissure sealant.

A practice session was organised for each of the participating dentists. During this session the criteria for each of the scoring grades was individually explained and the operators were asked to examine and score the restorations on cards identical to those used in the field trial.

2.2.2 Inter - and intra - assessor reproducibility.

Using the extracted teeth described in section 2.2.1 into which a selection of faults had been incorporated, the two assessors (G.B.G. and R.C. P.) scored the restorations using the graded monitoring forms for use in the field trial (see Chapter 3). Tooth samples were dried and inspected under good lighting conditions using a standard right angled probe.

In order to obtain some form of reproducibility between the two assessors, reproducibility studies were undertaken on two occasions six months apart. Scores were not available to the other assessor until after the study was completed. Kappa statistics and percent agreement between the two external assessors were calculated at each of the scoring sessions. To measure drift of the assessors over the time period between the assessments, a Kappa statistic was calculated for each as a measurement of continued reproducibility.

2.2.3 Data collection.

The features of the grading system used are shown in Table 2.1. An assessment of the presence or absence of the following features was modified from that originally described by Cvar & Ryge (1971) and shown in Chapters 3 to 5:

* restoration present
* surface wear of restoration
* marginal staining of restoration
* secondary caries adjacent to the restoration margin.

Fissure sealant retention was graded on a three point scale of:

* completely present in all pits and fissures
* partially missing
* entirely missing.

The necessity for modifying or replacing the restoration was also considered.

1. The sealant restoration was considered to require **modification** by the addition of further fissure sealant where:
    * fissure sealant had been partially or completely lost
    * evidence of decalcification in an exposed fissure
    * more than 2 other active caries lesions in the dentition
2. The sealant restoration was considered to require **replacement** where the following were observed:
    * loss of the restoration
    * surface wear had exposed dentine
    * presence of secondary caries
    * where treatment of new primary lesion implicated cavity preparation involving the original sealant restoration.

The patients were assessed independently from the Community Clinical Dental Officers under good operating conditions of light and tooth isolation. All review visits were conducted in Community Dental Clinics where the two assessors and the Community Clinical Dental Officer independently scored the features of the restoration on the same day: no discussion was entered into as to the need for further treatment to the restoration. Monitoring of the performance of the sealant restorations took place after 6, 12 and 24 months. Note was taken of any disagreements between the two assessors. In the event of a disagreement, the patient was examined again and a final score agreed.

2.2.4 Analysis of the results.

The gradings or scores were entered into a computerised data base surveys management system (Survey It, Version 4.0, Conway Information Systems Incorporated). For each participating operator, a cross-tabulated table was analyzed for the percentage agreement on the presence or absence of clinical signs or symptoms.
A Kappa statistic was calculated, by operator, for each of the clinical signs and symptoms. When complete agreement exists between assessors and operator, the Kappa statistic is 1. When the agreement is no better than could have occurred by chance, however, then the Kappa statistic is 0.

An overall Kappa statistic value was calculated for each of the operators as a median value and a quoted range, taken from all individual Kappa statistics for the clinical signs and symptoms investigated. This allows a comparison of operator variability without specific regard to the individual clinical signs and symptoms. Use of a median value for Kappa statistic will be more meaningful than tabulating a mean value and standard deviation, which would be artificially distorted by some high values for individual Kappa.

For each clinical feature of the restoration scoring system, statistical differences among the median Kappa statistics were calculated using Wilcoxon Signed Rank Test for paired data - paired differences are signed and ranked so as to provide a non-parametric version of the paired t-test.

2.3 RESULTS.

All tables and figures have been placed at the end of this chapter to allow continuity of the text. This is also intended to make the reading of the text and figures more straightforward.

2.3.1 Inter - and intra - assessor agreement.

The data in Tables 2-1 and 2-2 show the inter-examiner agreement at the initial scoring session and again after six months. The median Kappa statistic for agreement between the two assessors was "very good" on both occasions (between 0.81 and 1). A slight fall in agreement was observed in respect of wear on the restoration surfaces where fissure sealant was partially or completely missing (0.62 compared to 0.58 after six months), but a corresponding increase in the Kappa statistic was noted for agreement on the retention of fissure sealant (0.89 compared to 1 after six months).
As a measure of drift over the time between scoring sessions, intra-examiner Kappa statistics were calculated and are shown in Tables 2-3 and 2-4. The median Kappa statistic for each examiner shows a "very good" level of agreement with minimal drifting or inconsistency of scoring.

2.3.2 Median Kappa statistics for *in vivo* study.

In Table 2-5 the median Kappa statistic and range of Kappa results are shown for each of the clinical features reviewed. The results for individual operators can be seen in table and graphic forms in Tables 2.7 to 2.15 and Figures 2.2 to 2.10 These features were measured to assess the performance of sealant restorations in the conditions pertaining to the Community Dental Services.

2.3.3 Presence of the restoration.

In Table 2.7 the results of the comparison of operators to assessors regarding the presence of the composite or glass ionomer restoration are shown. Ten Community Clinical Dental Officers (77%) had complete agreement with the scoring of the assessors regarding the presence of the composite or glass ionomer cement restoration. The Kappa statistic for this group of operators was therefore 1.

Two of the remaining Community Dental Officers (16%) had greater than 98% agreement but due to the distribution of agreement within the table of results, this reflected agreement that was no better than could have occurred by chance - the Kappa statistic was therefore 0. The remaining operator had 87.8% agreement and a moderate agreement beyond chance with a Kappa statistic of 0.59.

The overall median percentage agreement was 100% (range 87.8 to 100%) and very good agreement beyond chance occurred with a median Kappa statistic of 1 (range 0 - 1).

2.3.4 Surface wear on the restoration.

The absence of fissure sealant from the surface of the filling material and the loss of restorative material from its surface is documented in Table 2.8 The assessors considered wear to be present on the filling surface in only 3.6% of all the sealant restorations reviewed.

The percentage agreement ranged from 23.8 to 97.6% with a median value of 82.5%. Nine operators (69%) had greater than 70% agreement with the assessors. By comparison the median Kappa statistic was 0.04 reflecting very poor agreement. The Kappa statistic ranged from -0.03 to 0.4: the former value showing agreement slightly worse than that which could have occurred by chance. Four operators (3, 7, 8 and 11) incorrectly over diagnosed the presence of wear.

2.3.5 Marginal discolouration.

In Table 2.9 the agreement for the presence of marginal discolouration between the filling material and the investigated cavity margin is shown.

Agreement between the operators who placed the restorations and that of the assessors reviewing the performance of the restoration with regard to marginal discolouration ranged from 54.9 to 100% complete agreement: the median percentage agreement was 85.8%.

Only fair agreement beyond chance was found as the resulting median Kappa statistic was 0.25. Individual Kappa statistics ranged from -0.05 to 1.

2.3.6 Presence of secondary caries.

The results for the presence of secondary caries at the margin of the filling material are presented in Table 2.10. Secondary caries developed in only 3.1% of the restorations successfully reviewed.

The overall median percent correct agreement was 97.5% with a range of 85.4 to 100%. A moderate agreement between the operators and the assessors was indicated by the overall median Kappa statistic of 0.63.

Two operators (1 and 3) missed the presence of secondary caries in over 75% of occasions where present.

2.3.7 Retention of fissure sealant.

The overall retention of fissure sealant is presented in Table 2.11 but the Kappa statistics for examiner variability in scoring the state of opaque and clear fissure sealant retention is shown in Tables 2.16 and 2.17.

In Table 2-6, a comparison of the medians is given for the correct assessment of fissure sealant retention when opaque and clear sealants are used and for the correct grading or scoring of sealant retention to maxillary and mandibular first molar teeth.

Agreement between assessors and operators was assessed using Wilcoxon Rank Signed Test where significantly greater agreement was found when opaque sealant was employed ($P<0.05$). The correct identification of the extent of pit and fissure sealant retention to maxillary or to mandibular first molar teeth was also significant with improved agreement when scoring or grading maxillary molar teeth ($P>0.05$). No difference in the retention of the sealant to right or to left first permanent molar teeth could be demonstrated using this paired non-parametric test ($P>0.05$).

Individual Kappa statistics summarised in Figure 2-6 can be seen in Tables 2-16 to 2-21.

2.3.8 The need for modification.

Modification was considered necessary by the two assessors if the fissure sealant was either partially retained or missing **and** the exposed fissure was stained and decalcified. It was also considered prudent to replace the sealant if the patient had two or more other active caries lesions in other teeth despite the exposed fissure currently being apparently caries free.

In Table 2.12 there was good percentage agreement with the decision not to modify the sealant restoration. When the assessors considered the restoration to require modification, however, the Community Dental Officers concurred poorly with this decision. The median Kappa statistic (0.2 range -0.13 to 0.57) for correct agreement with the assessors was only fair.

2.3.9 The need for replacing the restoration.

The results on the decisions to replace sealant restorations is given in Table 2-13. Restorations were considered to be in need of replacement if the composite resin filling had been lost or there were visible signs or symptoms of secondary caries. It was also agreed that sealant restorations would require removal if new primary caries occurred on the approximal surfaces.

The assessors considered that only 5.8% of the reviewed restorations should be replaced. There was high agreement on the decisions indicating no need for replacement of the fillings but agreement was low when the assessors considered the restoration in need of removal and replacing with new restoration.

The median Kappa statistic (0.48 range 0 to 1) would indicate a moderate agreement had been achieved.

2.3.10 Immediate sensitivity.

In Table 2.14 the results are shown for the verbal questioning of the patient at review on the presence of sensitivity immediately following the placement of the restoration. On only one occasion was there a discrepancy between the verbal response given to the Community Dental Officer and the assessors. This would indicate excellent agreement and the median Kappa statistic (1 range 0.67 to 1) would indicate very good agreement beyond chance.

2.3.11 Continued sensitivity.

At the review appointments no patient indicated the presence of continued sensitivity following placement of the sealant restorations (Table 2.15). The percentage agreement and the median Kappa statistic would therefore indicate excellent agreement.

2.3.12 Median Kappa statistic for participating operators.

The graphics in Figures 2.1.1 and 2.1.2 indicate median percentage agreement and median Kappa statistic for each participating operator as an indication of the overall agreement with the external assessors. To avoid artificially high Kappa statistics - due to 3 categories with Kappa values of 1 - median values were calculated.

All operators had an overall greater than 82.9% agreement but when this was corrected for the possibility of chance corrected agreement by the use of the Kappa statistic, five operators had agreement consider poor or fair. Four operators had moderate agreement and three were considered to have good agreement. One operator had very good agreement with the assessors.

2.4 DISCUSSION.

2.4.1 Kappa statistic.

There are difficulties in achieving absolute agreement between operators or observers scoring from the same clinical material. A close measure of agreement is required for the comparison of the data: it would be inappropriate to subject the data to the Chi Squared test because this would provide a measure of association and there is not a hypothesis testing problem.

A measure of agreement can be achieved by observing the number of exact agreements that were achieved and expressing it as a percentage figure. There are two principle disadvantages to this method: firstly, it is impossible to deduce from this figure where agreement accorded in a cross-tabulated table and secondly, no correction is allowed for agreement that can be achieved by chance i.e. guessing.

A more reasonable method would be to measure the agreement that occurs over that which could have happened by chance. The expected frequency of a cell in a frequency table may be calculated by taking the product of the column total and the row total and dividing it by the grand total. The expected number of agreements can be expressed as a proportion of the total. A measurement of the agreement can therefore be expressed as a numerical figure in excess of the expected value. Maximum agreement is 1 therefore the agreement achieved may be presented as a proportion of the possible scope for achieving a score better than by chance (1 - expected probability).

The agreement over that which can be achieved by chance is known as **Kappa** (K). When agreement is perfect the score is 1 and when it is no better than that achieved by chance the score is 0. Negative values can be achieved and indicate an agreement that is worse than that achieved by chance i.e. that guesswork is involved.

The mathematical formula for calculating Kappa (K) is given as:

$$K = \frac{P_o - P_e}{1 - P_e}$$

where P_o is the observed probability and P_e is the expected probability.

The strength of the agreement between operators is given in the following table modified from that by Landis and Koch (1977).

Value of Kappa	Strength of Agreement
< 0.2	Poor
0.21 - 0.40	Fair
0.41 - 0.60	Moderate
0.61 - 0.80	Good
0.81 - 1.00	Very good

It is important to inspect a table of frequencies to note the distribution of agreement because different distributions will frequently reveal a similar value for Kappa.

There are further difficulties associated with the use and interpretation of Kappa statistic. The value of Kappa is dependant on the prevalence or proportion of subjects in each category. Where the proportional agreement is identical but there are dissimilar subjects in each category, the value of Kappa will be different. This arises due to the different expected probabilities for the two samples. In addition, where the number of categories are limited, the value for the Kappa statistic is likely to be better.

The Kappa statistic is the *chance corrected proportional agreement* but for inter-rater agreement, statistics cannot provide a simple substitute for clinical judgement.

2.4.2 Inter - and Intra - examiner agreement.

Problems in reproducibility and validity of diagnosis have been noted (Mitropoulos & Downer 1987). The presence of well established carious lesions that are obvious to the naked eye can be diagnosed with excellent agreement, but if a group of operators are asked to diagnose small or early caries lesions, agreement is poor. They will frequently disagree with each other and even disagree with themselves if asked to re-examine previously scored surfaces (Merrett & Elderton 1984).

The collection of data from a field or clinical trial should be robust and consistent for the data to be meaningful. It is important, therefore, that inter-examiner agreement should be as close as possible. This can only be achieved if the examiners are calibrated to recognise and score consistently even in the case of borderline decisions.

The results obtained in Tables 2-1 and 2-2 show the inter-examiner agreement after the initial and second scoring sessions. The initial results were obtained before scoring of the restorations placed in the field or clinical trial commenced but the results of the second scoring session were obtained after many of the *in vivo* restorations had been assessed. It was heartening to note that agreement was still high and in some instances had improved with time.

The possibility of examiner drift with time is also a real possibility but the intra-examiner agreement shown in Tables 2-3 and 2-4 show this did not take place. If one examiner's decisions were shown to change or drift with time, this would be reflected in a reduction in inter-examiner agreement. Conversely, if both examiners showed drift in decisions taken, then the inter-examiner agreement may not necessarily reduce.

Rock and Evans (1983) showed significant differences between operators when the results of fissure sealant retention were examined carefully in a clinical trial of a light and self cured fissure sealant. Mitropoulos and Downer (1987) reported that following a two day course where caries diagnostic techniques were standardised, Officers of the Reference Service could achieve excellent agreement with the course tutor. In the context of the current study, excellent agreement was not only achieved but also maintained over the period of the trial by the two calibrated assessors.

2.4.3 Differences between assessors and Community Dental Services Staff.

Field and clinical trials are both expensive and labour intensive to execute. If it were possible to train a group of operators to place and score the performance of restorations using strict guidelines, the costs in monetary terms and the length of time for processing of data and publication of the results would be favourably reduced. In the current work, a uniform technique of placement for the sealant restorations was not advocated in order to observe how differences in the materials and techniques of placement would affect the restorations. It was decided, however, to observe the scoring of the Community Clinical Dental Officers and how this compared with the assessors. An initial practice session explained individually how the assessment of restorations was carried out and allowed each of the operators to score the performance of sealant restorations in extracted teeth. The results were compared with the external assessors at this time and areas of inconsistency were explained. Thereafter, assessment results from both the assessors and the Community Dental Staff were recorded independently when patients attended for review.

The data in Table 2-5 shows that excellent agreement can be achieved for some of the variables examined at each of the recall visits. In particular, the response to verbal questioning of the patient on the presence of initial or continued sensitivity was excellent. This would be expected, as this did not involve the making of any clinical decision by either party. The only variable would be in the translation of this response onto the monitoring form. The median Kappa statistic for the presence of the glass ionomer or composite filling also show an excellent agreement between assessors and operators. This was slightly more surprising as these restorative materials are tooth coloured and do not, therefore, contrast with the surrounding tooth structure as would silver amalgam restorations. The absence of a restoration, however, would leave a cavity in the tooth surface which dentists would detect both by visual and tactile methods.

The remaining Kappa statistics show agreement between the assessors and the operators was fair to moderate. Inter-observer variation of the signs and symptoms in a scoring system of a disease process has previously been reported and the agreement found to be similar to those achieved in the present investigation (Theodossi *et al* 1981 and Lindsay *et al* 1982). Lindsay *et al* (1982) reported no significant improvement when the observers were given written summaries of the scoring system. It would appear that observer variability is an inescapable component of clinical practice.

Good agreement was achieved on the presence or absence of secondary caries in the teeth treated with sealant restorations but the agreement was poor on the presence of wear on the surface of the restorative material. When Chadwick *et al* (1991) monitored the wear on the surface of restorations placed in denture teeth of partial prostheses, they reported that clinical detection using criteria USPHS was poor and the cavo-surface margin had to be exposed by up to 150 micrometers for wear to be detected and reflect in the scale of ranking. The use of replica techniques in the measurement of surface wear of restorations has been advocated and measurement of loss of volume (Urquiola & Charbenau 1981, Williams *et al* 1983, Eick *et al* 1984 and Lamb *et al* 1987) or depth of surface loss (Lambrechts *et al* 1985, Braem *et al* 1986) has been recommended. It would appear that *in vivo* measurement of surface wear is both unreliable and difficult and, therefore, it comes as no surprise that poor agreement was achieved among the operators.

Agreement for the correct identification of the extent and presence of fissure sealant is shown in Table 2-6. Although the rate of caries reduction has been shown as being 100% when the fissure sealant material is completely retained (Metz-Fairhurst 1984), caries prevention is not entirely dependent on complete retention, as reductions of 83% have been reported when sealant is partially retained (Elderton 1985).

The effectiveness of sealants can be enhanced, however, by the re-application of missing or deficient sealant. This relies on the correct identification of the extent of fissure sealant retention. The BDA/DHSS working party (1986) recommended the use of opaque or coloured fissure sealants to enhance the ability of dentists to correctly identify the extent of sealant presence. Rock *et al* (1989) investigated the visibility of clear and opaque fissure sealants among three operators and reported an identification error rate of 1.4% for opaque sealant but 22.8% for clear resins: the most common error was to identify the presence of clear sealant on untreated teeth. The results of the current study would confirm the above findings, as agreement between the assessors and the operators was significantly better when opaque sealants were used.

As no differences in agreement could be shown for examination of teeth from the right or left sides of the dentition, it is more difficult to then explain the improved agreement achieved by the operators when they scored the sealant retention in maxillary molar teeth. Isolation of mandibular teeth is more difficult to maintain due to pooling of saliva in the floor of the mouth but it was the finding of the external assessors that operators did not actively examine the buccal surfaces of these teeth but included the palatal fissure of maxillary molars in their assessment. The original practice scoring session emphasised that buccal fissures should be examined and during the inaugural lecture on sealant restoration techniques, sealing of buccal fissures was advocated.

2.4.4 Calculation of an overall Kappa statistic for operators.

The preparation of a median Kappa statistic for each operator shows the overall agreement of that operator with the external assessors. The inter-examiner agreement was measured for the two assessors on two occasions and found to be between 0.89 and 1.0.

The graph in Figure 2.1.2 shows that four of the thirteen participating operators achieved levels of agreement considered to be good or very good while the decisions of two of the dentists were in poor agreement. The remaining operators achieved levels of agreement considered to be only fair or moderate.

These results are significant in themselves as the collection of robust data on a self assessment basis would not have been possible. For the present time, the results indicate that the calibration of a limited number of examiners is still required. Further investigation of the effect of a calibration exercise at the start of each scoring or examination session may improve the level of agreement.

2.5 CONCLUSIONS.

1. Calibration of the two examiners produced very good levels of agreement.

2. No drift in the level of agreement between the examiners was observed over the two checks periods.

3. The decisions made by each examiner (inter-examiner agreement) during the calibration measurements remained consistent with time.

4. Agreement between the examiners and the Community Dental Officers was very high for responses to verbal questions and to the presence of absence of fillings in the teeth.

5. Fair to moderate agreement was achieved for scoring of features modified from USPHS system used to assess the quality of restorations.

6. Agreement on the presence or absence of wear on the surface of composite or glass ionomer cement restorations was no better than that which could have happened by chance.

7. Significantly better agreement was reached between examiners and CDO's when scoring the degree of retention of opaque fissure sealants and also while scoring sealant retention on maxillary first molar teeth compared to the corresponding mandibular tooth.

8. Five operators (38.5%) achieved good or very good overall agreement with the examiners, while the agreement with 53.8% of the participating operators was only fair to moderate. Only 1 operator had poor agreement.

9. The collection of data relating to the performance of sealant restorations using self assessment monitoring cards cannot be recommended as a technique for the compilation of robust data due to diversity of opinion of the condition of the restorations.

	% Agreement	Kappa statistic
Presence of restoration	100	1
Wear on restoration	91.3	0.62
Marginal discolouration	91.3	0.77
Secondary caries	96.2	0.89
Fissure Sealant retention	96.2	0.89
Modification required	100	1
Replacement required	100	1
Median values:	96.2	0.89

Table 2.1 Inter-examiner agreement after initial scoring session.

	% Agreement	Kappa statistic
Presence of restoration	100	1
Wear on restoration	85.8	0.58
Marginal discolouration	95.6	0.88
Secondary caries	96.1	0.88
Fissure Sealant retention	100	1
Modification required	100	1
Replacement required	100	1
Median values:	100	1

Table 2.2 Inter-examiner agreement after second scoring session.

	% Agreement	Kappa statistic
Presence of restoration	100	1
Wear on restoration	95.6	0.77
Marginal discolouration	91.3	0.77
Secondary caries	100	1
Fissure Sealant retention	100	1
Modification required	92.3	0.85
Replacement required	92.3	0.81
Median values:	95.6	0.85

Table 2.3 Intra-examiner agreement for first assessor (RCP) on decisions made between first and second scoring session.

	% Agreement	Kappa statistic
Presence of restoration	100	1
Wear on restoration	95.6	0.86
Marginal discolouration	95.6	0.88
Secondary caries	100	1
Fissure Sealant retention	96.1	0.89
Modification required	92.3	0.85
Replacement required	92.3	0.81
Median values:	95.6	0.88

Table 2.4 Intra-examiner agreement for second assessor (GBG) on decisions made between first and second scoring session.

	Median Kappa statistic (range)
Presence of restoration	1.0 (0 to 1)
Wear on restoration	0.04 (-0.03 to 0.27)
Marginal discolouration	0.25 (-0.05 to 1)
Secondary caries	0.63 (-0.02 to 1)
Fissure Sealant retention	0.36 (0.01 to 0.66)
Modification required	0.2 (-0.13 to 0.57)
Replacement required	0.48 (0 to 1)
Immediate sensitivity	1.0 (0.67 to 1)
Continued sensitivity	1.0 (1 to 1)

Table 2.5 Median Kappa statistic for each of the clinical variables examined.

	Median Kappa statistic (range)
Fissure sealant retention overall	0.36 (0.01 to 0.66)
Retention of opaque fissure sealant	0.63 (0.2 to 1)
Retention of clear fissure sealant	0.28 (0.15 to 0.57)
Sealant retention to maxillary first permanent molar teeth	0.48 (0 to 0.74)
Sealant retention to mandibular first permanent molar teeth	0.26 (0 to 0.57)
Sealant retention to right first permanent molar teeth	0.39 (0 to 1)
Sealant retention to left first permanent molar teeth	0.4 (0 to 0.75)

Values connected by vertical bar are **not** significantly different ($P > 0.05$).

<u>Statistical evaluation.</u> Wilcoxon Signed Rank Test
opaque v clear sealant $U=21$ $n=6$ $P<0.05$
maxillary v mandibular $U=76$ $n=13$ $P<0.05$
right v left $U=44$ $n=13$ $P>0.05$

Table 2.6 Median Kappa statistic for fissure sealant retention by type and tooth.

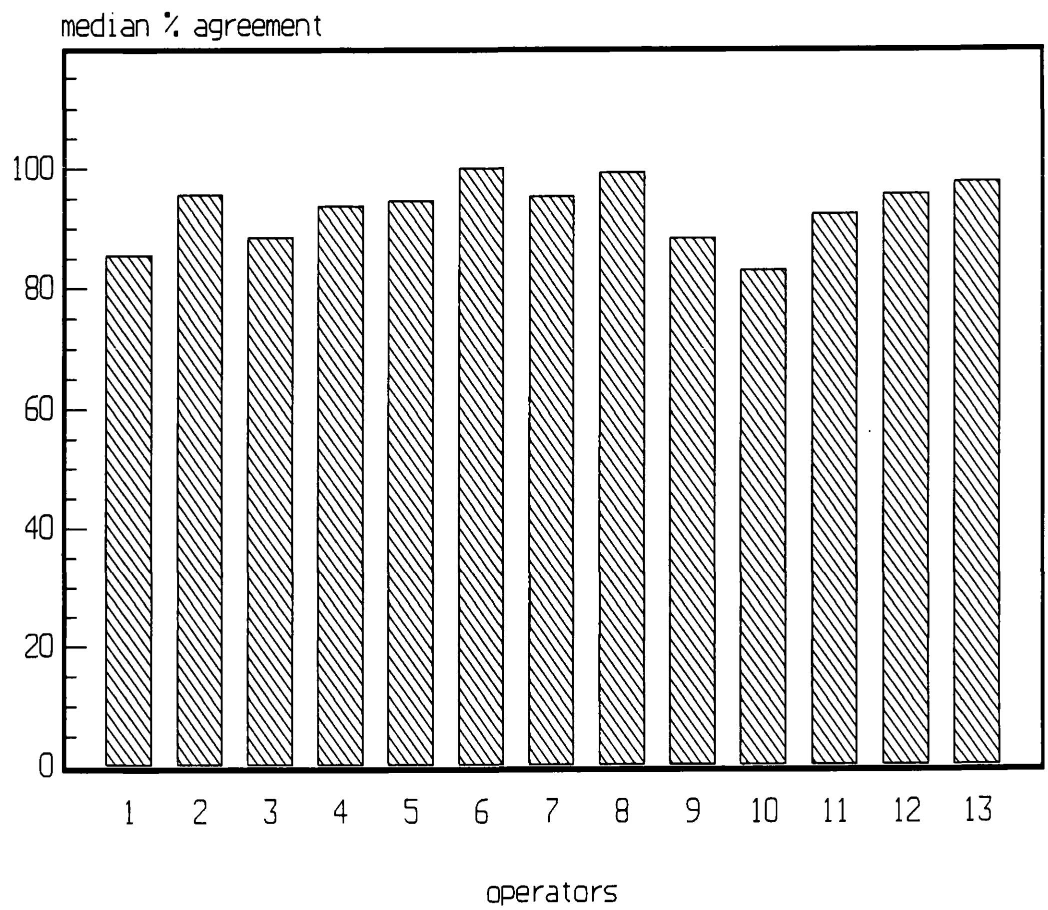


Figure 2.1.1 **The median percentage agreement between examiners and operators.**

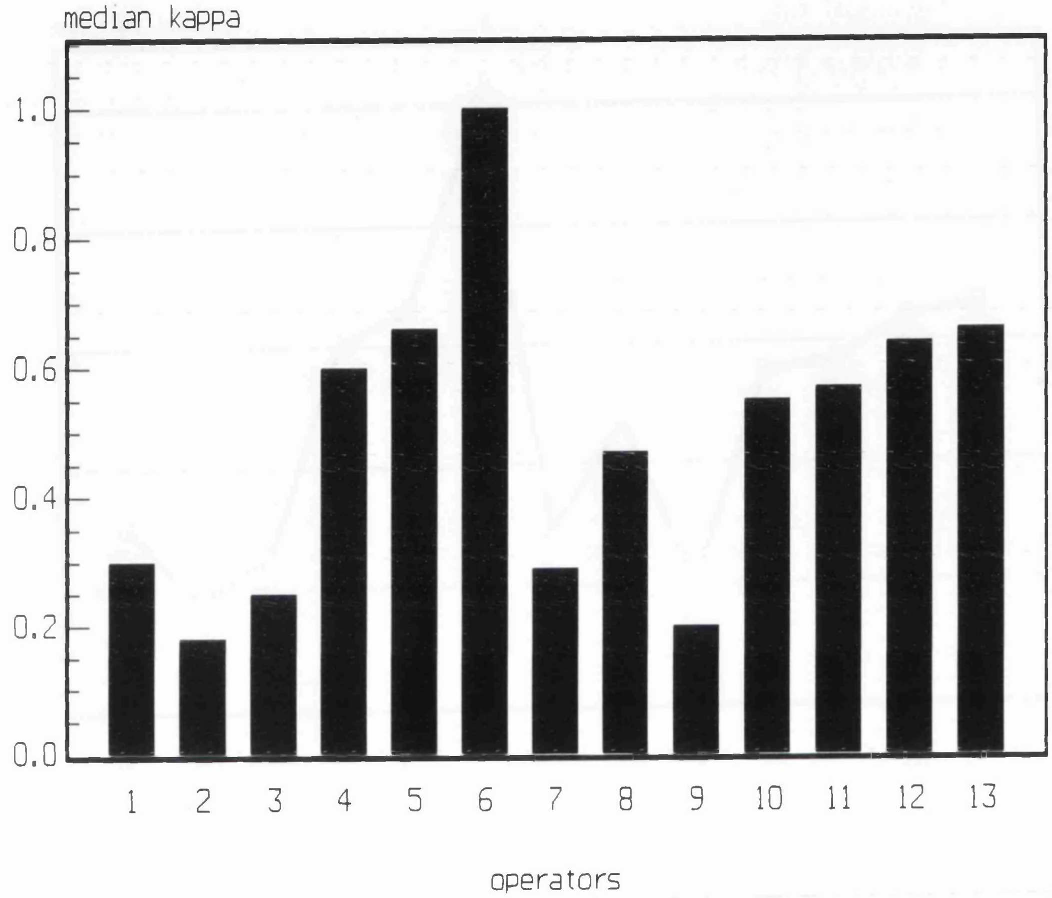


Figure 2.1.2 **The median Kappa statistic for agreement between examiners and operators.**

Operator	% Agreement Restn. pres	% Agreement Restn. abs	% Agreement overall	Kappa Statistic
1	122/122 100%	0/0 *	122/122 100%	1 *
2	68/68 100%	0/0 *	68/68 100%	1 *
3	61/61 100%	0/0 *	61/61 100%	1 *
4	40/40 100%	0/0 *	40/40 100%	1 *
5	92/92 100%	0/0 *	92/92 100%	1 *
6	7/7 100%	0/0 *	7/7 100%	1 *
7	126/126 100%	0/0 *	126/126 100%	1 *
8	143/144 99.3%	0/1 0%	143/144 99.3%	0
9	50/51 98.04%	0/0 *	50/51 98.04%	0
10	31/33 93.94%	5/8 62.5%	36/41 87.8%	0.59
11	13/13 100%	0/0 *	13/13 100%	1 *
12	46/46 100%	0/0 *	46/46 100%	1 *
13	123/123 100%	1/1 100%	123/123 100%	1 *

Medians:	100%	1
range	(87.5 - 100)	(0 to 1)

* contains table cell with no entries.
100% agreement or a Kappa statistic of 1 occurred.

Table 2.7 Presence of Restoration.

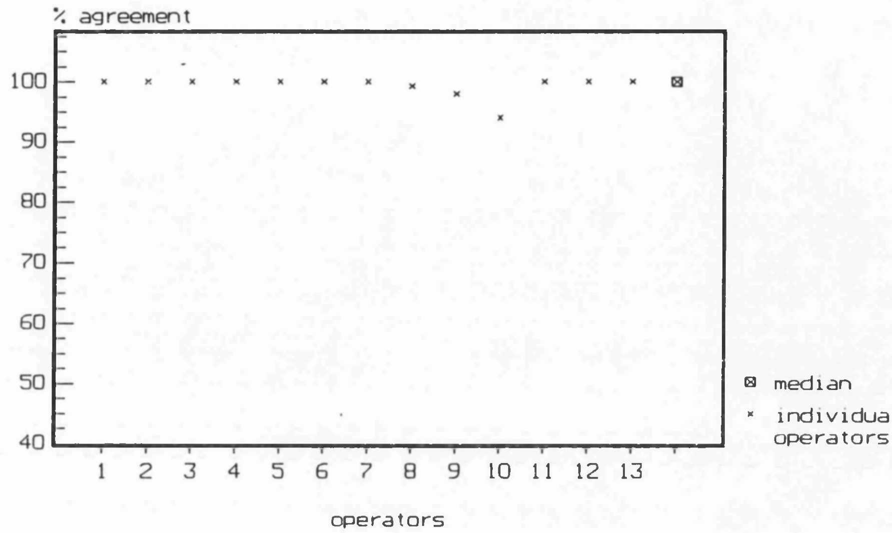


Figure 2.2.1 **Presence of restoration.**

Percentage agreement between examiners and operators.

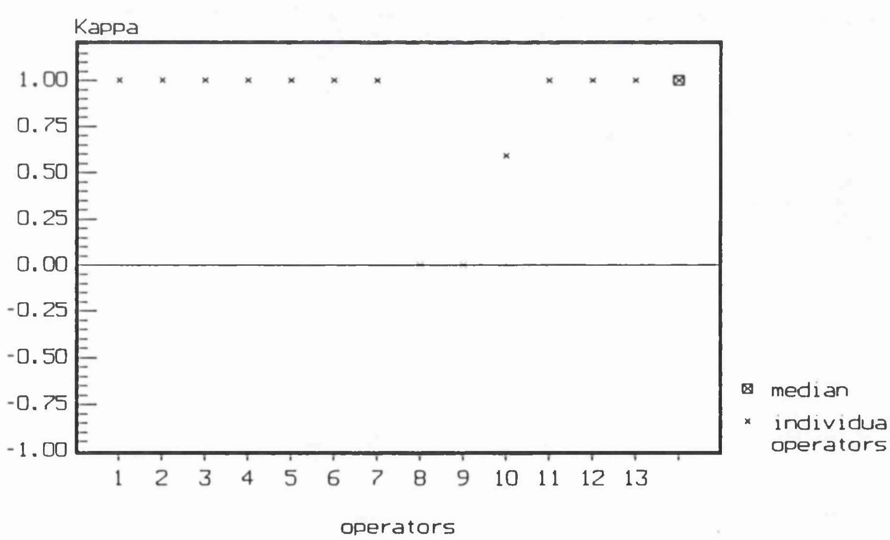


Figure 2.2.2 **Presence of restoration.**

Kappa statistic for the agreement between examiners and operators.

Operator	% Agreement Wear present	% Agreement Wear absent	% Agreement overall	Kappa Statistic
1	1/5 20%	107/117 91.4%	108/122 88.5%	0.07
2	0/0 *	53/68 77.9%	53/68 77.9%	0
3	6/8 75%	19/53 35.8%	25/61 40.1%	0.04
4	2/4 50%	31/36 86.1%	33/40 82.5%	0.27
5	0/0 *	87/92 94.6%	87/92 94.6%	0
6	0/0 *	6/7 85.7%	6/7 85.7%	0
7	5/6 83.3%	25/120 20.83%	30/126 23.8%	0.005
8	10/12 83.3%	72/132 54.5%	82/144 56.9%	0.117
9	0/1 0%	41/51 82%	41/51 80.4%	-0.03
10	1/3 33.3%	33/38 86.8%	34/41 82.9%	0.14
11	0/0 *	8/13 61.5%	8/13 61.5%	0
12	1/1 100%	37/45 82.2%	38/46 82.6%	0.17
13	1/2 50%	120/122 98.4%	121/124 97.6%	0.4

Medians:	82.5%	0.04
range	(23.8 - 97.6)	(-0.03 to 0.4)

* contains table cell with no entries.

100% agreement or a Kappa statistic of 1 occurred.

Table 2.8 Restoration Wear.

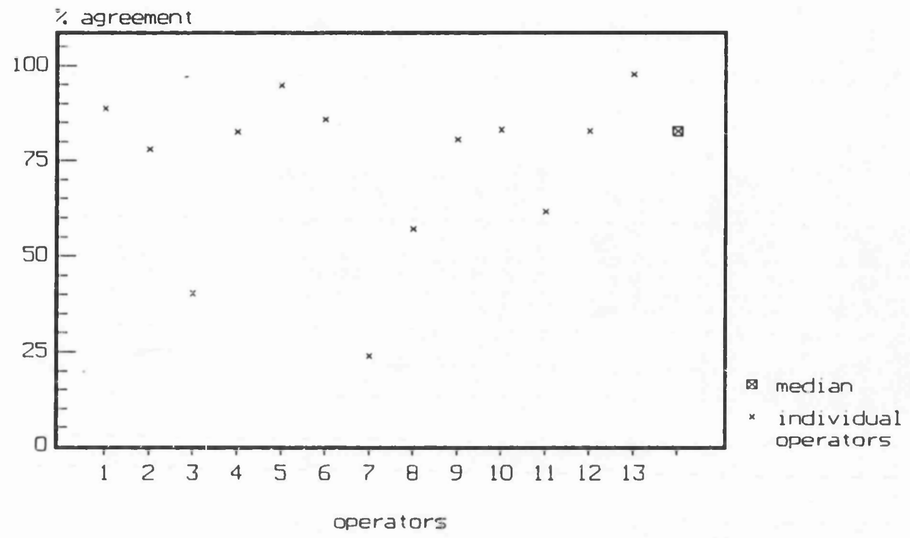


Figure 2.3.1 **Restoration wear.**

Percentage agreement between examiners and operators.

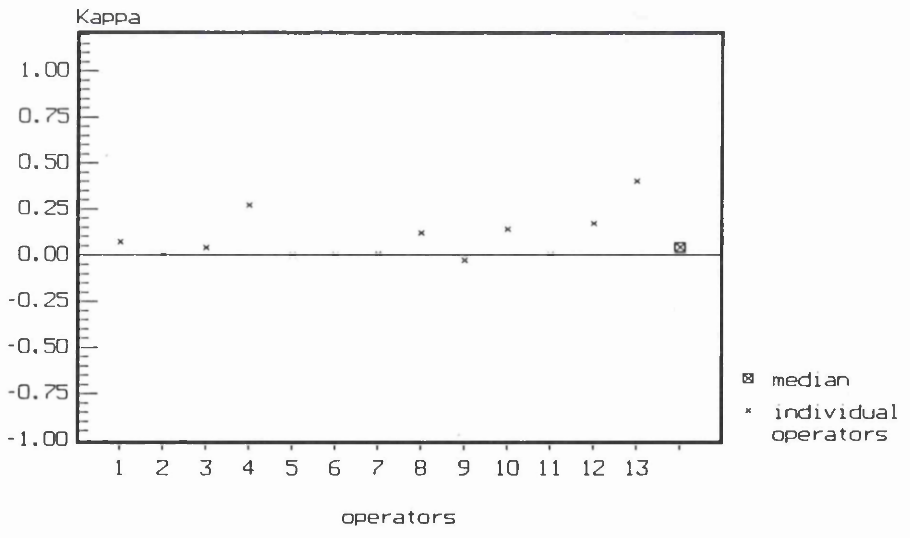


Figure 2.3.2 **Restoration wear.**

Kappa statistic for the agreement between examiners and operators.

Operator	% Agreement pres.disc. margin	% Agreement abs.disc. margin	% Agreement overall	Kappa Statistic
1	2/10 20%	106/112 94.6%	108/112 88.5%	0.16
2	1/7 14.3%	60/61 98.4%	61/68 89.7%	0.18
3	4/6 66.6%	44/51 86.3%	48/61 78.7%	0.25
4	2/5 40%	32/35 91.4%	34/40 85%	0.31
5	2/10 20%	77/82 93.9%	79/92 85.8%	0.15
6	0/0 *	7/7 100%	7/7 100%	1 *
7	2/12 16.6%	101/114 91.2%	106/126 84.1%	0.08
8	2/7 28.6%	125/137 91.2%	127/144 88.2%	0.13
9	3/9 33.3%	25/42 59.5%	28/51 54.9%	-0.05
10	9/12 75%	22/29 75.8%	31/41 75.6%	0.46
11	0/0 *	9/13 69.2%	9/13 69.2%	0
12	6/9 66.7%	36/37 97.3%	42/46 91.3%	0.7
13	5/9 55.5%	112/115 96.5%	117/124 94.3%	0.55

medians:	85.8%	0.25
range:	(54.9 - 100)	(-0.05 to 1)

* contains table cell with no entries.
100% agreement or a Kappa statistic of 1 occurred.

Table 2.9 Discolouration of margins.

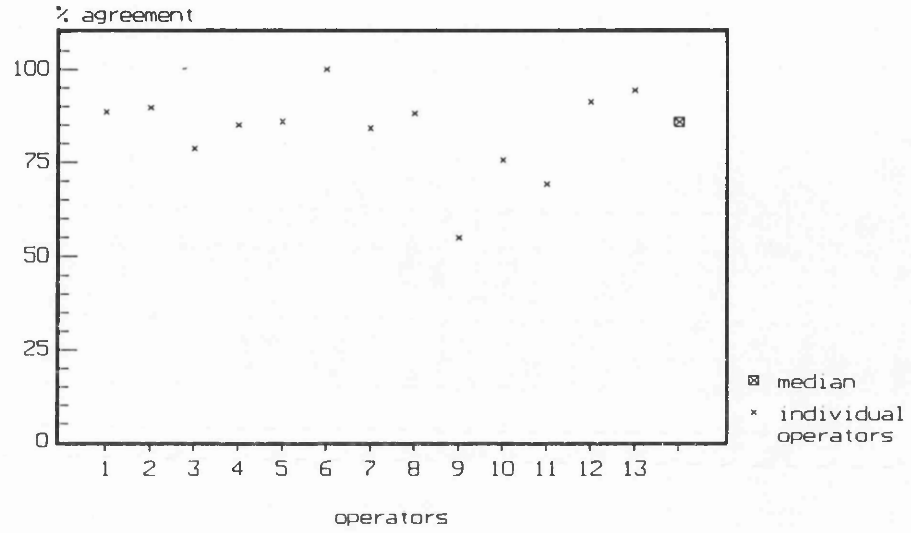


Figure 2.4.1 **Marginal stain.**

Percentage agreement between examiners and operators.

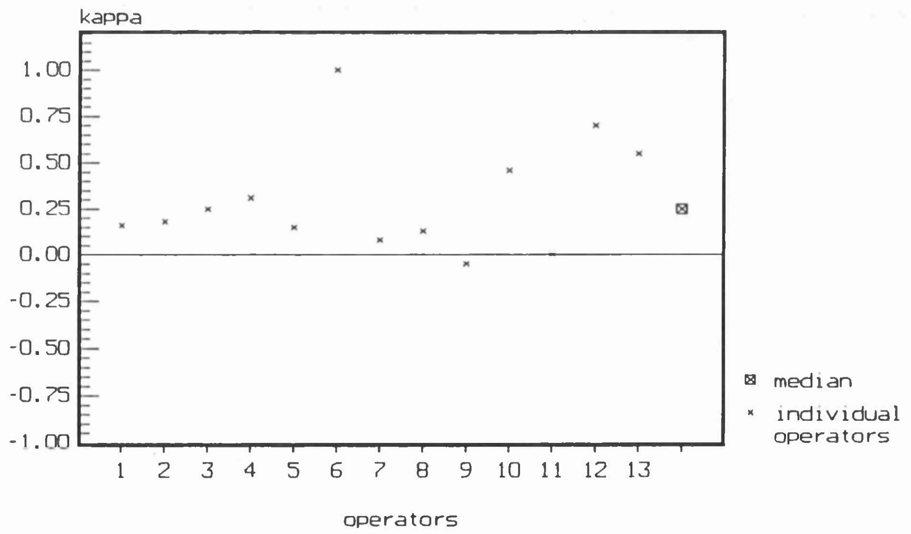


Figure 2.4.2 **Marginal stain.**

Kappa statistic for the agreement between examiners and operators.

Operator	% Agreement pres. sec. caries	% Agreement abs. sec. caries	% Agreement overall	Kappa Statistic
1	2/10 20%	106/112 94.6%	108/122 88.5%	0.16
2	0/0 *	67/68 98.5%	67/68 98.5%	0
3	1/4 25%	53/57 93%	54/61 88.5%	0.16
4	1/1 100%	38/39 97.4%	39/40 97.5%	0.66
5	0/3 0%	87/89 97.7%	87/92 94.6%	-0.02
6	0/0 *	7/7 100%	7/7 100%	1 *
7	1/1 100%	124/125 99.2%	125/126 99.2%	0.67
8	0/0 *	143/144 99.3%	143/144 99.3%	0.98
9	1/2 50%	44/49 89.8%	45/51 88.2%	0.2
10	8/9 88.9%	27/32 84.4%	35/41 85.4%	0.63
11	0/0 *	13/13 100%	13/13 100%	1 *
12	0/2 0%	43/44 97.7%	43/44 97.7%	0.63
13	4/4 100%	115/121 95%	119/124 95.9%	0.59

Medians:	97.5%	0.63
range:	(85.4 - 100)	(-0.02 to 1)

* contains table cell with no entries.
100% agreement or a Kappa statistic of 1 occurred.

Table 2.10 Presence of secondary caries.

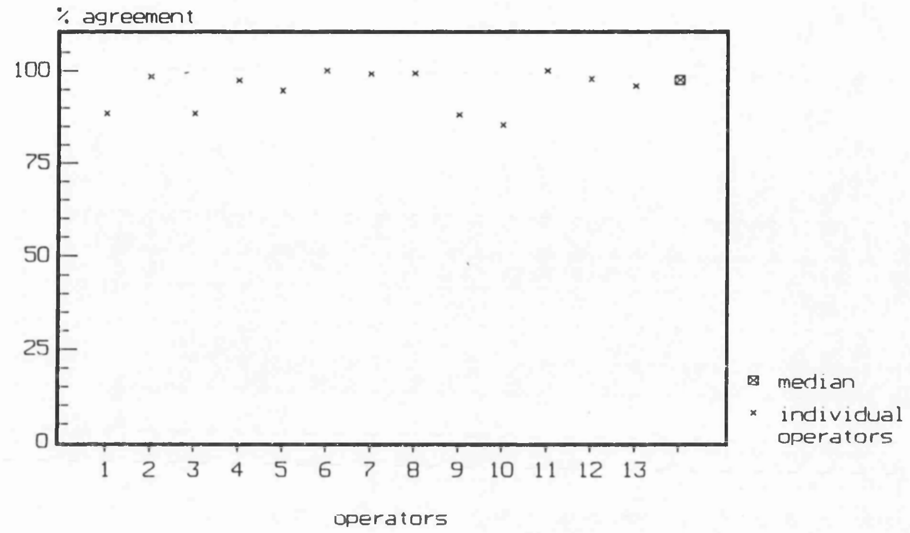


Figure 2.5.1 **Secondary caries.**

Percentage agreement between examiners and operators.

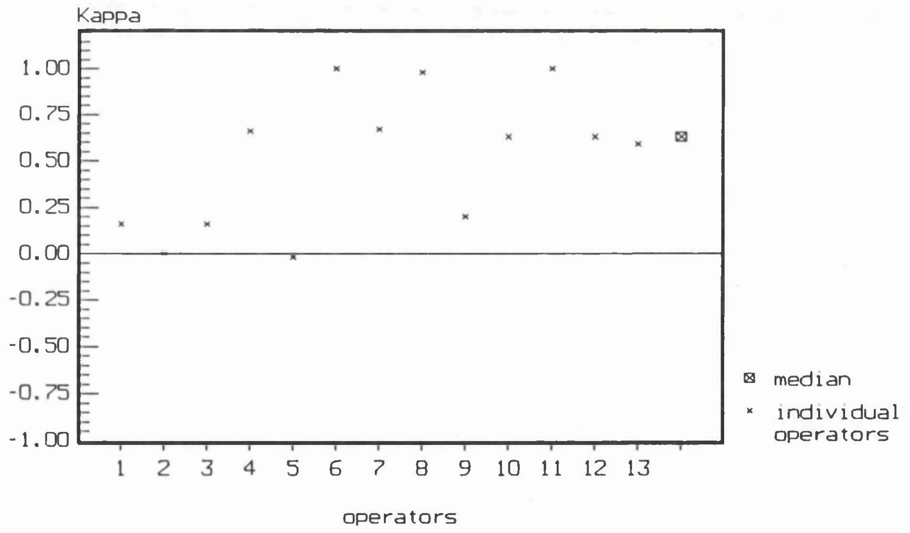


Figure 2.5.2 **Secondary caries.**

Kappa statistic for the agreement between examiners and operators.

Operator	% Agreement compl. ret	% Agreement part.ret.	% Agreement missing	% Agreement overall	Kappa
1	34/35 97.1%	38/86 44.2%	0/1 0%	72/122 59%	0.3
2	3/4 75%	38/60 63.3%	2/4 50%	43/68 63.2%	0.01
3	6/8 75%	24/63 38.1%	6/9 66.7%	36/80 45%	0.18
4	13/13 100%	32/45 71.1%	5/6 83.3%	50/64 78.1%	0.6
5	27/31 87.1%	66/79 83.5%	1/1 100%	94/111 84.7%	0.66
6	7/8 87.5%	1/5 20%	0/0 *	8/13 61.5%	0.22
7	3/12 25%	85/106 80.2%	7/11 63.6%	95/129 73.6%	0.29
8	93/103 90.3%	78/133 58.6%	1/3 33.3%	172/239 71.9%	0.47
9	1/2 50%	22/40 55%	6/9 66.7%	29/51 56.9%	0.19
10	3/3 100%	20/32 62.5%	6/8 75%	29/43 67.4%	0.42
11	2/3 66.7%	9/10 90%	0/0 *	11/13 84.6%	0.57
12	1/1 100%	38/44 86.4%	1/1 100%	40/46 86.9%	0.36
13	32/41 78%	130/146 89%	3/3 100%	165/190 86.8%	0.66

medians:	71.9%	0.36
range:	(45 - 86.9)	(0.1 - 0.66)

* contains table cell with no entries.
100% agreement or a Kappa statistic of 1 occurred.

Table 2.11 Overall Fissure Sealant Retention.

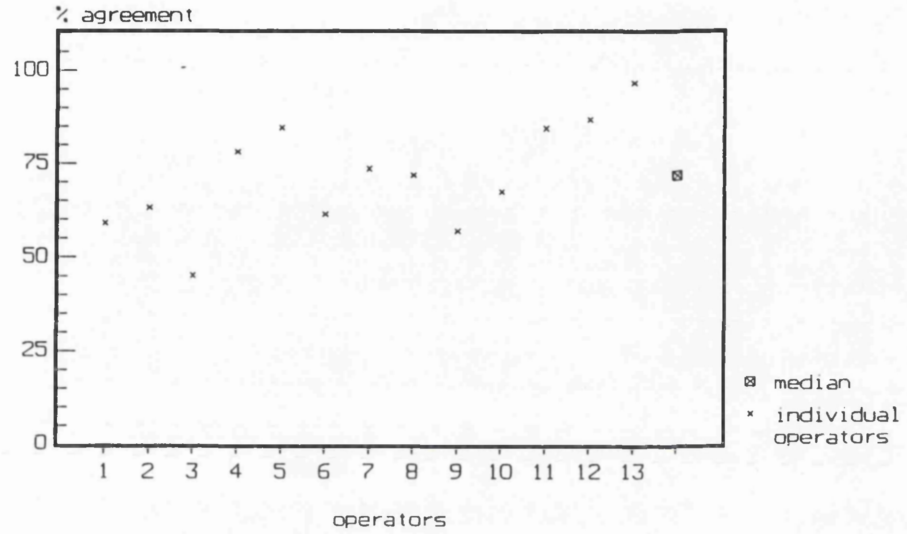


Figure 2.6.1 **Overall fissure sealant retention.**

Percentage agreement between examiners and operators.

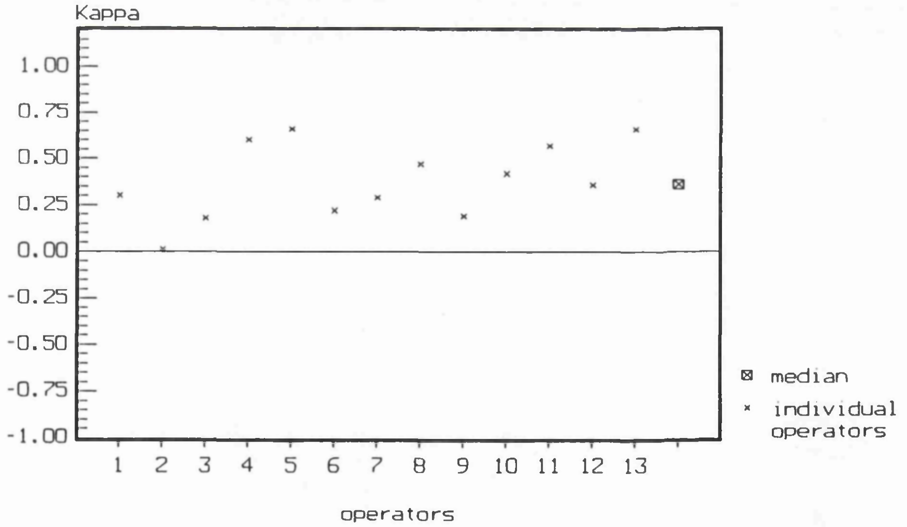


Figure 2.6.2 **Overall fissure sealant retention.**

Kappa statistic for the agreement between examiners and operators.

Operator	% Agreement modify	% Agreement not modify	% Agreement overall	Kappa Statistic
1	10/41 24.4%	73/81 90.1%	83/122 68%	0.16
2	18/51 35.3%	15/17 88.2%	33/68 48.5%	0.14
3	4/50 8%	29/30 96.7%	32/80 40%	0.01
4	18/33 54.5%	28/31 90.3%	46/64 71.9%	0.44
5	49/55 89.1%	38/56 67.8%	87/111 78.4%	0.57
6	0/3 0%	9/10 90%	9/13 69.2%	-0.13
7	18/63 28.6%	50/66 75.7%	68/129 52.7%	0.04
8	14/65 21.5%	168/174 96.5%	182/239 76.1%	0.23
9	21/35 60%	10/16 62.5%	31/51 60.8%	0.2
10	8/19 42.1%	19/24 79.2%	27/43 62.8%	0.22
11	4/7 57.1%	4/6 66.7%	8/13 61.5%	0.23
12	16/28 57.1%	11/18 61.1%	27/46 58.7%	0.17
13	73/106 68.9%	69/84 82.1%	142/190 74.7%	0.5

medians:	62.8%	0.2
range:	(40 - 78.8)	(-0.13 to 0.57)

* contains table cell with no entries.

100% agreement or a Kappa statistic of 1 occurred.

Table 2.12 Decision to modify sealant restoration.

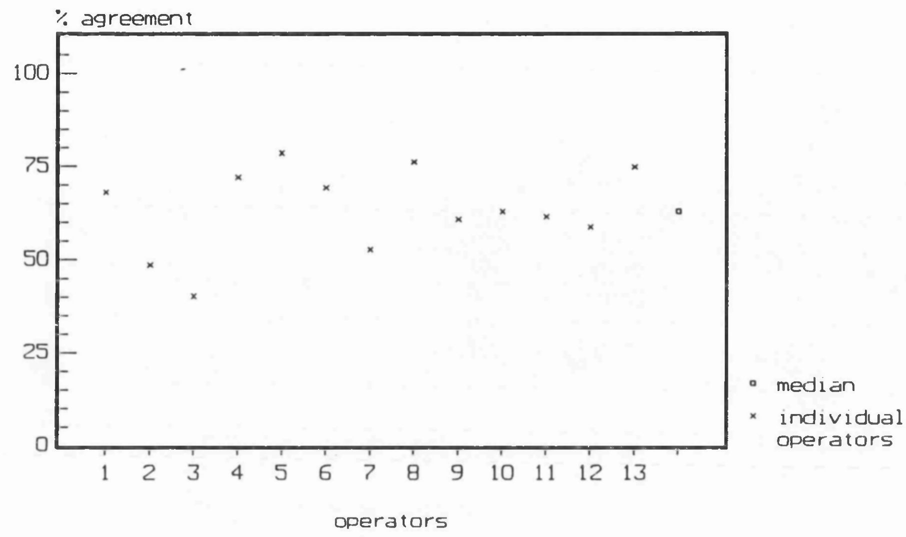


Figure 2.7.1 **Modification required.**

Percentage agreement between examiners and operators.

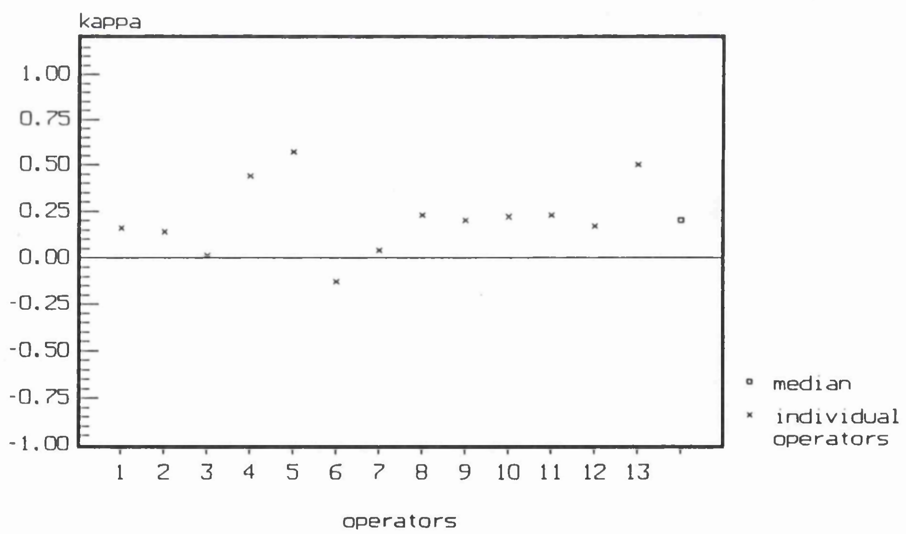


Figure 2.7.2 **Modification required.**

Kappa statistic for the agreement between examiners and operators.

Operator	% Agreement replace	% Agreement not replace	% Agreement overall	Kappa Statistic
1	1/4 25%	118/118 100%	119/122 97.5%	0.39
2	1/3 33.3%	64/65 98.5%	65/68 95.6%	0.38
3	4/9 44.4%	69/71 97.2%	73/80 91.2%	0.48
4	1/2 50%	59/62 95.2%	60/64 93.7%	0.3
5	2/4 50%	107/107 100%	109/111 98.2%	0.66
6	0/0 *	13/13 100%	13/13 100%	1 *
7	1/7 14.3%	122/122 100%	123/129 95.3%	0.23
8	1/3 33.3%	236/236 100%	237/239 99.2%	0.53
9	1/5 20%	46/46 100%	47/51 92.1%	0.31
10	11/17 64.7%	23/26 88.5%	34/43 79.1%	0.55
11	0/1 0%	12/12 100%	12/13 92.3%	0
12	2/4 50%	42/42 100%	44/46 95.6%	0.64
13	7/8 87.5%	179/182 98.3%	186/190 97.9%	0.76

medians:	95.6%	0.48
range:	(79.1 - 100)	(0 to 1)

* contains table cell with no entries.
100% agreement or a Kappa statistic of 1 occurred.

Table 2.13 Decision to replace sealant restoration.

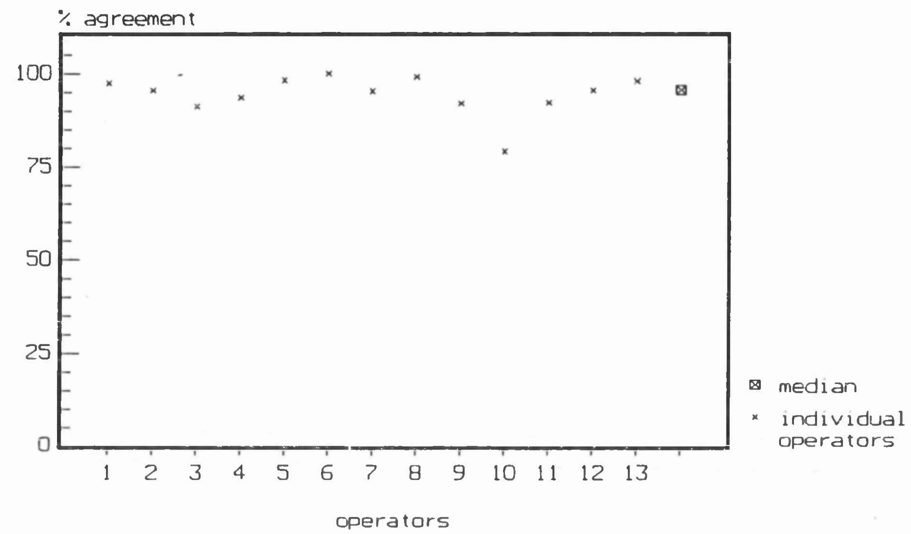


Figure 2.8.1 **Replacement required.**

Percentage agreement between examiners and operators.

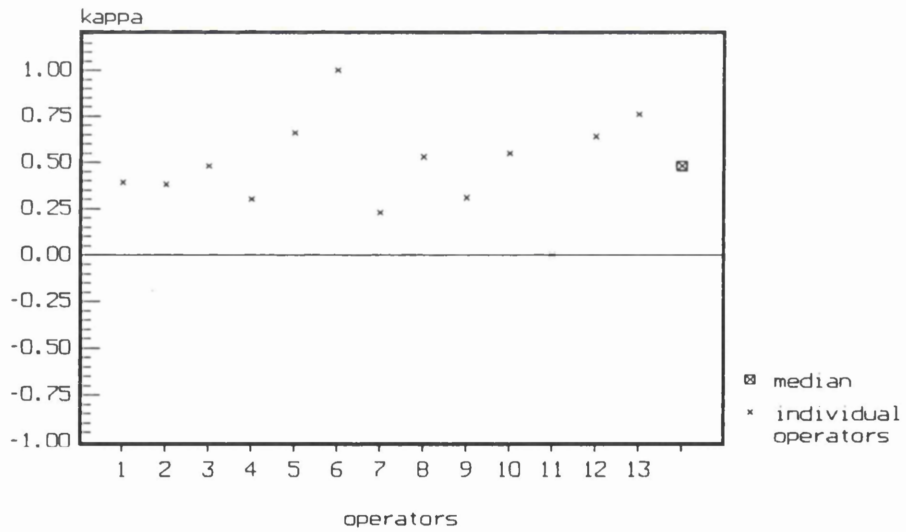


Figure 2.8.2 **Replacement required.**

Kappa statistic for the agreement between examiners and operators.

Operator	% Agreement immed.sens.	% Agreement no immed.sens.	% Agreement overall	Kappa Statistic
1	1/2 50%	120/120 100%	121/122 99.2%	0.67
2	0/0 *	68/68 100%	68/68 100%	1 *
3	0/0 *	80/80 100%	80/80 100%	1 *
4	0/0 *	64/64 100%	64/64 100%	1 *
5	1/1 100%	110/110 100%	111/111 100%	1
6	0/0 *	13/13 100%	13/13 100%	1 *
7	0/0 *	129/129 100%	129/129 100%	1 *
8	1/1 100%	238/238 100%	239/239 100%	1
9	0/0 *	51/51 100%	51/51 100%	1 *
10	0/0 *	43/43 100%	43/43 100%	1 *
11	0/0 *	13/13 100%	13/13 100%	1 *
12	1/1 100%	45/45 100%	46/46 100%	1
13	0/0 *	190/190 100%	190/190 100%	1 *
		Medians: range:	100% (99.2 - 100)	1 (0.67 to 1)

* contains table cell with no entries.
100% agreement or a Kappa statistic of 1 occurred.

Table 2.14 Presence of immediate sensitivity.

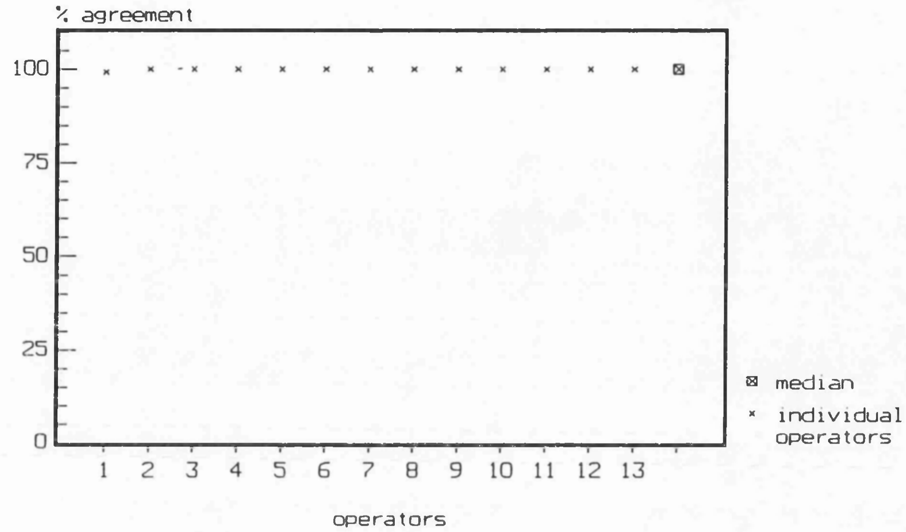


Figure 2.9.1 **Immediate sensitivity.**

Percentage agreement between examiners and operators.

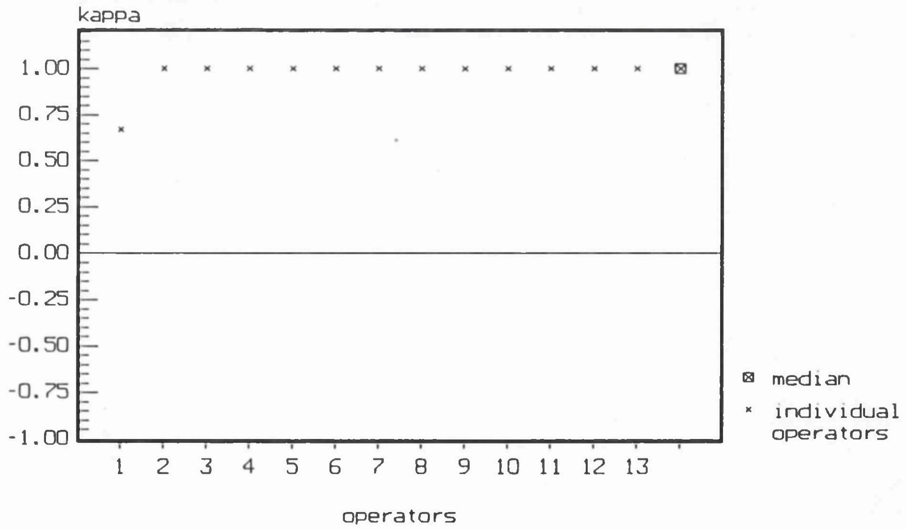


Figure 2.9.2 **Immediate sensitivity.**

Kappa statistic for the agreement between examiners and operators.

Operator	% Agreement	% Agreement	% Agreement overall	Kappa Statistic
1	0/0 *	122/122 100%	122/122 100%	1 *
2	0/0 *	68/68 100%	68/68 100%	1 *
3	0/0 *	80/80 100%	80/80 100%	1 *
4	0/0 *	64/64 100%	64/64 100%	1 *
5	0/0 *	111/111 100%	111/111 100%	1 *
6	0/0 *	13/13 100%	13/13 100%	1 *
7	0/0 *	129/129 100%	129/129 100%	1 *
8	0/0 *	239/239 100%	239/239 100%	1 *
9	0/0 *	51/51 100%	51/51 100%	1 *
10	0/0 *	43/43 100%	43/43 100%	1 *
11	0/0 *	13/13 100%	13/13 100%	1 *
12	0/0 *	46/46 100%	46/46 100%	1 *
13	0/0 *	189/189 100%	189/189 100%	1 *

Medians:	100%	1.00
range:	(100 - 100)	(1 to 1)

* contains table cell with no entries.
100% agreement or a Kappa statistic of 1 occurred.

Table 2.15 Presence of prolonged sensitivity.

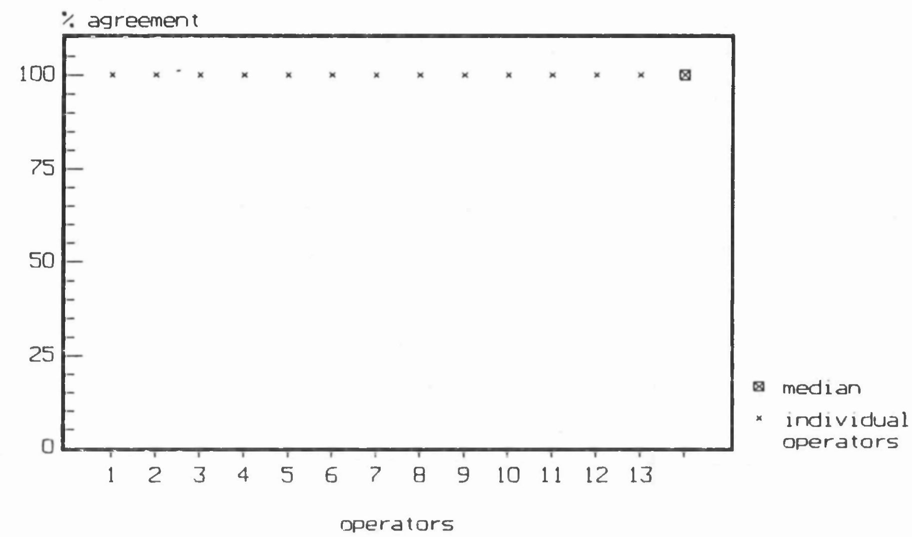


Figure 2.10.1 **Prolonged sensitivity.**

Percentage agreement between examiners and operators.

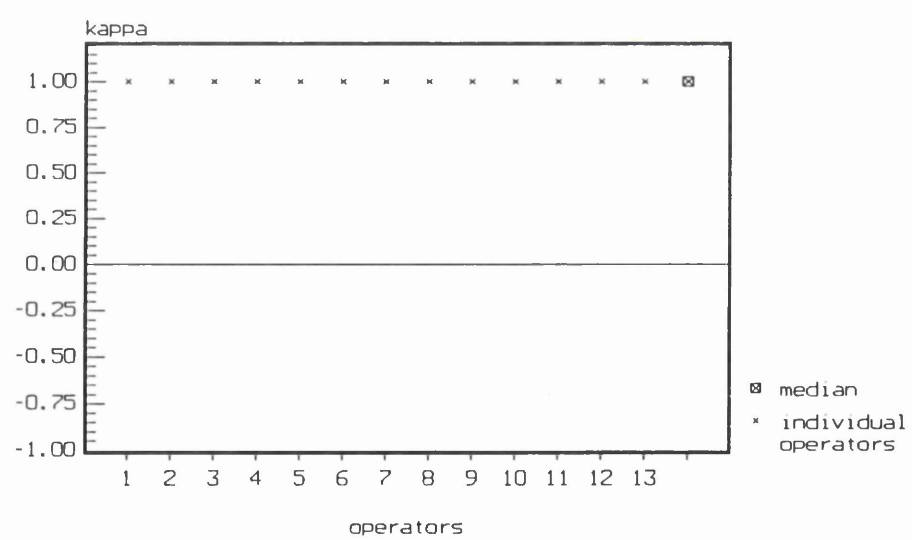


Figure 2.10.2 **Prolonged sensitivity.**

Kappa statistic for the agreement between examiners and operators.

Oper	% Agreement compl. ret.	% Agreement part.ret.	% Agree. f.s. missing	% Agreement overall	K
1	9/9 100%	14/26 53.8%	0/0 *	23/35 65.7%	0.38
2	0/0 *	2/7 28.6%	0/0 *	2/7 28.6%	1 *
3	3/5 60%	18/38 47.4%	3/4 75%	24/47 51.1%	0.2
4	11/11 100%	30/41 73.2%	4/4 100%	45/56 80.4%	0.63
5	14/14 100%	25/27 92.6%	1/1 100%	40/42 95.2%	0.9
6	+ + +	+ + +	+ + +	+ + +	+ +
7	0/0 *	3/3 100%	0/0 *	3/3 100%	1 *
8 #	93/103 90.3%	78/133 58.6%	1/3 33.3%	172/239 71.9%	0.47
9	+ + +	+ + +	+ + +	+ + +	+ +
10	+ + +	+ + +	+ + +	+ + +	+ +
11	+ + +	+ + +	+ + +	+ + +	+ +
12	1/1 100%	38/44 86.4%	1/1 100%	40/46 86.9%	0.36
13 #	32/41 78%	130/146 89%	3/3 100%	165/190 86.8%	0.66

medians:	80.4%	0.63
range:	(28.6 - 100)	(0.2 to 1)

operator used opaque fissure sealant exclusively.

+ + + operator used clear fissure sealant exclusively.

* contains table cell with no entries.

100% agreement or a Kappa statistic of 1 occurred.

Table 2.16 Agreement for opaque fissure sealant.

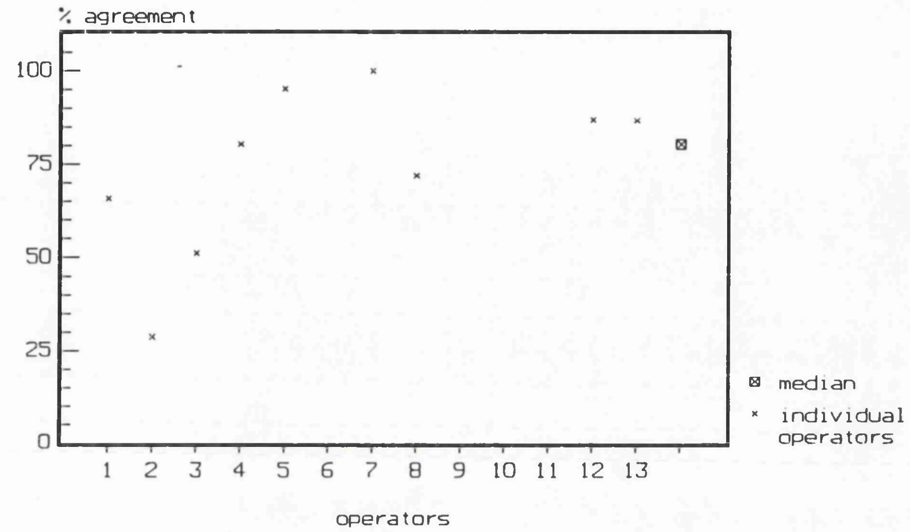


Figure 2.11.1 **Retention of opaque fissure sealant.**

Percentage agreement between examiners and operators.

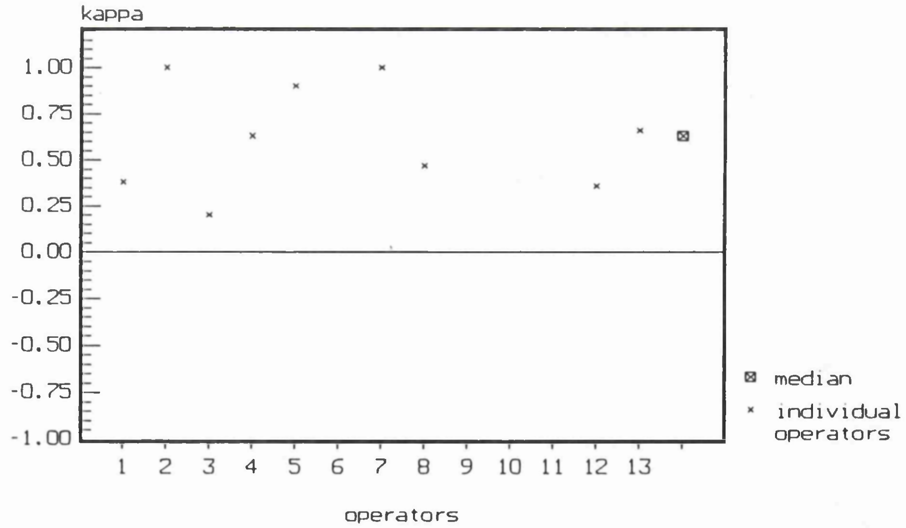


Figure 2.11.2 **Retention of opaque fissure sealant.**

Kappa statistic for the agreement between examiners and operators.

Operator	% Agreement compl. ret.	% Agreement part. ret.	% Agreement f.seal missing	% agreement overall	Kappa
1	25/26 96.1%	24/60 40%	0/1 0%	49/87 56.3%	0.28
2	3/4 75%	36/53 67.9%	2/4 50%	41/61 67.2%	0.22
3	3/3 100%	6/25 24%	3/5 60%	12/33 36.4%	0.15
4	2/2 100%	2/4 50%	1/2 50%	5/8 62.5%	0.43
5	13/17 76.5%	41/52 78.8%	0/0 *	54/69 78.3%	0.49
6	7/8 87.5%	1/5 20%	0/0 *	8/13 61.5%	0.22
7	3/12 25%	82/103 79.6%	7/11 63.6%	92/126 73%	0.28
8	+ + +	+ + +	+ + +	+ + +	+ +
9 #	1/2 50%	22/40 55%	6/9 66.7%	29/51 56.9%	0.19
10 #	3/3 100%	22/32 62.5%	6/8 75%	29/43 67.4%	0.42
11 #	2/3 66.7%	9/10 90%	0/0 *	11/13 84.6%	0.57
12	+ + +	+ + +	+ + +	+ + +	+ +
13	+ + +	+ + +	+ + +	+ + +	+ +

Medians:	64.9%	0.28
range:	(36.4 - 84.6)	(0.15 - 0.57)

operator used clear fissure sealant exclusively.

+ + + operator did not use clear fissure sealant.

* contains table cell with no entries.
100% agreement or a Kappa statistic of 1 occurred.

Table 2.17 Agreement for clear fissure sealant.

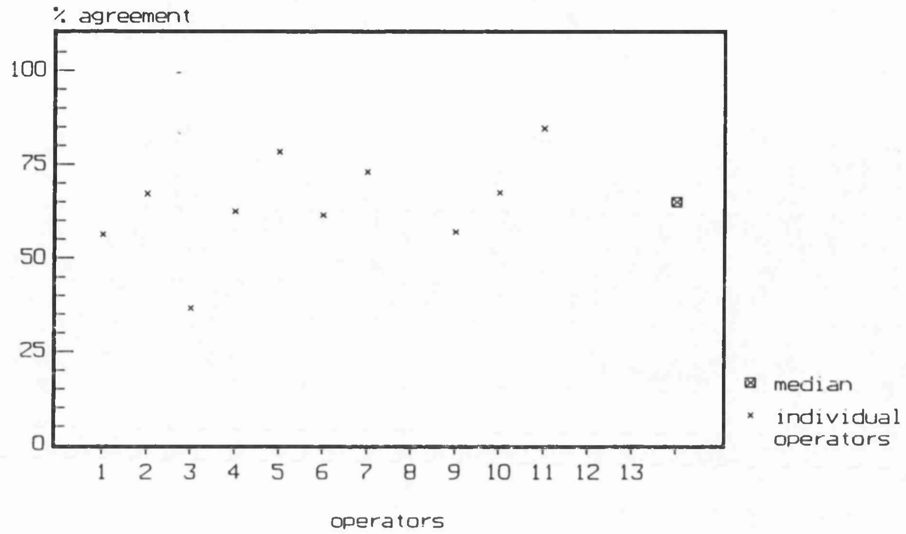


Figure 2.12.1 **Retention of clear fissure sealant.**

Percentage agreement between examiners and operators.

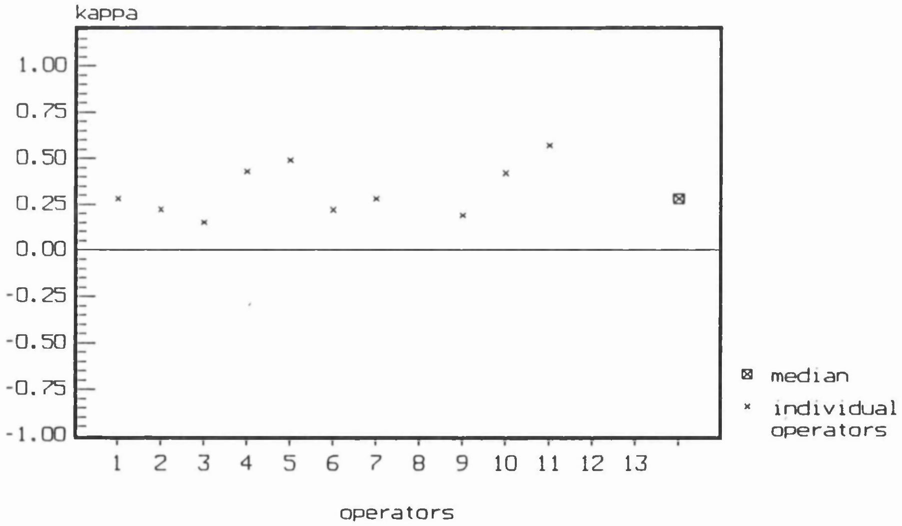


Figure 2.12.2 **Retention of clear fissure sealant.**

Kappa statistic for the agreement between examiners and operators.

Op	% Agreement compl. ret.	% Agreement part.ret.	% Agreement f.s. missing	% Agreement overall	K
1	4/4 100%	6/11 54.5%	0/1 0%	10/16 62.55%	0.37
2	2/3 66.7%	16/25 64%	2/2 100%	20/30 66.7%	0.32
3	2/3 66.7%	6/22 27.3%	2/3 66.7%	10/28 35.7%	0.11
4	5/5 100%	11/13 84.6%	1/2 50%	17/20 85%	0.71
5	19/20 95%	33/40 82.5%	1/1 100%	53/61 86.9%	0.74
6	3/4 75%	0/2 0%	0/0 *	3/6 50%	0
7	3/6 50%	27/36 75%	4/5 80%	34/47 72.3%	0.43
8	43/50 86%	29/46 63%	0/2 0%	72/98 73.5%	0.48
9	1/2 50%	11/23 47.8%	6/9 66.7%	18/34 52.9%	0.15
10	0/0 *	9/13 69.2%	5/6 83.3%	14/19 73.7%	0.53
11	1/2 50%	5/5 100%	0/0 *	6/7 85.7%	0.59
12	0/0 *	23/24 95.8%	1/1 100%	24/25 96%	0.65
13	14/19 73.7%	39/41 95.1%	1/1 100%	54/61 88.5%	0.74

Medians:	73.5%	0.48
range:	(35.7 - 96)	(0 - 0.74)

* contains table cell with no entries.
100% agreement or a Kappa statistic of 1 occurred.

Table 2.18 **Agreement for fissure sealant on maxillary first molar teeth.**

Oper.	% Agreement compl. ret.	% Agreement part.ret.	% Agreement f.s. missing	% Agreement overall	Kappa
1	10/11 90.9%	19/39 48.7%	0/0 *	29/50 58%	0.26
2	1/1 100%	11/21 52.4%	0/2 0%	12/24 50%	0.002
3	2/2 100%	10/23 43.5%	1/1 100%	13/26 50%	0.24
4	5/5 100%	17/28 60.7%	4/4 100%	26/37 70.3%	0.49
5	6/9 66.7%	33/38 86.8%	0/0 *	39/47 82.9%	0.5
6	4/4 100%	1/3 33.3%	0/0 *	5/7 71.4%	0.46
7	0/2 0%	20/23 86.9%	1/1 100%	21/26 80.8%	0.21
8	17/18 94.4%	39/70 55.7%	0/0 *	56/88 63.6%	0.33
9	0/0 *	11/17 64.7%	0/0 *	11/17 64.7%	0
10	0/0 *	9/17 52.9%	1/2 50%	10/19 52.6%	0.03
11	1/1 100%	4/5 80%	0/0 *	5/6 83.3%	0.57
12	1/1 100%	15/20 75%	0/0 *	16/21 76.2%	0.22
13	8/9 88.9%	55/65 84.6%	1/1 100%	64/75 85.3%	0.55

Medians:	70.3%	0.26
range:	(50 - 85.3)	(0 - 0.57)

* contains table cell with no entries.
100% agreement or a Kappa statistic of 1 occurred.

Figure 2.19 Agreement for fissure sealant on mandibular first molar teeth.

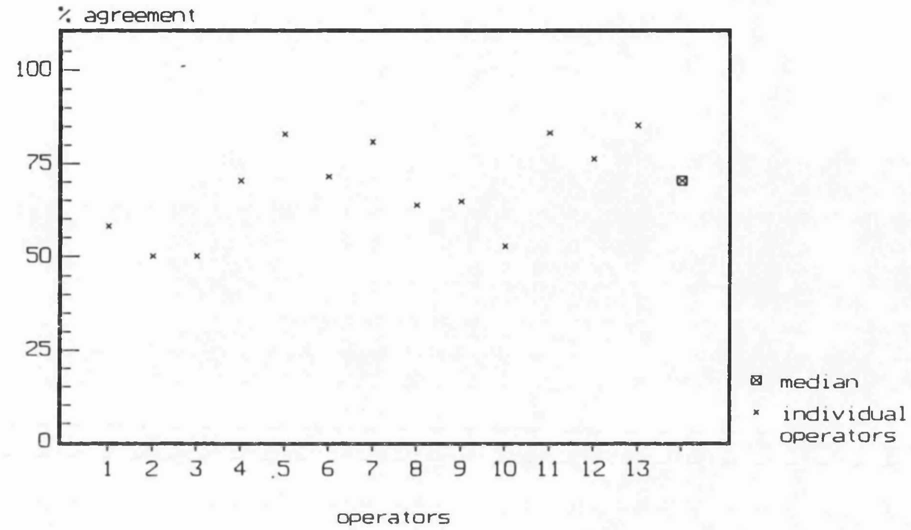


Figure 2.14.1 **Retention of fissure sealant on mandibular first molar teeth. Percentage agreement between examiners and operators.**

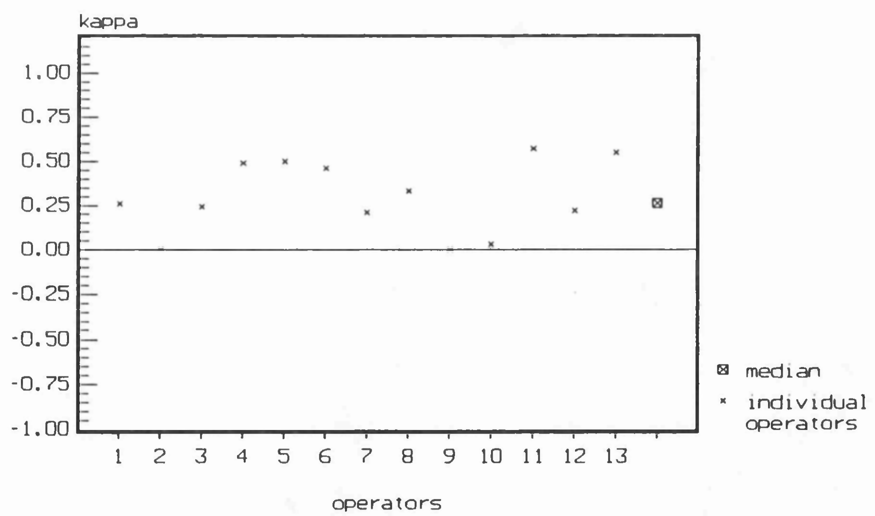


Figure 2.14.2 **Retention of fissure sealant on mandibular first molar teeth. Kappa statistic for the agreement between examiners and operators.**

Oper.	% Agreement compl. ret.	% Agreement part.ret.	% Agreement f.s. missing	% Agreement overall	Kappa
1	11/11 100%	14/30 46.7%	0/0 *	25/41 61%	0.34
2	3/4 75%	14/29 48.3%	0/2 0%	17/35 48.6%	0.08
3	3/3 100%	10/18 55.6%	2/3 66.7%	15/24 62.5%	0.39
4	4/4 100%	13/16 81.2%	1/1 100%	18/21 85.7%	0.69
5	13/15 86.7%	36/45 80%	1/1 100%	50/61 81.9%	0.6
6	6/6 100%	0/1 0%	0/0 *	6/7 85.7%	0
7	2/4 50%	22/29 75.8%	2/3 66.7%	26/36 72.2%	0.39
8	26/31 83.9%	26/42 61.9%	0/0 *	52/73 71.2%	0.45
9	0/0 *	8/17 47.1%	4/5 80%	12/22 54.5%	0.22
10	0/0 *	10/18 55.6%	1/2 50%	11/20 55%	0.05
11	1/1 100%	4/4 100%	0/0 *	5/5 100%	1
12	1/1 100%	14/17 82.3%	0/0 *	15/18 83.3%	0.34
13	10/11 90.9%	55/65 84.6%	1/1 100%	66/77 85.7%	0.6

Medians:	81.9%	0.39
range:	(48.6 - 100)	(0 to 1)

* contains table cell with no entries.
100% agreement or a Kappa statistic of 1 occurred.

Table 2.20 Agreement for fissure sealant on right first molar teeth.

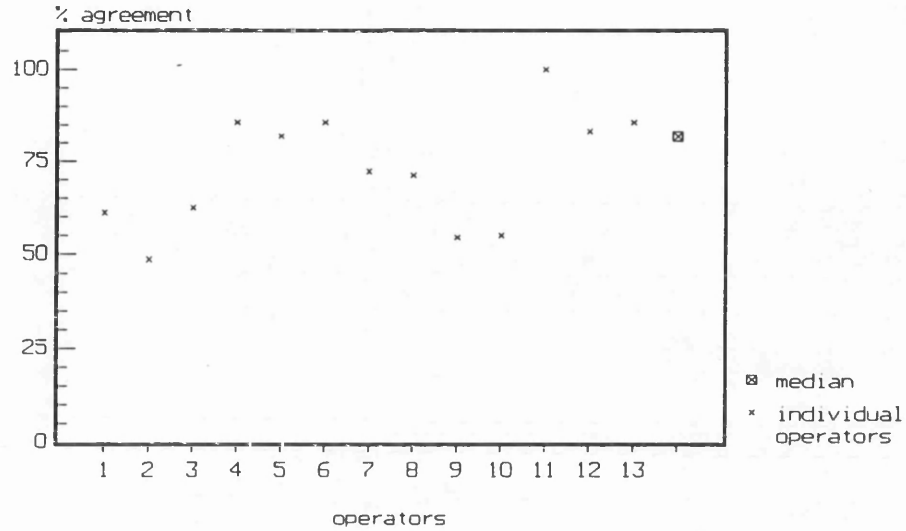


Figure 2.15.1 **Retention of fissure sealant on right first molar teeth. Percentage agreement between examiners and operators.**

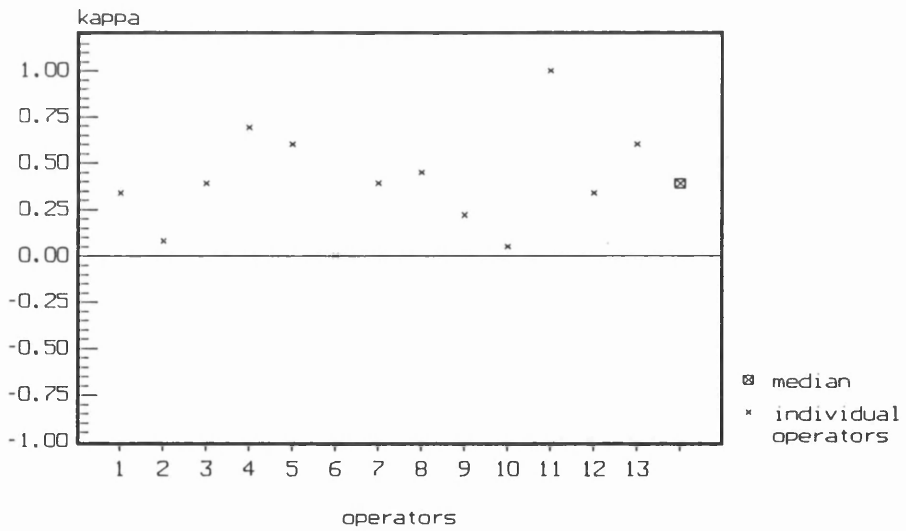


Figure 2.15.2 **Retention of fissure sealant on right first molar teeth. Kappa statistic for the agreement between examiners and operators.**

Op	% Agreement compl. ret.	% Agreement part. ret.	% Agreement f.s. missing	% Agreement overall	Kappa
1	3/4 75%	11/20 55%	0/1 0%	14/25 56%	0.18
2	0/0 *	13/17 76.5%	2/2 100%	15/19 78.9%	0.42
3	1/2 50%	6/27 22.2%	1/1 100%	8/30 26.7%	0.01
4	6/6 100%	15/25 60%	4/5 80%	25/36 69.4%	0.49
5	12/14 85.7%	30/33 90.9%	0/0 *	42/47 89.4%	0.75
6	1/2 50%	1/4 25%	0/0 *	2/6 33.3%	0
7	1/4 25%	25/30 83.3%	3/3 100%	29/37 78.4%	0.41
8	34/37 91.9%	42/74 56.7%	0/2 0%	76/113 67.2%	0.40
9	1/2 50%	14/23 60.9%	2/4 50%	17/29 58.6%	0.15
10	0/0 *	8/12 66.7%	5/6 83.3%	13/18 72.2%	0.50
11	1/2 50%	5/6 83.3%	0/0 *	6/8 75%	0.33
12	0/0 *	24/27 88.9%	1/1 100%	25/28 89.3%	0.38
13	12/17 70.6%	39/41 95.1%	1/1 100%	52/59 88.1%	0.71

Medians:	72.2%	0.4
range:	(26.7 - 89.4)	(0 - 0.75)

* contains table cell with no entries.

100% agreement or a Kappa statistic of 1 occurred.

Table 2.21 Agreement for fissure sealant on left first molar teeth.

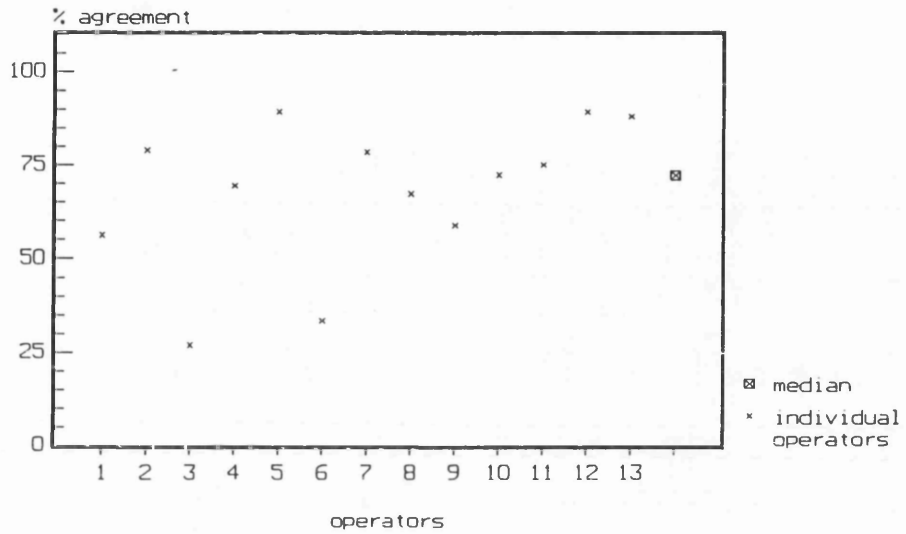


Figure 2.16.1 **Retention of fissure sealant on left first molar teeth. Percentage agreement between examiners and operators.**

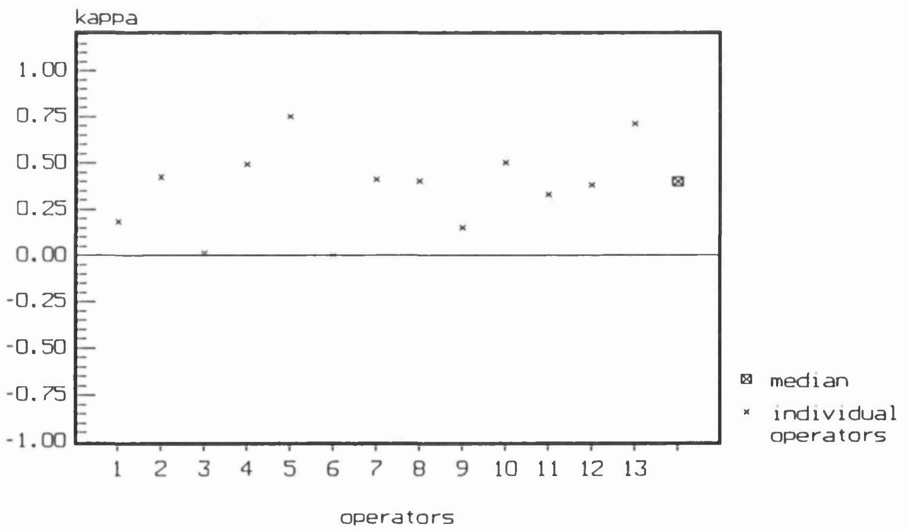


Figure 2.16.2 **Retention of fissure sealant on left first molar teeth. Kappa statistic for the agreement between examiners and operators.**

Chapter
3

The Use of Pit and Fissure Sealant Resin in the Management of Early Fissure Caries: Results from a Field Trial in the Community Dental Service.

3.1 Fissure sealants.

3.1.1 Rational for the use of fissure sealants.

The introduction of fluoride to the water supply has been shown to reduce caries rate principally on smooth and approximal tooth surfaces. The pits and fissures on the occlusal surfaces of premolar and molar teeth are the most susceptible sites according to Backer Dirks (1961) and Lewis & Hargreaves (1975) [see chapter 1].

In 1897, G.V. Black stated that it was not the fissures themselves that made the surface vulnerable, but that they could provide a sheltered environment or sanctuary for the agents responsible for the caries process.

The caries process, while not fully understood, has been described as multifactorial in nature (Keyes 1963). By their very morphology, pits and fissures encourage the accumulation of microorganisms (Galil & Gwinnett 1975) which cannot be thoroughly debrided by either patient or dental surgeon (Galil 1975). The subsequent accumulation of fermentable carbohydrate may result in the production of organic acids by the microflora. These may result in the demineralisation of the enamel surface. Fissure sealants have been shown to be an effective material in preventing pit and fissure caries by obliterating the sheltered environment of the fissure where caries may initiate (Gordon 1983) and progress bilaterally along the side walls (Mortimer 1964).

In the United States of America, the National Institute of Health Consensus Development Panel (1984) confirmed the efficacy of the fissure sealing procedure. The distribution of the caries on different tooth surfaces has changed. There has been an increase in the proportion of caries lesions observed in occlusal surfaces even in areas where the water supply has been fluoridated. This would appear to indicate an even greater need for the use of fissure sealants as part of caries prevention regimes.

The application of fissure sealant is an non-invasive technique which is readily accepted by most patients. It involves a prophylaxis, to remove plaque and accumulated food debris, followed by acid etching of the enamel surfaces before the application of an organic resin.

3.1.2 Criteria for tooth selection.

Harris (1991) reviewed the indications for the selection of teeth for fissure sealing and concluded that the application was warranted in deep occlusal fissures and buccal pits "particularly if the dental probe caught and resisted withdrawal". In his view, fissure sealant should not be applied where there is an obvious open cavity in pits and fissures or where caries lesions already exist on other surfaces of the tooth being considered for sealing. Before fissure sealant is applied to a tooth, the presence of previous restorations and the level of patient cooperation should be assessed to ensure that isolation is not problematic. Simonsen (1984a) stated the most important times to consider sealing teeth, on a cost benefit regime, were at ages 3 - 4 for the deciduous dentition, 6 - 7 for the first permanent molars and 11 - 13 for the second permanent molar and premolar teeth. Application of sealants to susceptible teeth in adults should also be considered if current or future caries rate is high e.g. where drug or radiation induced xerostomia is present as a result of the treatment of a medical condition.

Ripa *et al* (1988b) concluded the time since tooth eruption did not influence the susceptibility of pits and fissures to carious attack. This view was supported by Arthur & Swango (1987) who noted a high incidence of occlusal caries lesions among U.S. Navy recruits in their late teens and early twenties.

3.1.3 Early attempts at preventing fissure caries.

Around the turn of the last century, there was some interest in the application of chemicals to pits and fissures in an attempt to prevent caries. These materials were reported to act by altering the enamel surface in the depth of the fissure and not by obliterating them. At this time, the proteolytic theory of caries production was held true. It was thought that the precipitation of organic material onto the enamel surface would block any pathways into the tooth structure.

In 1905, Miller advocated the use of silver nitrate to prevent the onset of fissure caries but it was not until 1937 that a report by Prime showed this material to be of negligible benefit. Other materials tested included the use of nitro-cellulose (Gore 1939) and zinc chloride (Ast *et al* 1950). These materials were also found to be of little detectable benefit.

Another approach to fissure caries management was to obliterate the fissures by inserting a material which would eliminate accumulation of bacteria and their substrates. In 1923, Hyatt advocated insertion of zinc phosphate cement into the fissures of erupting molar teeth. Once eruption was complete, he believed a cavity should be prepared which would eliminate the fissures and allow the insertion of amalgam. He termed this technique the "prophylactic odontotomy". It was his belief that molar teeth would inevitably become carious and the early insertion of an amalgam restoration, before caries made cavity preparation more difficult, was advantageous. This view was not widely accepted and strong opposition ensured that the prophylactic odontotomy was not widely practiced.

In 1926, another alternative was suggested by Bodecker. He advocated that deep fissures should be widened by using a large round bur: the technique was termed fissure eradication or enameloplasty. This technique was not generally accepted by the profession because the amount of sound tooth structure which had to be removed frequently exceeded that required to place a small restoration.

Miller (1950) reviewed the effects of obliterating the fissures with copper phosphate cement and compared the results with a group of teeth subjected to the topical application of silver nitrate. He reported retention of the cement to be poor. Neither group, when compared with a control, was shown to be effective in preventing fissure caries.

3.1.4 The rationale for the use of therapeutic fissure sealants.

Accurate diagnosis of pit and fissure caries presents an increasingly difficult clinical problem. Concern has been voiced over the possibility of sealing over fissure lesions. Examination of histological sections of molar teeth which appeared to be sound when the dental probe was used in a clinical examination showed clear evidence of fissure caries (Miller and Hobson 1956). Historically, Besic (1943) and King *et al* (1965) described reductions in bacterial count when dentine, which had been indirectly pulp capped, was sampled. Mednick *et al* (1974) placed bacterially contaminated paper points within shallow cavities in primary molar teeth 4 to 16 weeks before exfoliation. They were covered with an ultra-violet light cured fissure sealant to isolate the organisms from nutrient supply in the saliva. The results from this study indicated a reduction in the viable bacterial count.

Studies have also been conducted by Going *et al* (1978) and Metz Fairhurst (1984) who placed pit and fissure sealant over active fissure caries. The results were similar to those reported by Handelman *et al* (1976b) who concluded that pit and fissure sealants could be used in the management of occlusal caries, without cavity preparation. In 1980, Jensen and Handelman investigated the role of the ultra violet light source in the bacterial count reduction by comparing the results with a new study using an autopolymerizing fissure sealant. The results indicated that it was the presence of intact sealant that was important in reducing the bacterial count and not the effect of ultraviolet radiation from the light source.

Jeronimus *et al* (1975) found similar reductions in the viable bacterial count of fissure caries under intact fissure sealant. Theilade *et al* (1977) attributed this effect to the close hermetic seal obtained between the resins used for sealing and the etched enamel surface. When the integrity of the seal was tested by Jensen & Handelman in 1978 using radioactive isotopes, it was discovered that no movement of fluid or ions took place.

Where carious lesions have extended into the underlying dentine and fissure sealant has been applied over the tooth surface, Going *et al* (1978) found negative bacterial counts and reported an 83% reversal from a caries active to a caries inactive state over a five year period. Handelman (1982) showed similar reductions in the microflora and when monitored radiographically observed that the lesions appeared to have arrested. Established dentine lesions treated in this way were found not to progress when the overlying pit and fissure sealant remained intact (Jorden & Suzuki 1984) and when the caries lesion was reinvestigated the nature of the caries had changed to a drier and firmer texture (Metz - Fairhurst *et al* 1986).

After consideration of the available evidence, the American Dental Association Council on Dental Therapeutics stated:

> "Studies indicate that there is an apparent reduction in microorganisms in infected dentin covered with sealant....These studies appear to substantiate that there is no hazard in sealing carious lesions."
> "However, additional long term studies are required before this procedure can be evaluated as an alternative to traditional restorative procedures."

In 1987, a symposium on the topic of "Criteria for Placement and Replacement of Dental Restorations" was held in the United States and resulted in a series of conclusions and recommendations regarding restorative dentistry. The conservation of tooth structure was of prime importance and, therefore, the use of fissure sealant or the sealant restoration technique was advocated in the management of active pit and fissure caries lesions in sites where the presence of a lesion was in doubt or where the activity of the lesion was questionable.

There has been a lack of enthusiasm among dentists for the concept of sealing fissures where there is a suspicion of enamel or dentine caries (Elderton 1985b). The author suggested that dental practitioners would prefer to prepare a cavity and restore the tooth with amalgam. Paterson *et al* (1990) reported that 81% of dentists in Greater Glasgow and Lanarkshire Health Boards were actively using the sealant restoration technique within a short time of its introduction.

The use and effectiveness of pit and fissure sealant on the occlusal surfaces of molar and premolar teeth has been widely investigated. Ten year results have shown retention from 56.7% (Simonsen 1987) to 84.4% (Wendt & Koch 1988). In his 10 year report on the performance of sealants, Simonsen (1987) concluded that they were safe, reliable and more cost effective than traditional methods of treating pit and fissure caries lesions. The surface of a permanent molar was 9 times more likely to become carious if it were not sealed.

3.1.5 Development of etch retained materials.

In an attempt to reduce microleakage around acrylic restorations, Buonocore (1955) etched the enamel surrounding the cavity before inserting the restorative material. The technique was found to increase significantly the adhesion of the material to the enamel surface. This technique was adopted to aid retention of resins to pit and fissure surfaces.

Among the first of the resin materials to be developed for the commercial market were the **polyurethanes**. Retention on the occlusal surface proved to be disappointing because the material underwent a process of degeneration in the oral fluids. In 1974, a report by Rock compared the effectiveness of the application of two polyurethane materials applied to pits and fissures. Acid etching was employed before the application of the resin with one of the materials. A fluoride was incorporated into the resins but this failed have an effect on caries. The material was used for some time, not as a fissure sealant, but as a medium to apply fluoride to enamel surfaces in an attempt to improve caries resistance (Lee *et al* 1972). This technique was later superceded by fluoride varnishes which were easier to apply.

The **cyanoacrylate materials** were tested as pit and fissure sealants and data from short trials showed acceptable results (Cueto & Buonocore 1967 and Ripa & Cole 1970). Re-application of the material every six months was found to be necessary. However, when the material was tested in Britain (Parkhouse & Winter 1971), complete failure of retention was found six months following application. Crabb & Wilson (1971) observed that the *in vitro* bond strength of the material was reduced by a factor of six when it was stored in water for 24 hours. This was assumed to be the most plausible explanation for the poor clinical performance. This material was subsequently withdrawn when it was found to degrade into formaldehyde and methyl cyanoacetate (American Dental Association 1974): the former material is cytotoxic.

Bis phenol A-glycidyl methacrylate or Bis GMA was developed by Bowen in 1962 at the National Bureau of Standards in Washington DC. A pilot study by Roydhouse in 1968 showed this group of sealant materials to have potential for long term intra-oral use. Buonocore (1971) reported on clinical success of the material following a single application of an ultra-violet curing bis GMA resin: 87% retention at 24 months was reported when applied to teeth with well defined pits and fissures.

3.1.6 Polymerisation of fissure sealants.

For polymerisation of bis-GMA resin to occur, the monomer units must chemically react and unite to form a long chain organic structure. To facilitate this reaction a catalyst is required which presents the monomer units in the correct position for bonding onto the growing polymer chain. Two methods have been developed to catalyze polymerisation:

a/ light curing *or*

b/ self curing

Two of the original products were Nuva-Seal and Nuva-Cote both of which employed ultra-violet light with a 365nm. wavelength for activation. Subsequent products used a visible white light filtered to emit only light in the region of 470nm. Sealants using a white light curing technique require only a resin containing a catalyst e.g. camphorquinone which is sensitive to visible blue light for its initiation.

The self curing or autopolymerising resins are presented as two bottles of liquid resin: the base resin also contains the catalyst while the other resin bottle contains *benzoyl peroxide* as an initiator.

Initially, an extra-oral light source was used but poor results were obtained with this type of polymerisation. Rock (1972) compared the results obtained using the same materials and operator but in place of the extra-oral light source, an intra-oral Nuva-Lite was employed. The retention of sealant was significantly improved by this practice. The depth of cure is influenced by the intensity of the light source and the length of exposure time. Leung *et al* (1982) showed increasing the exposure time from that recommended by the manufacturer was required to produce sufficient depth and complete curing in visible light cured composite resins. Over the ensuing 24 hour period there was continued but slow polymerisation (Leung *et al* 1983).

3.1.7 Self curing versus light curing materials.

When autopolymerising resins are used for fissure sealing, a light source is not required. It is important not to exceed the mixing and working times because this may adversely affect the retention of the sealant even though the resin may still appear to be in a fluid state suitable for application.

The use of light cured resins presents the advantage that the operator has control of the setting reaction. Overall, the polymerising time is shorter which is important when treating young children. The principal disadvantages of the light curing systems are the added expense of the curing light, particularly in third world community projects, and the unexpected setting of the resin when exposed to ambient light sources.

Blaubenau *et al* (1983) reported that light cured resins had a higher compressive strength and smoother surface than self cured materials. The most likely explanation for this was considered to be the incorporation of air into the resins during mixing (Council on Dental Materials 1985). Houpt *et al* (1987) found self cured resins to be as retentive as light cured sealants. The results obtained 12 months after placement by Sheykholeslam & Houpt (1978) compared favourably with those obtained using light cured products. Comparable results were reported also by Thylstrup & Poulsen (1978) twenty four months after the application of Concise Enamel Bond (3M Manfg Co Ltd Minnesota).

In 1990, Rock *et al* reported on the results obtained with two light cured and one self cured fissure sealants over a three year period using contralateral control teeth. They found all materials retained better on the teeth on the right side of the dentition. Results for self cured Delton (Johnson & Johnson now de Trey/Dentsply), however, were not significantly different on the left side. The light cured products displayed significantly poorer retention on the left side: a feature that Rock *et al* (1989) attributed to the positioning of the light source. They also postulated that improperly cured material would be more porous and therefore less likely to retain successfully. They considered that the results from a group of left handed operators would be worthy of investigation.

3.1.8 Use of fissure sealants as part of a preventive package.

Fissure sealants should be used as only part of an overall primary preventive dental regime (Horowitz 1982). To obtain maximum benefit, dietary advice on the consumption and frequency of carbohydrate intake along with an explanation on the advantages on the use of fluoride rinses and methods of plaque control should be given.

Ripa *et al* (1987) reported on the advantages of following fissure sealant applications with a topical fluoride. After two years he noted a statistically significant reduction in caries experience in the children who had received this treatment. Only three lesions developed in the 84 children in this group compared to 24 cavities in the control group of 51 children. He concluded that caries could be controlled and almost eliminated.

3.1.9 Development of the sealant restoration technique.

In an attempt to conserve the maximum amount of tooth structure possible, a technique using minimal composite restorations in combination with fissure sealant was described, and the one year results reported, by Simonsen and Stallard in 1977. The technique was later termed the "Preventive Resin Restoration". This involves the preparation of a minimal cavity in a localised, suspect area of the fissure pattern using small round burs. This is restored using a composite or diluted composite resin before the application of a pit and fissure sealant over the restorative material and remaining fissure pattern. The fissure sealant eliminates the need to extend the cavity to prevent the development of new primary caries and has also been reported to minimise the abrasion of the composite restoration surface (Dickinson *et al* 1988). The preventive glass ionomer restoration was described by Garcia-Godoy in 1986 to restore minimal cavities where the lesion was found to extend into dentine but where the margins were not in occlusion.

The term "Sealant Restoration" is now used to describe a range of minimal restorative procedures used to treat incipient or overt fissure caries. Walls *et al* (1988) found the average minimal composite restoration occupied only 5% of the occlusal surface compared to 25% when a minimal amalgam restoration was placed. The advantages of this newer restorative technique lie in the small cavity size which only minimally weakens the tooth and, because the materials used in the technique are tooth coloured, the restoration is aesthetically pleasing to the patient.

Simonsen & Stallard (1977) reported 100% retention of sealant in all pits and fissures 12 months after placing 56 restorations in permanent molar teeth. Restorations were placed in one of three groups according to size and restored using either fissure sealant, diluted Concise and fissure sealant or undiluted Concise and fissure sealant. They compared their results with those reported by Ulvestad (1975) who placed diluted Concise composite resin as a fissure sealant. In the latter trial, 224 sealants were placed and 100% retention of sealant in occlusal fissures was reported after 15 months. Only

91% of buccal fissures in mandibular molars, however, retained the sealant while 94% of palatal fissures were successfully sealed after the same time interval.

Results of sealant restoration performance three years after placement was published by Simonsen in 1980: 97 - 100% "adequate retention" was reported: the author considered adequate retention to mean that no additional sealant material was required to replace missing areas.

3.1.10. Requisites for retention of fissure sealants.

It is generally considered that errors in the following areas of technique will lead to premature failure of the sealant.

A: Surface area.

As the organic resins in fissure sealants do not adhere chemically to tooth structure, the surface area to which the sealants mechanically bond must be increased by etching (Buonocore 1963). The adhesive potential of the increased surface area is achieved by the application of a 30 - 40% buffered phosphoric acid (Gwinnett & Buonocore 1965) in the form of a liquid or gel. The depth of pore formation into enamel would appear to increase as concentration of etchant reduces (Gwinnett & Buonocore 1965) but Chow & Brown (1973) reported the formation of an insoluble reaction product on the surface of the etched enamel when an etchant of less than 30% concentration was used. Colourless liquid etchants are easier to apply and remove but suffer from the disadvantage that they cannot be controlled or seen easily: gel etchants do not suffer from these disadvantages and it has been shown that liquids and gels are equally effective in promoting the retention of sealants (Garcia-Godoy & Gwinnett 1987). In 1955, Buonocore used an 85% phosphoric acid on the enamel around cavity margins in an attempt to improve marginal adaptation of acrylic resin. In 1974, Silverstone showed enamel etching worked in two ways. The first involved the removal of plaque and pellicle and approximately 10 micrometers of enamel surface to produce an uncontaminated surface. In the second, the remaining enamel surface is rendered porous. This allows the resin to penetrate up to a depth of 50 micrometers increasing the surface area for bonding. Pyruvic, lactic and citric acids have been used to etch enamel but found to be less effective (Silverstone 1974 and Galil & Wright 1979).

Silverstone *et al* (1975) described three types of etch pattern in enamel when exposed to phosphoric acid. In type 1, there is a preferential removal of the prism centres leaving the peripheries proud and enclosing 3 micron central hollows. In a type 2 etch pattern, the peripheries are removed leaving central cores of projecting crystals forming each prism. The last type of etch pattern morphology described does not relate the roughened surface to prism pattern. The etch pattern produced by similar etch regimes can be seen on the same enamel surface thereby displaying variations in structure within enamel that can occur on different sites on the same tooth surface. Irrespective of the etch pattern produced, micromechanical retention will occur between sealant resins and the etched tooth surface (Silverstone 1984). Most reports on acid etching have used the smooth tooth surfaces in their protocols. Conlon & Silverstone (1982) performed both *in vivo* and *in vitro* studies and found the results of the *in vitro* work to be comparable with that carried out *in vivo*. They reported more distinct etch patterns on smooth tooth surfaces than those created on the occlusal surface.

Etched enamel has a frosty appearance and if not covered by sealant will remineralise within a few hours (Arana 1974) to a few days (Lee & Swartz 1971) from constituents in the saliva. Enamel, whose covering layer of sealant has been lost, may still be protected by the presence of residual resin tags (Ripa 1973). Soft tissue contact with etchants should be avoided to eliminate the possibility of ulceration and acute mucosal irritation.

Eidelman *et al* (1988) studied the effect of shortening the etch time from the standard one minute to 20 seconds during the placement of 105 fissure sealants. After three years the retention of sealant was comparable (at 91% complete retention) to those studies in which the protocol involved a 60 second etch regime. An *in vitro* investigation on the bond strength achieved to enamel following a 15 second etch was reported by Tandon *et al* (1989). These authors reported similar bond strengths to those achieved when longer etch times were employed.

Williams and von Fraunhofer (1977) reported small time differences in the rinsing time after etching enamel can make a considerable difference to the resulting bond strength. They recommended that the enamel should be rinsed for the same length of time as the duration of the etch regime i.e. 30 seconds.

B: Fissure depth.

Masticatory forces apply a shear loading to the fissure sealant. This is resisted best when the occlusal surface contains deep and irregular fissures (Harris 1991). König (1963) reported the incidence of caries to be greater where the incline planes of the cusp slopes were high. The potential for sealant retention is therefore highest when the morphological features of the tooth make it most susceptible to the development of fissure caries.

C: Surface cleanliness.

There has been debate in the dental literature on the need for a pre-sealant prophylaxis. All appear to agree on the need for removal of heavy stains and deposits. Gwinnett (1984) stated that prophylaxis was an important step which Miura *et al* (1973) confirmed in their study in which they observed that bond strengths were reduced by 33% when this stage of the procedure was omitted.

Omission of the prophylaxis before etching has been shown to result in islands of organic material contaminating the etch surface producing a non uniform effect (Gwinnett 1976).

In a clinical trial where 175 paired fissure sealants were placed in 59 children aged 7 to 16 years old, half were placed using a prophylactic regime while the contra-lateral control group received only a 60 second etch. Donnan & Ball (1988) reported 97.3% complete retention after 12 months where a pumice prophylaxis had been omitted: this result was not significantly different from the group receiving the prophylaxis. Levinkind & Auger (1988) suggested dredging fissures with the dental probe while using liquid etchant if a prophylaxis were not used.

The use of a pumice slurry and brush can result in impaction of particles into the fissures and ultimately into the sealant resin (Taylor & Gwinnett 1973). The use of a flavoured and contrasting coloured paste would be of benefit to both patient and operator. Aboush *et al* (1991) tested the bond strength of Silux Plus (3M) to etched enamel which had been subjected to a prophylactic regime of either pumice slurry, fluoride containing non-oil based paste, non-fluoride containing oil based paste or non fluoride non-oil paste. Shear bond strength results obtained after 24 hours storage at 37^{0}C showed no statistical differences among the prophylaxis regimes.

D: Dryness.

Current fissure sealants consist of bisGMA or urethane dimethacrylate with the addition of lower molecular weight resins to reduce the viscosity. These resin systems are hydrophobic and therefore require a dry tooth surface at the time of placement. The presence of saliva on the tooth forms a glycoprotein barrier on the etched enamel surface (Harris 1991). Should such contamination occur, it is recommended that the enamel be re-etched for a period of 10 seconds. It has also been reported that the dental triple syringe may deliver an air stream which may contain moisture and/or oil (Harris 1991).

Most studies on the performance of fissure sealant retention have relied on experienced operators placing sealants using cotton wool roll isolation along with the use of high volume, low vacuum aspirator. Simonsen (1987) has reported the longest recorded fissure sealant trial which relied solely on cotton wool roll isolation. Harris (1991) reported a personal communication from Metz-Fairhurst in 1984, which showed no difference in sealant retention when rubber dam was used compared to cotton wool roll isolation.

Ferguson & Ripa (1980) and Eidelman *et al* (1983) reported the use of rubber dam did not improve the retention of a chemically curing fissure sealant in the hands of experienced clinicians. The former authors, however, reported improved results when students placed an ultra-violet curing sealant under rubber dam isolation.

3.1.11 Performance of fissure sealant materials.

Four methods of interpreting the results from sealant trials have been described (Rock 1984).

i/ Percentage fully sealed. The results can be reported as the proportion of surfaces which remain fully sealed after a given period.

ii/ Statistical testing of caries reduction. A matched pair analysis of a half mouth study design.

iii/ Percentage effectiveness. The net gain is divided by the number of carious control teeth.

$$= \frac{\text{Pairs with carious control teeth - pairs with carious test teeth.}}{\text{Pairs with carious control teeth.}} \times 100$$

iv/ Net gain. This expresses the number of teeth which have been saved from occlusal caries. It is usually expressed as number of teeth saved per 100 teeth sealed.

Valid statistical measurements can be calculated from well designed studies and yet misleading conclusions can be drawn (Cvar 1973).

Following the introduction of bisGMA as a fissure sealant material, there were a number of trials conducted. Twelve months after application, results for the complete retention of sealant ranged from 85% (McCune *et al* 1973) to 100% (Ibsen 1973). These results showed variation among researchers even when those results are considered only from groups of patients with the same age at the start of treatment and from trials where first permanent molars were sealed. Higson (1976), Leake & Martinello (1976), Leske *et al* (1976) and Harris (1976) conducted clinical trials using Nuva-Seal and obtained results for complete retention ranging from 32% to 81%.

From a vast literature on sealant retention on first permanent molar teeth, the following studies have been tabulated to show resin is gradually lost over a period of time. Horowitz *et al* (1977) reported sealant loss to occur mainly in the first six months but with a continued progressive loss of approximately 10% per annum thereafter.

	Age of child	% Ret 6M	% Ret 12M	% Ret 18M	% Ret 24M	% Ret 30M	% Ret 36M	% Ret 48M	% Ret 60M
Charbeneau & Dennison (1977)	5-8	91	79	74	71		61	52	
Leake & Martinello (1976)	6-8	84	65	54	43		29	20	
Harris *et al* (1976)	6-14	81	72	60	50	48	42		
Raadal (1978b)	5-7	95	90	85	82	75			
Rock *et al* (1978)	6-7	80	75						
Sheykholesam & Houpt (1978)	6-10	97	92		85				
Stephen *et al* (1978)	6-10	97	93						
Horowitz *et al* (1974, 1976, 1977)	5-14				48			13	7
Average Retention		90	82.6	72.7	67	76	56	44	7

3.1.12 Cost effectiveness of preventive fissure sealants.

It is impossible to quantify in purely financial terms the cost of preventing pain and avoiding the need for dental restorative procedures. Houpt & Shey (1980) reported difficulty in assessing if fissure sealants were cost effective. The fissure sealing of all posterior teeth would be a more expensive form of treatment than the restoration of carious lesions using amalgam (Horowitz 1980). The technique used in the application of the sealant is not particularly time consuming and the materials used are not prohibitively expensive but not all teeth which would be sealed would necessarily become carious. Leverett *et al* (1983) calculated that for every five sound teeth sealed, only one pit and fissure lesion was prevented over a 5 year period. Similarly, in 1982 Rock & Anderson estimated one in three teeth was protected from fissure caries attack by the application of sealant.

Epidemiological data allows a forecast to be made of which teeth are likely to develop caries and at what age. In this way, the number of teeth requiring fissure sealant can be reduced, improving the cost effectiveness of the technique. First permanent molar teeth, shortly after eruption, emerge as prime candidates for fissure sealing because 50% have been reported as requiring a restoration after one year (Jackson 1965), 80% by 2 years (Hargreaves and Chester 1973 and Lewis & Hargreaves 1975) and 90% within four years of eruption (Bergman & Anneroth 1972). In more recent years, declining caries prevalence has been reported but occlusal caries still accounts for 84% of all new caries lesions (Ripa *et al* 1988a). Stamm (1984) observed that carious lesions in children under the age of twelve occur virtually exclusively in first permanent molar teeth. Thereafter, lesions in second permanent molars become increasingly frequent.

Dennison & Straffon (1981) reported 29% less time was required for the placement and maintenance of a fissure sealant than a single surface amalgam restoration over a four year period. Greater savings can be encountered if the sealant is applied by a dental therapist or hygienist (Brown & Charbenau 1981).

3.1.13 Comparison of fissure sealant with amalgam.

Fissure sealants may be used to prevent the development of caries lesions in pits and fissures while amalgam is used to restore cavities prepared in the treatment of established fissure caries. Many operators believe amalgam can be placed in less time and is a permanent restoration (Harris 1991). Burt (1984) and Dennison & Straffon (1984) addressed these assumptions and reported that it took approximately 6-9 minutes to place a fissure sealant while an occlusal amalgam restoration took 13 -15 minutes. The life expectancy of an amalgam restoration varies from only a few years to an average of ten years (Allen 1977 and Cecil *et al* 1982). The life span is much shorter in younger children than in adults (Hunter 1982). In one large study, it was reported that 16.2% of the amalgam restorations exhibited marginal leakage of sufficient magnitude to warrant replacement of the restoration (Robinson 1971).

Metz-Fairhurst (1984) reported the average sealant loss per year was 1.3% to 7%. The average life of a sealant, therefore, is comparable with that of an amalgam restoration. Mitchell and Murray (1987) also reported that the survival of sealants was dependant on age: 40% of sealants survived 24 months in a six year old compared to 82% which survived a similar time in 14 - 15 year old children. Fissure sealants should, therefore, not be considered to be a temporary preventive procedure but a *predictable* procedure used in the practice of preventive dentistry.

Further application of fissure sealant material is usually required due to partial loss of material: re-application is a non-invasive procedure unlike that for replacement of amalgam restorations where cavity size is invariably increased (Elderton 1977).

3.2 Sealant Restorations.

3.2.1 Types of sealant restorations.

.The management of fissure lesions presents a difficult challenge as reliable diagnosis of active disease is problematic (Paterson & Watts 1990). Inspection of the cleaned and dried occlusal surface appears to provide the only completely non-invasive method of caries diagnosis (see Chapter 1).

The use of the acid etch technique with composites and fissure sealants has now made it possible to restore discrete carious lesions in fissures and prevent the development of further fissure caries.

In 1977, Simonsen and Stallard faced the challenge of providing a minimal approach to restoring small discrete occlusal lesions. They reasoned that if this should fail, a more radical restoration could be placed without further jeopardising the tooth. The aim was to excise the lesion and prevent further caries in the unrestored fissures and avoid the problems inherent with amalgam restorations i.e. over preparation, marginal leakage, marginal breakdown and secondary caries.

In 1977, Simonsen and Stallard presented one year results of a new technique (subsequently termed Preventive Resin Restorations) and described the selection of materials and techniques employed. Minimal cavity types were restored using either unfilled resin alone or in combination with a filled composite resin. Teeth were graded into three categories according to a system described by Hinding and Buonocore (1974):

A. In this category discrete suspect areas were investigated using a round bur of size less than a Number 1. Fissure sealant was introduced into the minimally prepared area on an explorer before covering the remaining fissures. Sealing over carious areas has been shown to be a safe procedure as the bacterial count reduces markedly and the lesion does not progress (Handelman 1976a and Handelman *et al* 1976b).

B. The suspect area was investigated with a small round bur (up to a size 2) and if caries was found, larger burs were used to remove all stained and softened dentine. After lining, the etched cavity and surrounding fissures were restored using a diluted composite resin.

C. The removal of carious enamel and dentine was performed with minimal extension before lining with a setting calcium hydroxide cement. After bevelling of the enamel margins, the cavity and surrounding fissures were etched for 60 seconds. After placement of an unfilled resin, a composite was injected into the cavity and carried over the pit and fissure surfaces.

Raadal (1978a) reported his findings on microleakage around the margins of small composite restorations used to restore occlusal lesions in posterior teeth. He concluded that there was no microleakage - as seen by dye penetration - if the cavities were etched. The dilution of the filled composite resin did not influence the microleakage.

In 1974, McLean & Wilson described the use of glass ionomer cement to seal fissures and also to restore minimal fissure cavities which had undergone investigation. They reported the technique to be suitable only for fissures with a width of at least 100 micrometers. Garcia-Godoy (1986) reported on a technique for restoration of minimal occlusal cavities using glass ionomer cement. The restoration was left slightly underfilled and both it, and the remaining fissures, were etched prior to the application of a bisGMA resin. In a subsequent report, Garcia-Godoy (1989) found glass ionomer and fissure sealant restorations exhibited less leakage than composite and fissure sealant restorations.

In the United Kingdom, the General Dental Service regulations provided a fee scale for sealant restorations in 1987. This was substantially revised the following year (1988). The original concepts have been revised and a series of sealant restoration techniques developed which are based on newer generation materials. These techniques allow the restoration of enamel lesions and those extending into dentine. The Scottish Home and Health Department produced a distance learning programme which was distributed to all General Dental Practitioners in Scotland (Trends in the Management of Fissure Caries, 1989).

These newer techniques comprise:

- Fissure sealant alone
- Composite resin plus fissure sealant
- Glass ionomer cement plus fissure sealant
- Laminate or sandwich restoration where a base of glass ionomer cement is covered with composite resin and then overlaid with fissure sealant.

3.2.2 Selection of sealant restoration type.

Paterson *et al* (1991) stated that the operator must not only consider a questionable fissure lesion but also the caries state of the entire dentition. An isolated, decalcified fissure lesion in a mouth with fewer than two other carious lesions can be managed without investigation. In such clinical circumstances, the absence of caries in dentine on radiographic assessment would indicate the application of fissure sealant alone in the management of early fissure caries.

Where the caries state is not controlled or clinical and/or radiographic evidence of caries can be demonstrated, suspect lesions should be investigated using a technique known as the "enamel biopsy". A small round bur of 0.8mm diameter may be used to gently stroke the decalcified enamel. The indications for each of the four types of sealant restoration are summarised below:

Type of Sealant Restoration	Indications
Fissure Sealant Alone (Type 1)	Stained and decalcified fissure. No radiographic sign of dentine involvement. Less than two other carious lesions in mouth.
Composite plus Sealant (Type 2)	Stained and decalcified fissure. More than two other carious lesions in mouth. Enamel biopsy shows lesion confined to enamel.
Glass-ionomer cement plus Sealant (Type 3)	Enamel biopsy indicated. Cavity in dentine with minimal lateral spread. Margins not in occlusal contact.
Laminate Restoration (Type 4)	Enamel biopsy indicated. Lesion in dentine with lateral spread along EDJ. Cavity margins in occlusal contact. Fissures emanating from cavity margin.
Amalgam Restoration	Enamel biopsy indicated. Large radiolucency in dentine. Significant lateral spread along EDJ. Few fissures remaining surrounding cavity.

3.2.3 Technique of sealant restoration placement.

Paterson *et al* (1991) described techniques for the use of sealant restorations. Minor differences exist between these and those described by other authors (Simonsen & Stallard 1977 and Garcia Godoy & Malone 1986).

A: Anaesthesia and isolation.

In many instances, the administration of a local analgesic agent is considered unnecessary because the cavity is small and the caries may not extend into dentine. Preparation of superficial dentine with an air turbine handpiece can be painful and the placement and comfort of a rubber-dam clamp may be more acceptable after local analgesia.

Rubber-dam prevents salivary contamination of the teeth. This is considered mandatory by some authors where restorations requiring use of resins and the acid etch technique are employed. Barghi *et al* (1991) reported significantly greater shear bond strengths in an *in vitro* study where composite resin tags to etched enamel when placed under rubber-dam isolation. A control group of teeth from the same patient were also tested where isolation was limited to cotton wool rolls and saliva ejector. The paired teeth involved in this study were all scheduled for extraction due to orthodontic reasons and included only premolar and molar teeth. Unfortunately, the exact age of the patients was not given.

In 1993, Smales reported on the initial quality and subsequent survival of anterior composite restorations and amalgam restorations placed in posterior teeth. One hundred and forty nine conventional and microfilled composite restorations and 644 low and high copper content amalgam restorations were evaluated after a period of ten years clinical performance. No differences were reported in either isolation group for initial quality or survival of the restorations. Unfortunately, no composite restorations were placed in posterior teeth where the effect of superior isolation by rubber dam on the performance of acid etched enamel bond retained restorations could be assessed.

B: Prophylaxis and caries removal.

Miura *et al* (1973) reported maximal bond strengths could only be achieved if a pre-etch prophylaxis were performed; bond strengths were reduced by approximately 33% when prophylaxis was omitted (Gwinnett 1984). Aboush *et al* (1991) found no difference in the shear bond strength of composite to etched enamel of extracted third molar teeth when oil based, non-oil based and fluoride containing prophylactic pastes were used before acid etching for 20 seconds. When prophylaxis was omitted randomly to one of a contralaterally paired group of fissure sealants, Donnan and Ball (1988) observed no difference in sealant retention at six and twelve months post placement.

The prime objective of the sealant restoration technique is to remove only the caries with no extension for prevention or preparation of undercuts in the cavity design to provide retention. If the lesion is seen to "burn out" in enamel, the cavity preparation is terminated at that stage. The margins of the cavity are not bevelled: no significant effects were reported in the performance of posterior composite restorations with and without bevelling of the cavo-surface angle (Eisenberg and Leinfelder 1990).

In certain clinical situations used in the management of an isolated suspicious or decalcified enamel lesion, no cavity preparation is required. In the absence of radiographic or clinical signs of caries in dentine, the application of a fissure sealant has been shown to vastly reduce the number of viable organisms (Handelman *et al* 1973) .

C: Lining.

Preparations which are limited to enamel do not require a lining. Where the cavity preparation is narrow and extends just into the outer layer of dentine, placement of a lining is difficult. Such cavities may be restored using a glass ionomer cement provided that the margins of the cavity are not in functional occlusion and, therefore, not subject to wear (Garcia-Godoy 1986 & Paterson *et al* 1991).

In larger cavity types, the lost dentine should be replaced with a glass ionomer cement. In very deep cavities, a sub-lining of a quick setting calcium hydroxide cement is advocated (Stanley *et al* 1975 & Tobias *et al* 1978). This stimulates reparative dentine formation when the cavity base is close to pulpal tissue. Glass ionomer cements bond to dentine (Mount 1989), provide a surface to which the composite resin may bond micro-mechanically (McLean *et al* 1985 and Causton *et al* 1987) and release fluoride to the walls of the cavity (Swartz *et al* 1984).

D: Etching of enamel.

The occlusal surface, enamel cavity walls and any fissures which extend onto buccal or palatal surfaces are etched using a 37% buffered phosphoric acid liquid or gel. Gel etchants have the advantages of being able to be placed with a degree of accuracy and being coloured can be seen more readily. Reduced etching times of 20 seconds have been studied and the reports would indicate that shorter etch periods are equally effective (Stephen *et al* 1982 & Fuks *et al* 1983).

Originally, etching of the glass ionomer cement surface was advocated (McLean 1988). If this was extended for more than 30 seconds a precipitate was reported to form over the surface of the cement (Smith 1988). This was the time limiting factor (McLean 1988). It has now been shown, however, that even short etch periods of 10 seconds can cause deterioration of the cement by deep penetration of the acid within the set material (Taggart & Pearson 1988) and for this reason, Paterson *et al* (1991) no longer recommend etching these cements.

Following etching of enamel or glass ionomer cements, the surfaces should be washed for 20 seconds to achieve a satisfactory etch pattern which is capable of achieving maximal bond strength with adhesive resins (Williams & von Fraunhofer 1977).

E: Application of adhesive bonding resins.

When a glass ionomer cement lining is present, application of a bonding resin before etching the cavity walls will prevent the inadvertent etching of this cement. Paterson *et al* (1991) recommended that a bonding agent should be applied with a small endodontic paper point to prevent accidental coverage of the enamel surface. Following etching of the enamel surfaces, the bonding resin is applied and cured using a visible blue light source. This has been found to improve the bond strength between glass ionomer cement and composite resin (Subrata and Davidson 1989 and McCabe and Rusby 1994).

F: Cavity restoration.

Cavities which are limited to enamel and those which are larger and have been structurally lined using glass ionomer cement, are then restored using a posterior composite resin (Burke 1988). In the original description of the preventive resin restoration (Simonsen & Stallard 1977) the use of diluted composite intended for anterior use was advocated. This may account for the wide use of anterior and posterior composite resins in the sealant restoration technique as reported in general practice (Paterson *et al* 1990).

The composite resin mechanically bonds to etched enamel to provide an effective marginal seal (Gwinnett & Matsui 1967). To ensure complete polymerisation in deeper cavities, an incremental build-up technique should be used (Wilson 1990). The use of light curing resins ensures command curing and operator control.

G: Fissure sealant application.

The composite resin surface and the remaining etched enamel surface - which includes fissures not included in the original cavity - are covered with fissure sealant and this is cured either chemically or by light initiation. Deficient areas can be re-etched for 10 seconds, washed and dried before a new application of sealant resin (Hormati *et al* 1980). Both glass ionomer/fissure sealant and the laminate restorations have been shown to minimise microleakage (Garcia-Godoy 1989 & Saunders *et al* 1990).

After rubber dam removal, the occlusion should be equilibrated particularly if a filled fissure sealant is employed. Unfilled sealants wear quickly but filled materials are more resistant to abrasion and require the removal of high spots (Raadal 1978b).

3.3 Results from clinical trials.

The first description and report on the performance of sealant restorations in a clinical trial was presented by Simonsen and Stallard in 1977. Subsequent reports by other authors (Raadal 1978a, Azhdari *et al* 1979, Houpt *et al* 1982, Walker *et al* 1990 & Walls *et al* 1988) are comparable in teeth selected and techniques used. Some studies have compared sealant restorations with other types of restoration: Walls *et al* (1988) compared sealant restorations with small amalgam restorations. Similarly, Azhdari *et al* (1979) placed control amalgam restorations and noted that it took 25% longer to place these. Raadal (1978a) compared composite plus sealant with fissure sealant used alone: he reported slightly higher retention of sealant in preventive resin restorations than in the restorations where fissure sealant was used alone. He concluded that placement of a fissure sealant over composite did not effect the longevity of the enamel-sealant bond.

The above studies employed different criteria to measure their success. The presence of the fissure sealant portion, amount of wear and the presence of new primary caries lesions have all been used by different authors. Simonsen & Stallard (1977) reported success at one year with complete retention of sealant in all restored teeth. By 1980, however, success was measured by adequate retention of sealant: Simonsen reported "adequate retention" to mean no further addition of sealant was required. Results reported from the sealant restoration technique were favourable. The commonest cause of failure was loss of fissure sealant. This could be compensated for by further additions of fissure sealant resin: Walls *et al* (1988) successfully recalled 80% of the restorations placed and reported 20 out of the 72 composite plus sealant restorations placed (27.8%) in his clinical trial required further additions of fissure sealant. Five of these 20 restorations (25%) required further additions of material during the follow-up period. Walls *et al* suggested that small composite restorations were no worse than amalgam in the management of occlusal caries in molar teeth of young patients.

Author(s) of study	**Duration of study**	**Reported Success**
Simonsen & Stallard (1977)	1.0 years	100%
Azhdari et al (1979)	1.0 years	86%
Walker et al (1990)	1.25 years	82%
Houpt et al (1982)	1.5 years	91%
Walls et al (1988)	2.0 years	97%
Simonsen & Jensen (1979)	2.5 years	96%
Raadal (1978a)	2.5 years	84%
Simonsen (1980)	3.0 years	99%
Houpt et al (1984)	3.0 years	77%
Houpt et al (1985)	4.0 years	64%
Houpt et al (1988)	6.5 years	65%
Simonsen & Landy (1984b)	7.0 years	90%

3.4 A Field Trial on Therapeutic Fissure Sealants: An Investigation into the Materials and Techniques used during the Placement of Pit and Fissure Sealants and Retention of Fissure Sealant during Initial Two year period.

3.4.1 INTRODUCTION.

From a peak in caries prevalence during the mid 1950's (Sheiham 1984), there has been a fall throughout the U.K. (Todd & Dodd 1985, Todd 1988, Evans & Dowell 1990) and most of the developed countries in the world (Renson *et al* 1985). In Scotland, a higher prevalence of caries has been noted than in other areas of the U.K. mainland (Todd & Dodd 1985, Todd 1988). Pitts & Kidd (1992) examined 5 and 12 year old children in the 15 Health Board areas of Scotland and although reporting generally improved caries status since 1983, there were marked regional variations: children in the West of Scotland have a higher dmft/DMFT than those in the East and over 65% of 12 year olds in Strathclyde and the Western Isles have had some caries experience.

As the caries prevalence falls, the proportion of pit and fissure caries rises with 83% of all new carious lesions occurring on this tooth surface (Ripa *et al* 1988a). McDonald & Sheiham (1992) investigated how the relationship between the prevalence of caries was linked to the affected tooth surfaces. They reported involvement of occlusal surfaces to have a curvilinear relationship with increasing caries prevalence: occlusal DFS initially rising steeply with the overall increasing DMFS. As caries prevalence falls, however, the least susceptible sites on the proximal and smooth surfaces reduces by the greatest proportion, while the most susceptible occlusal sites reduce by the smallest proportion.

The British Dental Association and the Department of Health and Social Security (1986) endorsed the use of fissure sealants as an alternative to amalgam fillings for the treatment of questionable or early lesions in pits and fissures. Where discrete carious lesions exist, the recommend caries removal and placement of fissure sealant in combination with a restorative material. In response to the need for concise indications for the use of sealant restorations, the Scottish Home and Health Department (1989) produced a Distance Learning Package "Trends in the Management of Fissure caries". This was distributed to all Scottish dentists with an FPC list number. The authors indicated that fissure sealant alone could be used to seal stained and decalcified pits and fissures where there were no radiographic signs of dentine caries and where there were fewer than two other suspect carious lesions in the patient's dentition.

3.4.2 AIMS of study.

The West of Scotland has the highest prevalence of caries in the mainland UK (Pitts & Kidd 1992).

This study is a combination of a survey - designed to determine the materials and techniques used in the Community Dental Services during the provision of sealant restorations - and a field trial in that individual restorations are assessed 6, 12 and 24 months after placement.

Participating operators received the distance learning package "Trends in the Management of Fissure Caries" as guidance for their management of fissure lesions and instruction in the techniques of placing sealant restorations.

In this section, of the present thesis the materials and methods used to place therapeutic fissure sealants in the management of incipient fissure lesions will be examined and the results of sealant retention after six months, 1 year and 2 years will be reviewed in association with factors which influence retention.

3.4.3 MATERIALS AND METHOD.

Fourteen Clinical Community Dental Officers from Greater Glasgow and Lanarkshire Health Boards participated in the field trial by placing therapeutic fissure sealants in patients attending the Community Dental Services for treatment. All therapeutic fissure sealants placed over a one year period were recorded on a registration card providing information on patient details, tooth, materials and techniques used for their application (see registration card Plate 3.1).

Registration Card

Operator Number........... **Restoration Number.........**

Patient's Details:

Name:........................ Date of Birth:.................

Post Code:................... Sex: Male/Female

Tooth: F.D.I............... Was tooth functional: yes/no

Was local anaesthetic used: yes/no

Date restoration placed: / /19 Type of restoration: 1 2 3 4

Cavity:	was cavity in enamel only	yes/no	
	size of cavity:	as expected	
		larger	*(please tick)*
		smaller	
	type of bur used	diamond	round
		tungsten carbide	fissure
		other	**size:** ISO........
	isolation	cotton wool rolls	
		c/w rolls + aspirator	
		rubber dam	
		other	
	enamel etching	liquid/gel	etch time ....s.
	lining	was glass ionomer lining used: yes/no	
		was this etched	yes/no
	materials used	glass ionomer cement...........	
		composite resin..................	LC/SC
		fissure sealant...................	LC/SC
	light curing time	..........sec	

Plate 3.1 Initial Registration Card.

The selection criteria for patients were explained to the CDO's at the outset of the field trial and was that described by Paterson *et al* (1991) i.e. stained and decalcified fissure lesions without cavitation or evidence of radiographic dentine caries could be sealed only where there were fewer than two other active carious lesions. Patients were recalled to the Community Dental Clinics after six, twelve and twenty four months at which time the restorations were reviewed independently by the Community Dental Officer who placed the sealant and by the author and another calibrated examiner (GBG and RCP). In the event of a disagreement on the scoring between the two examiners, the patient was re-examined and a final score agreed.

Missing areas of fissure sealant and the caries status of the tooth were noted. Examinations were carried out under good lighting conditions using standard operating lamps and with the aid of a compressed air supply to dry the operating field. Standard right angled probes were used to detect the presence and extent of fissure sealant. No attempt was made to influence the Community Dental Officer as to the need for modification by the addition of further sealant.

The level of patient cooperation was subjectively assessed at review with the C.D.O. into 3 groups:

Good - patient was able to hold mouth open for 2-3 minutes for dental treatment.
- tongue control was easily achieved by using the dental mirror or saliva ejector.
- salivary control was tolerated and easily achieved.

Satisfactory - this category was selected for patients who achieved only 2 of the 3 selection criteria.

Poor - in this category patients achieved either none or only 1 of the selection criteria.

At all review examinations, monitoring cards - which were common to both CDO and examiners - were completed by the calibrated examiners and also by the CDO who placed the restorations (see Monitoring card in Plate 3.2). The data presented are that of the calibrated examiners. Differences in the scoring between the examiners and the CDOs are discussed in Chapter 2.

The data was analyzed on microcomputer using a Database programme (Survey it!, Conway Information Systems Inc. 1991. Version 4.0) and was subjected to statistical analysis using Chi-square test with the level of significance set at 5% using C-Stat (Oxtech Ltd 1991).

MONITORING CARD

6/12/24 Months

Reference number:

Recall date: / /19

Patient's name:.................................

Tooth previously registered: F.D.I............

Restoration:	Is the restoration still present	- yes/no
	Is occlusal wear evident	- yes/no
	Are the margins discoloured	- yes/no
	Is secondary caries evident	- yes/no
Fissure seal:	Is the fissure sealant still present	- yes/no
	Partially present	- yes/no
	Entirely missing	- yes/no
At this visit was the restoration modified		- yes/no
	Replaced	- yes/no
Sensitivity: immediately following placement		-yes/no
still present at time of exam		- yes/no

Plate 3.2 Monitoring card.

3.4.4 RESULTS.

A: Materials and techniques used in the field trial.

The 14 Clinical Community Dental Officers participating the field trial of sealant restorations placed 520 restorations. Ninety six restorations were of the therapeutic fissure sealant variety, i.e. sealant was placed without an investigative cavity being prepared: this constituted 18.4% of all restorations placed.

In Figure 3.1, the distribution of the restorations is graphically shown. Sixty three restorations (65.6%) were placed in the first permanent molar teeth with the second permanent molar teeth being the tooth next most frequently restored. Only five restorations (5.2%) were placed in premolar teeth. The graphic shows a fairly even distribution of therapeutically sealed teeth among the four quadrants with 83.3% of the restorations placed in teeth which were functional: at the time of placement only eleven restorations were recorded as non-functional.

86.6% of therapeutic fissure sealants were placed in the first permanent molar of children between the ages of 6 and 8 years old. The mean age of patients receiving restorations in first permanent molar teeth was 8.62 years (Standard Deviation of 1.69 years) while that of patients with therapeutic fissure sealants placed in second permanent molars was 13.42 years (Standard Deviation of 2.14 years). The mean age of the patients who had restorations placed in premolar teeth was 12.5 years (Standard Deviation of 2.36 years). The data in Tables 3.1 and 3.2 and in Figures 3.2 and 3.3 show the age distribution of patients receiving restorations in first and second permanent molars.

Twelve teeth were investigated by the operators before sealant was applied. Before sealing, no filling materials were used to restore the cavities prepared by the enamel biopsy. The bur used most frequently for the enamel biopsy technique was a round, ISO 008 sized bur (used in 7 teeth). No preference was shown for diamond or tungsten carbide with both materials being used equally. Local anaesthetic was administered for only two restorations which were subject to an enamel biopsy.

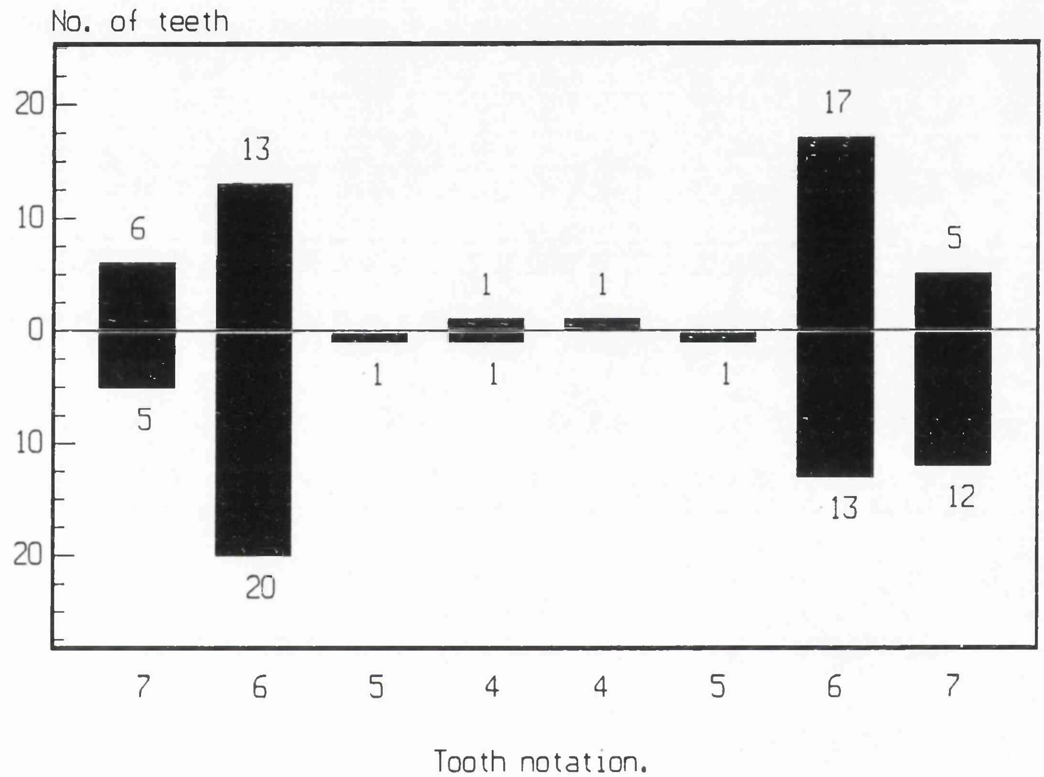


Figure 3.1 **Distribution of teeth with theraeutic fissure sealants (n=96).**

Age of patient	Number of restorations	Percent of total
6.0 - 6.9	9	14.2
7.0 - 7.9	12	19
8.0 - 8.9	24	38
9.0 - 10.9	11	17.3
11.0 - 12.9	5	7.8
13.0 - 14.9	1	1.5

Table 3.1 **Age distribution of patients receiving therapeutic fissure sealants in first permanent molar teeth (n=63).**

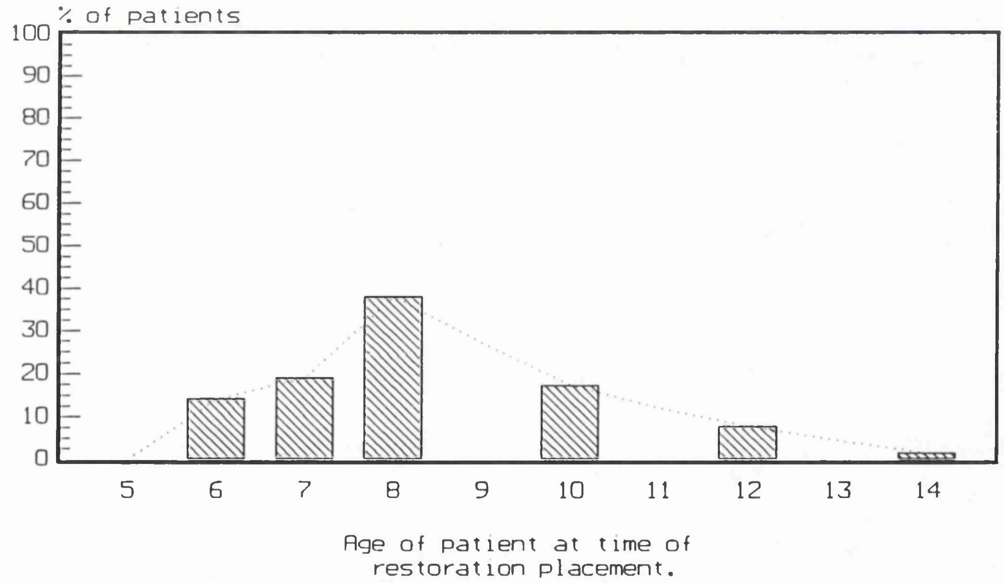


Figure 3.2 **Graphic distribution of therapeutic fissure sealants in first permanent molars by age of patient.**

Age of patient	Number of restorations	Percent of total
8.0 - 9.9	1	3.5
10.0 - 10.9	1	3.5
11.0 - 11.9	9	32.1
12.0 - 13.9	3	10.7
14.0 - 14.9	11	39.2
15.0 - 16.9	2	7.1
17.0 and greater	1	3.5

Table 3.2 **Age distribution of patients receiving therapeutic fissure sealants in second permanent molar teeth (n=28).**

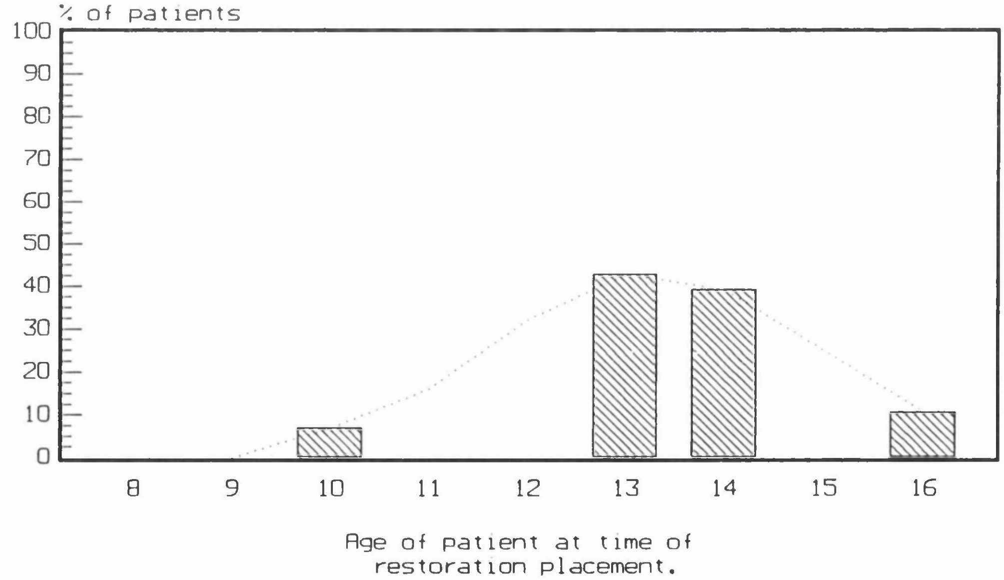


Figure 3.3 **Graphic distribution of therapeutic fissure sealants in second permanent molars by age of patient.**

In Table 3.3 the use of etchant materials is shown. Gel etchant was preferred by most operators, with the liquid variety used during the placement of only 19.7% of sealants. Only one operator diluted the gel with liquid etchant before use. Three teeth (3.1%) were etched for less than 30 seconds while in the majority, the etch time was extended to between 30 and 45 seconds (Table 3.4)

The methods of isolation used during the placement of the sealant restorations are shown in Table 3.5. Sealants were placed with either cotton wool rolls alone or in combination with a saliva ejector or use of an aspirator tip in 92.7% of occasions. Rubber dam was seldom used to achieve isolation: only 7 sealants were placed under rubber dam isolation by one operator.

Among the operators, only two pit and fissure sealants were used: light and self cured Delton (Johnson & Johnson, now De Trey/Dentsply). The light cured material was preferred by most operators, with 75 sealants (78.2%) placed using this version and the remainder placed using the autopolymerising material (21 sealants). Seven of the light cured sealants (10.5%) were polymerised for less than 30 seconds, while 55 (83.3%) were cured for more than 60 seconds (Table 3.6)

B: Performance of sealant after six Months.

After six months, 83 patients were successfully recalled - a review rate of 86.5%. If the number of patients is restricted to those who were also seen at twelve months (71 patients), direct comparison of performance is possible. Table 3.7 shows the sealant retention rate after six months: 56.3% of sealants were completely retained and only one sealant had been completely lost from all pit and fissure surfaces. Table 3.8 shows the treatment that the two reviewing examiners considered necessary after the initial review period. The complete replacement of one sealant - where it had been entirely lost - was suggested, but in 92.7% of the sealed teeth either no treatment was considered necessary or only small additions of further sealant to areas that had been lost. Five teeth were eliminated from the trial after 6 months due the presence of decalcified fissures lesions requiring investigation.

Type of etchant	Number of restorations	Percentage answered
Liquid	19	20.9
Gel	71	78.0
Mixture	1	1.1
No data	5	-

n=96 (n=91 answered)

Table 3.3 The use of etchant materials during the placement of therapeutic fissure sealants.

Etch times	Number of restorations	Percentage answered
0 - 14	0	0
15 -30	3	3.1
31 - 45	79	83.2
46 - 60	13	13.7
no response	1	-

n=96 (n=95 answered)

Table 3.4 The distribution of etch times employed by the operators placing the sealant restorations.

Isolation Method	Number of Restorations	Percentage
Cotton wool rolls	41	42.7
C/W rolls + aspirator	48	50
Rubber dam	7	7.3

n=96

Table 3.5 Isolation methods used by the operators during the placement of therapeutic fissure sealants.

Light Curing times	Number of restorations	Percentage answered
1 - 15	0	0
16 - 20	3	4.5
21 - 30	4	6.0
31 - 40	4	6.0
41 - 50	0	0
51 - 59	0	0
60 and greater	55	83.3
no response	9	-

n=75 (n=66 answered)

Table 3.6 Distribution of light curing times for seventy-five restorations polymerised with visible blue light.

Fissure sealant retention	Number of restorations	Percentage answered
Fully retained	40	56.3
Partly missing	30	42.3
Entirely missing	1	1.4

n=71

Table 3.7 Sealant retention for the 71 therapeutic fissure sealant restorations reviewed after six months.

Treatment required after 6 months	Number of restorations	Percentage answered
No treatment.	50	60.2
"Top-up" sealant.	27	32.5
Replace sealant.	1	1.2
Tooth requires investigation.	5	6.0

n=83

Table 3.8 The treatment the two examiners considered was required after six months. The five teeth requiring investigation were eliminated as restorations were subsequently inserted.

C: Management of fissure caries: results after one year.

After one year 82.3% (79) of the 96 therapeutic fissure sealants placed were reviewed. 60% of these restorations had been placed in female patients. Six months after placement, 56.3% of the fissure sealants were entirely present. After a further six months, 41.7% of therapeutic sealants in the same group of patients were intact. The treatment decisions which the external examiners considered necessary after one year is shown in Table 3.9. Seventy four restorations (93.6%) continued into a second year of clinical performance. The same five restorations that the external examiners considered should be eliminated after 6 months were again considered to require elimination: 3 due to the continued development of pit and fissure lesions and two where approximal caries necessitated the provision of a Class II restoration.

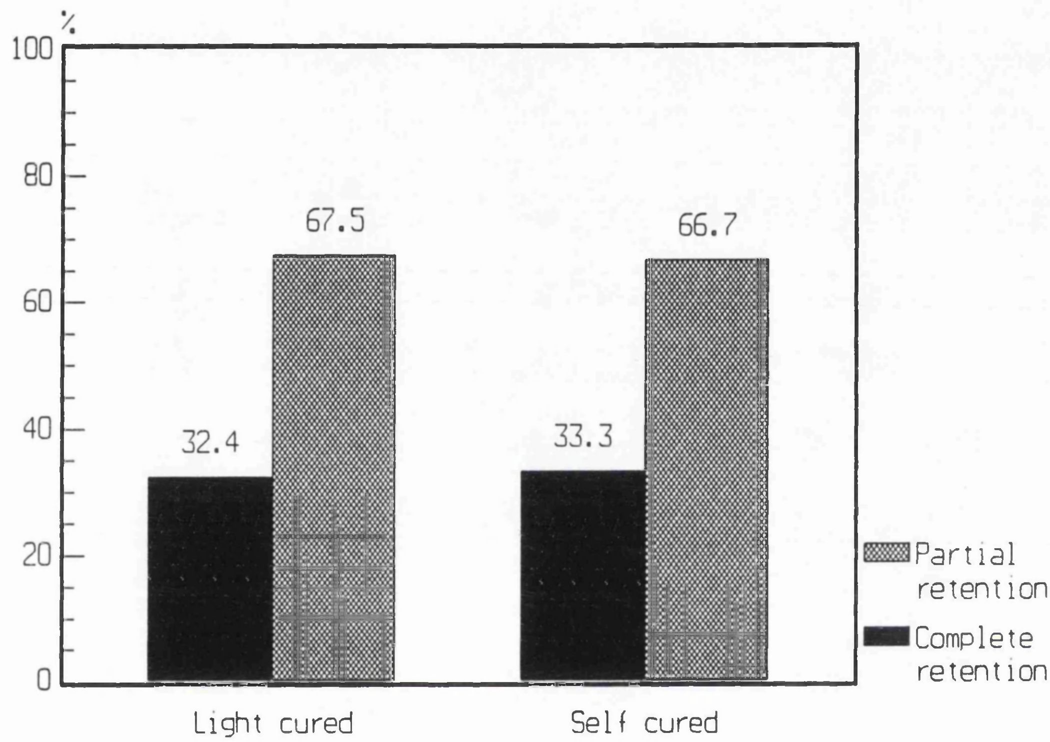
Figure 3.4 shows sealant retention by curing type of fissure sealant resin. No difference in sealant retention was shown statistically between the two materials ($P > 0.05$). In Table 3.10, the positive effect of rubber dam isolation on sealant retention is shown.

In Table 3.11 surface retention in first and second permanent molar teeth is shown. Retention of sealant in the buccal fissure of lower first permanent molar teeth was significantly poorer than that from either the occlusal surfaces or the palatal fissures of the upper first molars ($P < 0.01$). In second permanent molars, retention in the buccal fissure was significantly better than that observed on the same surface of first molar teeth ($P < 0.05$) and was not significantly different from that noted in the palatal fissure of maxillary second molars ($P > 0.05$).

Retention of sealant to the various surfaces of right and left first molar teeth ($n = 54$) can be seen in Figure 3.5 Although sealant retention in the palatal fissure of teeth on the left side appears to be poorer, the difference was not significant ($P > 0.05$). No difference in sealant retention was found between right and left sides for occlusal and buccal fissure surfaces ($P > 0.05$)

	No.	%
No Treatment	45	56.4
Addition of Fissure sealant	29	37.2%
Eliminate - Class II lesion	2	2.6%
Eliminate - Class I lesion cavitated	3	3.9%

Table 3.9 Treatment considered necessary by the reviewing examiners after 1 year.



Statistical comparison:

light cured v self cured $Chi^2 = 0.04$ $DF = 1$ $P > 0.05$

Figure 3.4 **Retention of light and self cured fissure sealants in Type 1 restorations after 1 year (n=79).**

	Compl. Retention		Partial Retention	
Cotton wool rolls (42.7%)	14	40%	21	60%
C.Wool + Aspirator (50%)	13	35.1%	24	64.9%
Rubber Dam (7.3%)	6	85.7%	1	14.3%
TOTALS	33	(41.7%)	46	(58.2%)

Statistical Comparisons

C/W v C/w+A $Chi^2=0.18$ $DF=1$ $P>0.05$

R/dam v others $Chi^2=6.14$ $DF=1$ $P<0.05$ *

Table 3.10 Retention of sealant and isolation technique.

	Occl.	Pal.
Lost	9 (32.1%)	7 (25%)
Retain	17(67.9%)	21 (75%)

n=28

Maxillary first molar

	Occl.	Buc.
Lost	10(38.5%)	21(80.8%)
Retain	16(61.5%)	5(19.2%)

n=26

Mandibular first molar

Statistical differences between upper and lower first molar

Occlusal surfaces $Chi2 = 0.083$ $DF = 1$ $P > 0.05$

Palatal and buccal surfaces $Chi2 = 16.80$ $DF = 1$ $P < 0.01$ *

	Occl.	Pal.
Lost	2 (28.6%)	1 (14.3%)
Retain	5 (71.4%)	6 (85.7%)

n=7

Maxillary second molar

	Occl.	Buc.
Lost	4 (28.6%)	7 (50%)
Retain	10(71.4%)	7 (50%)

n=14

Mandibular second molar

Statistical differences between upper and lower second molar.

Occlusal surfaces $Chi^2=0.26$ $DF=1$ $P>0.05$

palatal and buccal surfaces $Chi^2=2.52$ $DF=1$ $P>0.05$

Statistical differences between first and second molar teeth.

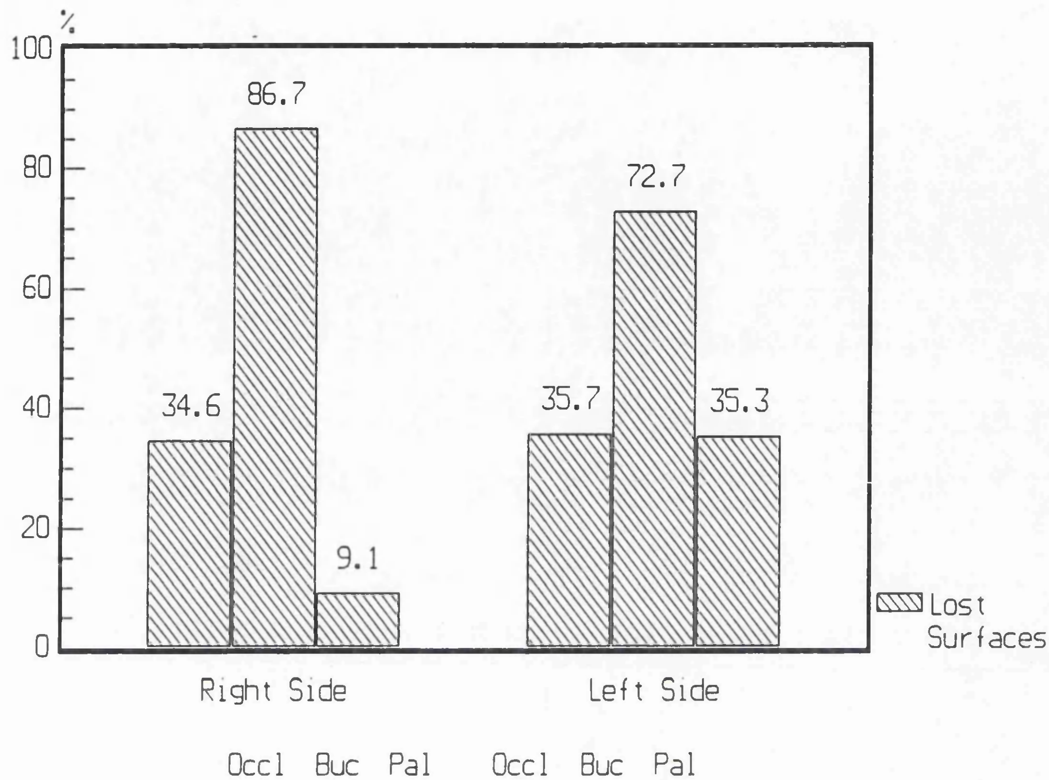
Upper 1st and 2nd molars: *Occl* $Chi^2=0.09$ $DF=1$ $P>0.05$

Pal $Chi^2=0.35$ $DF=1$ $P>0.05$

Lower 1st and 2nd molars: *Occl* $Chi^2=0.39$ $DF=1$ $P>0.05$

Buc $Chi^2=4.1$ $DF=1$ $P<0.05$ *

Table 3.11 Surface retention in first and second molar teeth.



<u>*Statistical comparisons:*</u>

Occlusal	$Chi^2 = 0.007$	$DF = 1$	$P > 0.05$
Buccal	$Chi^2 = 0.790$	$DF = 1$	$P > 0.05$
Palatal	$Chi^2 = 2.450$	$DF = 1$	$P > 0.05$

Figure 3.5 **Areas of lost sealant from right and left sides of the dentition in first permanent molar teeth (n=54).**

In Figure 3.6 sealant retention is considered by level of patient cooperation. Only 10.1% of the patients were assessed by the examiners and the C.D.O.s as cooperating poorly. Significantly fewer sealants were completely retained in the group of patients who were assessed as uncooperative ($P<0.05$).

Thirty four percent of first and second molar teeth had accessory fissures. The effect of accessory fissures on sealant retention can be seen in Figure 3.7: the presence of accessory fissures significantly lowered sealant retention ($P<0.05$).

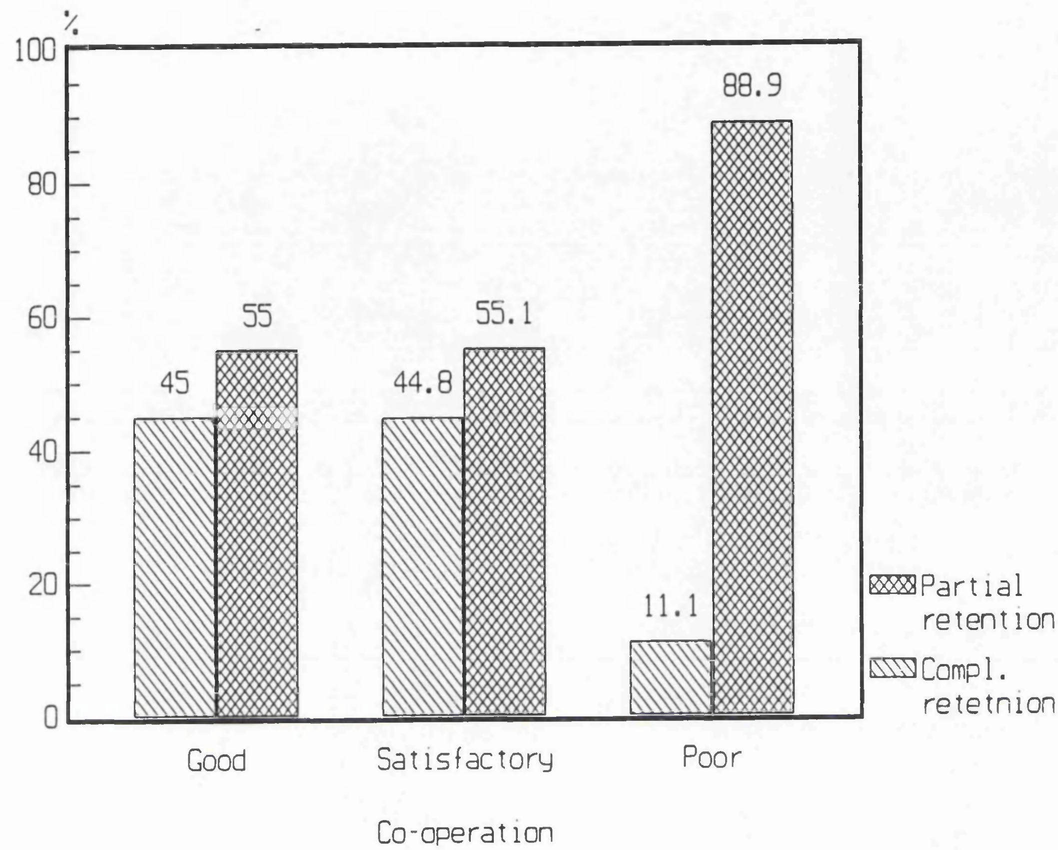
The effect of age on sealant retention was also considered. The results are shown in Table 3.12 which demonstrates that sealant was placed primarily in first molars in the 5 to 10 year old age group. Retention of the sealant in the 8-10 year olds was significantly better than in the younger age group ($P < 0.05$). Children older than 11 years had therapeutic sealants placed predominantly in second molar teeth. No similar improvement in sealant retention could be demonstrated in children over the age of 14 when compared to that observed in the 11 to 13 year old age group ($P > 0.05$).

Seventy seven percent of light cured sealants were polymerised for times greater than 30 seconds. In Figure 3.8 the effect of the increased curing time is demonstrated. No significant differences in sealant retention could be demonstrated ($P > 0.05$).

D: Performance of therapeutic fissure sealants after two years.

Twenty four months after the initial placement of fissure sealant in the posterior teeth of children attending the Community dental Services, 62 of the restorations from the treatment group were still available for inspection. This represented a loss of 35.4% of the therapeutic sealant restorations from review. Of the 64.6% of the restorations successfully recalled, representative proportions were placed in first and second molar teeth.

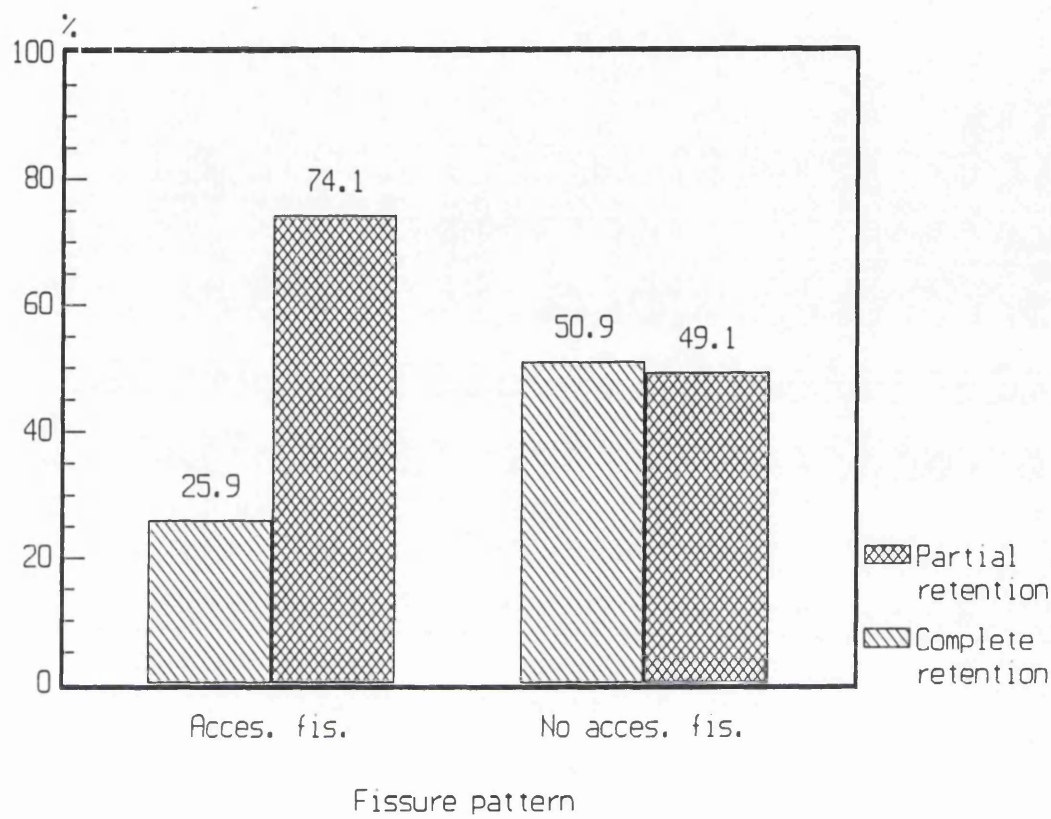
In Table 3.13 the two year findings on fissure sealant retention are demonstrated. Of the 62 teeth reviewed, 33.2% had retained sealant completely while partial loss of sealant was recorded by the two assessors in 66.1% of the treated teeth. These results follow the same trend shown by the composite and glass ionomer sealant restorations (chapters 4 & 5): namely few restorations showed complete loss of sealant (1.7%) while the majority of sealants were partially retained. The presence of a composite or glass ionomer cement restoration would appear to reduce the number of teeth which remain completely sealed.



Statistical comparisons:

Poor v Satisfactory or Good $Chi^2 = 3.85$ $DF = 1$ $P < 0.05$ *

Figure 3.6 **Variation in fissure sealant retention by the level of patient co-operation.**



__Statistical comparisons:__

Accessory fisure pattern v no accessory pattern

$Chi^2 = 4.54 \quad DF = 1 \quad P < 0.05$ *

Figure 3.7 **Variation in fissure sealant retention by the type of fissure pattern.**

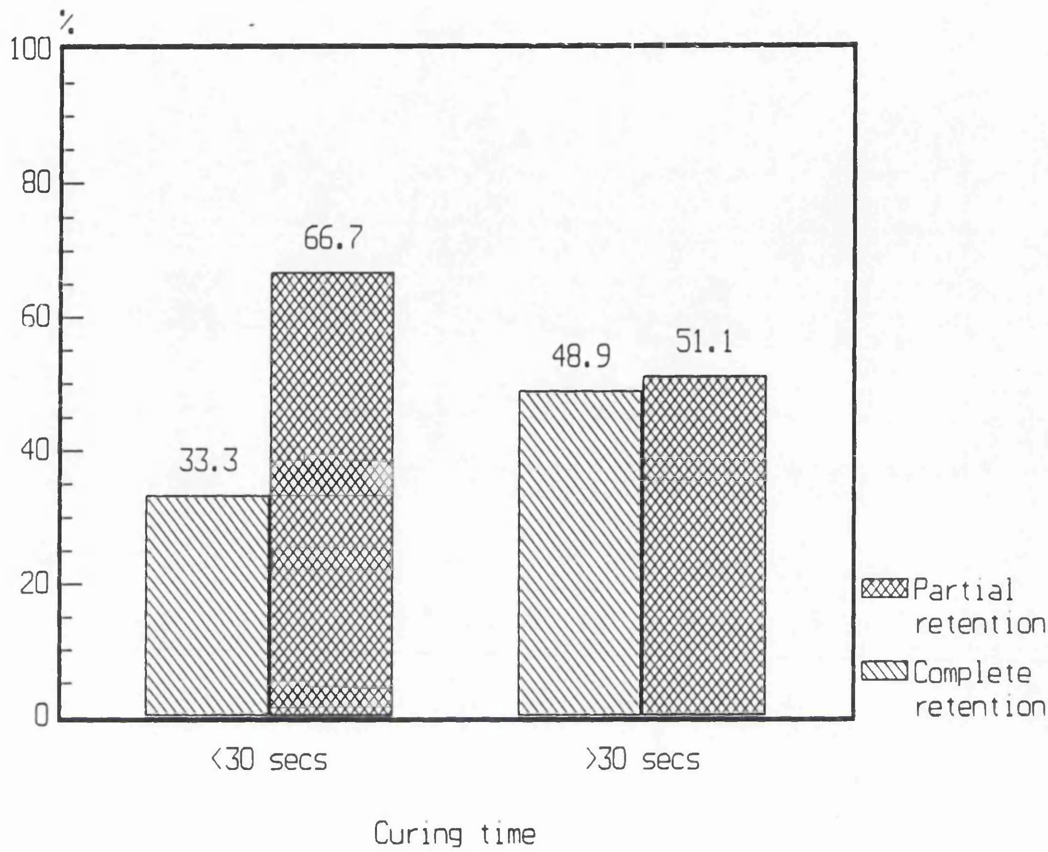
Age	Complete retention	Partial retention
5-7	5 (26.3%)	19 (73.7%)
8-10	18 (52.9%)	16 (47.1%)
11-13	4 (30%)	9 (70%)
14+	6 (50%)	6 (50%)

Statistical comparisons :

5-7 v 8-10 $Chi^2=3.52$ $DF=1$ $P < 0.05$ *

11-13 v 14+ $Chi^2=0.96$ $DF=1$ $P > 0.05$

Table 3.12 **Retention of sealant dependant on age of child at time of placement.**



Statistical comparisons:

< 30 second v > 30 second curing time

$Chi^2 = 0.52 \quad DF = 1 \quad P > 0.05$

Figure 3.8 **The influence of curing time on fissure sealant retention.**

Fissure sealant retention	**24 months sealant retention**	**Restricted 24m data***
Completely retained	20 (32.2%)	20 (33.9%)
Partially missing	41 (66.1%)	38 (64.4%)
Completely missing	1 (1.7%)	1 (1.7%)
TOTALS	62 (100%)	59 (100%)

*Restricted data comprises those sealants that were seen after 12 and after 24 months

Statistical Comparisons:

Differences between the sealant retention in restricted and unrestricted groups:

$Chi^2 = 0.09$ $DF = 2$ $P > 0.05$

Differences between sealant retention in the restricted groups:

24 months v 12 months

$Chi^2 = 0.95$ $DF = 2$ $P > 0.05$

24 months v 6 months

*$Chi^2 = 6.55$ $DF = 2$ $P < 0.05$ **

Table 3.13 Retention of therapeutic fissure sealants after two years.

Although the sealant retention was significantly worse than that observed 6 months after placement ($P < 0.05$), it was not significantly different from that recorded after one year ($P > 0.05$).

Table 3.14 shows the status of the sealant by tooth surfaces. Sealant retention in the buccal fissure of the mandibular molar teeth was significantly poorer than all other fissure surfaces ($P < 0.05$). In Table 3.15, the partial or complete loss of sealant from first permanent molar teeth is shown and can be compared with that after 6 months. Significant differences in sealant retention existed among the tooth surfaces of the first permanent molar teeth ($P < 0.05$) with the sealant retention in the palatal fissure no longer being significantly poorer than that to the pits and fissures of the occlusal surface.

Over the 12 month period since the restorations were last reviewed, no significant differences in the surface retention of the sealant were noted ($P > 0.05$). It could be observed, however, that sealant loss from the palatal fissure followed an almost linear progression, unlike the rate of sealant loss from the other tooth surfaces, where rapid loss was noted after a short period of time before reaching a plateau for the remainder of the observation period.

The graphic in Figure 3.9 shows the percentage loss of sealant dependant on the curing type of fissure sealant used. Twenty seven percent of the therapeutic sealants in the first permanent molar teeth reviewed after 2 years, were of a self cured variety. The greater loss of self cured fissure sealant from the occlusal surface of the first permanent molar teeth fell below the level of significance ($P > 0.05$). No difference in sealant performance between the two materials could be demonstrated ($P > 0.05$).

In Table 3.16 the treatment required after 24 months is shown. Theses results were not dissimilar to those for the composite and glass ionomer sealant restoration types. The most common reason for replacing restorations was the presence of an approximal lesion. Only two lesions proceeded to actual cavitation in pit and fissure surfaces where the sealant had been lost: a new fissure caries increment of 3.2% (2/62 x 100).

A conservative life expectancy for the sealants was estimated by the external assessors and is presented in Figure Table 3.17: almost 47% of the sealants were expected to survive for at least a further 2 years.

	Occlusal	Buccal	Palatal
Retained	37 (59.7%)	7 (21.2%)	15 (55.6%)
Lost	25 (40.3%)	26 (78.8%)	12 (44.4%)
	n = 62	**n = 33**	**n = 27**

Statistical comparisons:

Buc v Pal — *$Chi^2 = 7.542$ DF = 1 $P < 0.01$* **

Buc v Occl — *$Chi^2 = 12.816$ DF = 1 $P < 0.01$* **

Occl v Pal — *$Chi^2 = 0.132$ DF = 1 $P > 0.05$*

Among surfaces — *$Chi^2 = 13.479$ DF = 1 $P < 0.01$* **

Table 3.14 **Areas of completely and partially lost and completely retained fissure sealant.**

	Occlusal	Buccal	Palatal
Retained	31 (68.9%)	5 (20.8%)	12 (57.2%)
Lost	14 (31.1%)	19 (79.2%)	9 (42.8%)
	n = 45	**n = 24**	**n = 21**

<u>Statistical Comparisons:</u>

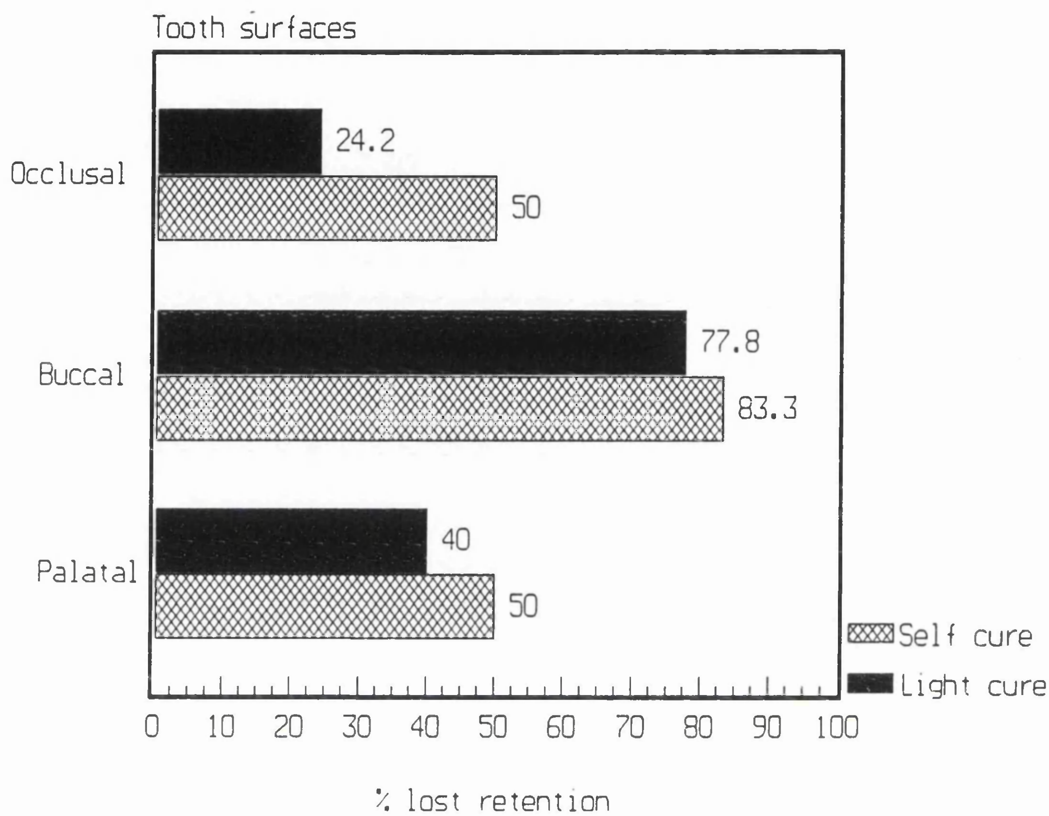
Differences in sealant retention among surfaces:

All surfaces	*$Chi^2 = 14.7$*	*DF = 2*	*$P < 0.01$*	**
Palatal v Buccal fissure	*$Chi^2 = 6.28$*	*DF = 1*	*$P < 0.05$*	*
Palatal v Occlusal Fissure	*$Chi^2 = 0.87$*	*DF = 1*	*$P > 0.05$*	

Sealant retention in the same surface compared after 12 and 24 months

Occlusal	*$Chi^2 = 0.18$*	*DF = 1*	*$P > 0.05$*
Buccal	*$Chi^2 = 0.02$*	*DF = 1*	*$P > 0.05$*
Palatal	*$Chi^2 = 1.74$*	*DF = 1*	*$P > 0.05$*

Table 3.15. **Areas of completely or partially lost fissure sealant in first permanent molar teeth after 24 months.**



Statistical comparisons:

Occlusal	*Chi^2 = 2.72*	*DF = 1*	*P > 0.05*
Buccal	*Chi^2 = 0.08*	*DF = 1*	*P > 0.05*
Palatal	*Chi^2 = 0.17*	*DF = 1*	*P > 0.05*

Figure 3.9 **Areas of complete or partial loss of sealant in therapeutic fisure sealant restorations placed using light and self cured Delton. Results after 24 months.**

No treatment required	29 (46.7%)
Addition of fissure sealant	25 (40.3%)
Restoration required	8 (12.9%)
Class I	2
Class II	6

Table 3.16 Treatment requirements after 24 months.

Life expectancy	
Immediate replacement	8 (12.9%)
1-2 years	25 (40.3%)
More than 2 years	29 (46.8%)

n = 62

Table 3.17 Prediction of the estimated future life of therapeutic fissure sealant restorations after 24 months.

3.4.5 DISCUSSION.

A: Technique variations.

Over a one year period, 520 sealant restorations were placed by the fourteen Clinical Community Dental Officers. Only 18.4% of the restorations placed did not include the preparation of a minimal cavity - an enamel biopsy - and its restoration with adhesive resin materials as described by Paterson *et al* (1991). It was interesting that during the provision of twelve of the therapeutic fissure sealant restorations, the operators employed an enamel biopsy but did not restore the cavity with either composite resin or glass ionomer cement before sealing with a pit and fissure sealant. This may be a reflection of the older techniques of prophylactic odontotomy (Hyatt 1923) (where minimal fissure cavities were prepared and restored) or fissure eradication as described by Bodecker in 1926. In the latter technique, the cusp slopes were flattened to smooth the sharp pits and fissures in the belief that this would make them easier to keep clean. Alternatively, many practitioners may still be apprehensive of leaving tooth structure with suspect fissures before fissure sealing (Elderton 1985). It was not clear which areas of the fissure pattern had been investigated, or indeed if the entire fissure pattern had been minimally prepared. Where investigation had been performed, the operators followed the recommendation of Paterson *et al* (1991) and used small round burs.

B: Distribution of teeth selected for therapeutic fissure sealant.

In 1984, Stamm reported that in the age group of the children in the current field trial, caries lesions occurred virtually exclusively in the first permanent molar tooth: this was also confirmed by Van Palenstein *et al* (1989) who reported that the first molar tooth contributed significantly to the caries experience. This tooth is the first permanent posterior tooth to erupt and is subjected to cariogenic challenges from an early age. As it erupts at the posterior edge of the alveolar ridge where space is limited, cleaning is difficult to achieve and stagnation occurs readily. The well developed pits and fissures form natural harbours for bacteria where they may stagnate within the valleys formed by the fissure walls. They are also free from possible dislodgement by toothbrush bristles. Early fissure sealing as a preventive measure is advantageous and the acknowledged caries inhibition potential has been documented widely by U.S. National Institutes of Health (Consensus Development Conference 1984) and the British Paedodontic Society (1987).

C: Use of preventive fissure sealants in area covered by the field trial.

Stephen *et al* (1989) reported a higher incidence of sealant use in twelve year old children who attended state schools in Lanarkshire, than in the U.K. generally. They found that 14.3% of occlusal surfaces examined had been sealed compared to the national average of 4% reported by Todd & Dodd (1985). In the same cohort of patients, Chestnutt *et al* (1994) reported that there had been an increase in percentage of occlusal surfaces with sealant: this had risen from 14.3% in 1989 to 18% by 1992. These authors also commented that 61.2% of the children examined had some evidence of fissure sealant present, with a mean number of sealants of 4.71 per child. This may reflect a provision to meet the needs of the area with an acknowledged high caries rate. Only 10% of those with sealants had all four first permanent molar teeth sealed (Stephen *et al* 1989) and that 85% of the sealants had been placed by the Community Dental Services in Lanarkshire: some of the staff are those included in the current field trial.

The U.S. National Institutes of Health Consensus Conference (1984) recommended that premolar teeth should only be sealed in priority cases. If the participating operators in the current field trial were following this recommendation, this would reflect the low prevalence of therapeutically fissure sealed premolar teeth within the sample group (5.2%).

D: Fissure caries in teeth selected for therapeutic fissure sealing.

Sixty-eight percent of patients receiving therapeutic fissure sealants in first permanent molar teeth were between the ages 6.93 and 10.31 years (mean age 8.62, Standard Deviation 1.69 years). This would indicate that 14.2% of suspect fissure caries lesions developed within a year of eruption and 71.2% by the age of ten years. Although the results are not conclusive, the argument that fluoride may delay the onset of caries may be being substantiated in this situation. A similar situation was presented for second permanent molar teeth. In 1956, Miller and Hobson observed that 50% of 'sticky' fissures had developed within a year of eruption. Over the next 41 months, up to 70% became clinically carious.

E: Selection and use of etchant materials.

Among the operators there was a preference for gel etchant: the ease of control, application and ability to easily see the material was evidently superior. Only one operator placed a single fissure sealant using gel diluted with liquid etchant, despite reports in the literature that both etchant types penetrate fissures equally well (Brown *et al* 1988). These authors concluded that there was no need to dilute gel etchant to lower its viscosity, in the belief it would penetrate the depth of fissures more efficiently. In the current study, 80% of the restorations were placed using gel etchant material. In a recent postal survey of General Dental Practitioners, gel etchants proved to be most popular material, with over 58% exclusively using this material (Paterson *et al* 1990). The majority of enamel surfaces were etched for between 30 and 45 seconds although reports have already appeared in the literature showing similar retention of fissure sealants in clinical trials using reduced etching times of 20 seconds (Eidelman *et al* 1988).

Van Dorp and ten Cate (1987) measured the mineral loss on etching from both sound enamel surfaces and those containing enamel caries. After a 60 second etch, less mineral was lost from the surfaces containing enamel caries lesions, although a scanning electron micrograph showed a surface topography suitable for resin tag formation and support of a successful bond. The authors attributed the lower mineral loss to the incorporation of fluoride in the crystals of hydroxyapatite in the lesion. Van Dorp (1982) showed that once a lesion is sealed, the underlying enamel is isolated from calcium and fluoride ions and all nutritional substrate molecules. There does not appear to be any difference in microleakage between etched carious enamel and etched sound enamel when tested by dye penetration methods.

F: Factors influencing the choice of materials and techniques.

There is a reluctance by operators to use rubber dam for isolation of teeth in children, with only 3% of therapeutic fissure sealants in the current study having been placed using this excellent means of isolation. Inexperience in the application of rubber dam is the most likely explanation for its limited use. Most operators clearly believed they could achieve and maintain a dry working field using aspirator tips and cotton wool rolls. Forty-two percent of sealants were placed using cotton wool rolls alone as the sole means of isolation. This may indicate low levels of patient cooperation during operative procedures but may also be an indicator for the future successful retention rates of fissure sealant. Etched enamel surfaces are vulnerable to moisture contamination and in the presence of salivary contamination, early or partial failure can be expected.

The principal factor influencing the choice of fissure sealant materials within the Community Dental Services in the two Health Boards is the single ordering system which is in operation. Under General Dental Service regulations, the use of opaque fissure sealants is required when placed as part of sealant restorations. No similar guidelines have been issued to Community Dental Service staff. In 1988, Simonsen discussed the use of opaque sealants and favoured them because of the ease of checking retention at periodic recall examinations. Use of filled sealants make both placement and control easier with the patient in the supine position. Filled sealants have also been shown *in vitro* to exhibit superior wear and abrasion resistance while still retaining similar retention to etched enamel surfaces (Strang *et al* 1989).

G: Sealant retention and retreatment.

There have been few, if any, reports where the performance of sealants applied to decalcified and stained fissures in field trials have been reported. The practice of applying fissure sealant to decalcified and stained fissures is widely advocated. However, as Elderton (1985) has noted in these circumstances, the sealant must be applied "exquisitely well". It seemed pertinent, therefore, to obtain data on this important area of practice.

Eighty-six percent of patients were successfully recalled after six months but to allow direct comparison of sealant retention after six and twelve months the number of patients included in the table of sealant retention has been restricted to those attending both recall examinations. The fissure sealant which was entirely lost at the initial review, most probably reflects poor attention to details of isolation and etching procedures. Intact fissure sealant was present in 56.3% of the restorations where all occlusal and buccal/palatal fissures were sealed: this would indicate, however, that partial loss of sealant was relatively common. Loss of sealant from fissure areas resulted in five caries lesions progressing to cavitation and requiring further investigation. Where sealant has been lost and the fissure caries noted to progress to cavitation within six months, indicates that some lesions selected for treatment or management with therapeutic fissure sealants were larger and more advanced than those recommended for the therapeutic fissure sealant technique by Paterson *et al* (1991). These authors recommended that fissure sealant was used in early fissure caries lesions. These data represent poorer retention of sealant than occurs in most clinical trials where the sealant application is of a preventive type (Richardson *et al* 1978, Stephen *et al* 1978, Stephen *et al* 1981 and Stephen *et al* 1982). The treatment that the two examiners considered was necessary after six months, indicate that 92.7% of sealed teeth required either no treatment or the addition of small amounts of further sealant. The latter treatment is not time consuming and indicates the low maintenance requirement of this form of treatment over that for the placement of occlusal amalgam restorations.

H: Factors influencing sealant retention.

In considering the factors within the control of the operator which might be expected to influence the retention of fissure sealants, the most obvious is the method of isolation. The data obtained in the present study does suggest that rubber dam improves retention of sealants. This was applied, however, on a limited number of occasions and not used by all the operators in the group. It could be argued that its use might be limited to meticulous operators working with cooperative patients where better results would be expected. Straffon *et al* (1985) compared the effectiveness of rubber dam with cotton wool and saliva ejector isolation on the performance of 50 paired fissure sealants, over a three year period, and observed that rubber dam did not improve the retention of the sealant. The findings were confirmed by Smales (1993) who also reported that rubber dam did not improve the initial quality, or the subsequent performance, of amalgam or composite restorations.

The data supports the observation of Rock *et al* (1990) who reported that the choice of either liquid or gel etchant does not influence the retention of the sealant. It is also perhaps surprising that the majority of operators were still using etch times of 45-60 seconds, despite several reports which have shown that etch times of longer than 30 seconds are unnecessary (Eidelman *et al* 1988 & Tandon *et al* 1989).

The selection of materials within the Community Dental Service in Scotland is not within the control of the operator. Some clinics do not have continuous access to a curing light and are thus compelled to use self cured fissure sealants. This does not appear to have influenced the retention of sealant over the initial observation period of one year.

Our measure of patient cooperation is a crude one. Nevertheless, in assessing the effectiveness of placing sealant over early caries lesions, we considered it important to try and introduce some measure of patient cooperation. In patients identified as uncooperative by our method, complete retention of fissure sealant was reduced significantly.

Mitchell and Murray (1987) reported that only 40% of fissure sealants placed in 6 year olds survived 2 years, compared to 82% which survived a similar period when placed in 14-15 year old children. They believed, along with Ripa (1988a), that patient cooperation improved with age.

The effect of accessory fissures is perhaps surprising. It might be expected that the more irregular the enamel surface, the better the retention would be. The reverse appears to be the case. It may be that the surface irregularity makes the achievement of a good seal at the margin of the fissure sealant more difficult or the reduction in area of cusp slopes, reduces the potential bonding area.

I: The Early Fissure Caries Lesion.

In the laboratory, exposing human enamel to a gel containing lactic acid produces artificial caries lesions. The longer the enamel is exposed, the greater the size of the resultant lesion. Where early lesions are exposed to fluoride and then re-exposed to the acid medium, the caries lesion was noted to virtually arrest. This was found not to occur when the fluoride was only available at a later stage of lesion progression (Kidd and Joyston Bechal 1982). Koulorides *et al* (1980) explained this phenomenon as cariogenic priming: *in vivo* testing of enamel slabs carried in partial dentures in volunteer patients, showed remineralised early lesions were more resistant to acid attack than sound enamel. It is impossible to accurately monitor the progress of early fissure caries, however, as the caries alternates between demineralisation and remineralisation (Silverstone 1977) and the early lesion occurs bilaterally on the side walls of the fissure (Mortimer 1964) where it cannot be visually inspected. Currently, any form of non intervention in active fissure caries is not practical, as monitoring of such lesions is difficult. The electrical resistance between tooth structure and the oral mucosa may allow lesion monitoring and intervention could then be delayed until dentine is involved (Sawada *et al* 1986).

An essential stage in the development of a new material or technique is to evaluate it against an established material or alternative management option. This study was established to

assess the longevity and effectiveness of fissure sealants placed as a therapeutic measure by comparing the results with the established technique of preventive fissure sealants. Rock and Bradnock (1981) highlighted the sensitivity of fissure sealants to technique variation. This was difficult to overcome in the current field trial where multiple operators were used to place therapeutic fissure sealants under the pressures of everyday dental practice. When Rock and Evans (1983) tested a new light cured resin as a fissure sealant and compared the results with that obtained from a self cured pit and fissure sealant, they reported no difference in the retention after 6 and 12 months, but by three years the newer light cured material had significantly poorer retention.

Chestnutt *et al* (1994) advocated that all deficient areas of fissure sealant should be replaced if fissure sealants are to be entirely effective. This conclusion was deduced from an epidemiology based study where the caries increment was measured over a four year period in which teeth, which were sound but not fissure sealed, developed a significantly greater number of fissure caries lesions than a group of teeth in which fissure sealant was intact at the baseline evaluation. In the current trial, results after 2 years may reflect the performance of the materials but it is conceivable that caries may not have fully manifested in the areas of lost sealant. It was for this reason, that further additions of sealant were recommended where exposed fissures were decalcified or there were two or more other active lesions in the dentition. As the sealants were subject to regular review examinations, no influence was brought to bear on the Community Dental Officers on the decision to replace missing areas of sealant.

Total or partial loss of sealant from the tooth surfaces was examined and the results indicated that over a two year period no difference was observed in the performance of light and self cured fissure sealants. It may be argued that better retention could have been expected in buccal fissures, where light cured materials were used, because shorter periods of isolation would be required before the command cure of the sealant. This proved not to be the case and may reflect the overall similar time of polymerisation of these materials. It would appear that the properties of the two resins were similar over the two year evaluation period. The graphic in Figure 3.9 shows the slightly better retention of light cured fissure sealant on all surfaces was not significant.

Unlike other studies, where the retention of sealant in the mesial and distal pits of maxillary molar teeth was considered separately (Cons *et al* 1976), the presence of sealant was considered together for all pit and fissures on the occlusal surface. It was interesting that the early loss of sealant was observed in the buccal and occlusal fissures but with the palatal fissure the loss was almost linear over the two year follow up. This surface is the easiest in which to maintain isolation, as it is situated furthest away from the opening of the parotid duct and can readily be protected from salivary contamination. Surfaces which continue to retain sealant for long periods, probably have the sealant placed under ideal conditions and are most suited to resist the shearing forces of mastication (Harris 1976). The rate of sealant loss was greatest during the first six months than between other subsequent review examinations.

In a fluoridated area, Bagramian *et al* (1979) noted that 12.2% of fissure sealed first permanent molar teeth became carious over a three year period. In the current study, which was performed in a non fluoridated area, 10 previously sealed surfaces proceeded to cavitation over the entire two year follow up period of the field trial: this represents 10.4% of the teeth, which had established or suspected carious fissure lesions, progressed to cavitation over this observation period. This demonstrates the effectiveness of pit and fissure sealants in areas with high caries prevalence. At the two year review, 75% of teeth with caries lesions had approximal cavities. This highlights the need for careful radiographic assessment of teeth before placing fissure sealant on stained and decalcified fissures.

3.5 Conclusions.

1. Therapeutic fissure sealants were placed predominantly in permanent molar teeth within a few years of eruption.

2. The majority of operators etched for periods of greater than 30 seconds and preferred gel etchants.

3. Isolation during the placement of the sealants was achieved by cotton wool rolls either alone or in combination with an aspirator. Rubber dam was seldom used.

4. Most operators use light curing periods of in excess of 60 seconds.

5. The greatest loss of fissure sealant occurred during the first 6 months. After this interval the rate of loss of sealant is significantly reduced.

6. This non invasive method of management of fissure caries required regular review and maintenance.

7. The commonest cause of total failure was the development of approximal caries.

8. Improved sealant retention was noted in older patients

9. Loss of fissure sealant from the buccal fissures of mandibular first molars was significantly greater than from other tooth surfaces or from the buccal fissure o f second mandibular molars.

10. No difference could be demonstrated between the retention rates of self cured and light cured fissure sealants.

Chapter 4

A Field Trial of Composite and Fissure Sealant and Glass Ionomer Cement, Composite Resin and Fissure Sealant Restorations ("Laminate" or "Sandwich" Restorations) in the Community Dental Service.

4.1 Development of composite resins.

In the 1870's, silicate cement was introduced to the dental profession as an aesthetic restorative material for use in anterior teeth. Aesthetics of this material were good and the thermal expansion co-efficient was similar to that of tooth structure. Despite these advantageous properties, silicate cement was susceptible to cracking if allowed to desiccate in mouth breathers and it could deteriorate in oral conditions where a low pH prevailed. The incorporation of fluoride, as a flux, during the manufacture of the alumino-silicate glass produced a low incidence of secondary caries around the margin of these restorations.

Acrylic resin was introduced as an alternative, tooth coloured, restorative material during the 1950's. This material was presented as a powder/liquid: the powder consisted of polymethylmethacrylate, an initiator (0.3 to 0.5% benzoyl peroxide) and pigments to provide variation in shade; the liquid comprised a monomer - methylmethacrylate - and frequently a cross linking agent, ethylene dimethacrylate. Microleakage led to marginal stain, secondary caries and pulpal irritation. These materials were flexible and had a high polymerisation shrinkage, but a low resistance to wear.

In 1962, Bowen developed the first bis-GMA resin composite system at the United States National Bureau of Standards. By definition, a composite material refers to the three-dimensional combination of at least two chemically different materials with a distinct interface separating them (Lutz 1983). This provides the material with superior properties to either of the constituent materials alone. Commercial dental composites consist of a mixture of resins in a matrix and a filler or blend of fillers (Asmussen 1975b).

Over the past 30 years, filled composite resins have evolved in an attempt to improve mechanical properties (lower thermal expansion coefficient, lower polymerisation shrinkage, lower water absorption, increase adhesion between filler and resin matrix and increase abrasion resistance) and, therefore, result in superior clinical performance. Early materials suffered surface wear in clinical use (Eames *et al* 1974). Current materials are much improved but still not ideal. Improvements to composite resins have included the use of different glass and ceramic fillers, use of single paste photocuring systems using visible blue light and improved particle size distribution and filler shape. Further enhancement of these materials came with the introduction of the acid etch technique described by Buonocore (1955) as a means of increasing the area for micromechanical retention (Buonocore 1963).

4.2.1. Organic Matrix.

A: Matrix components.

The components involved in the matrix of a typical dental composite have been described by Bowen (1979). One of the principle components of all composite resins is the high molecular weight monomer bis-GMA produced by the reaction of bis-phenol A and glycidyl methacrylate.

The structural formula for bis-GMA is:
2,2-bis-[-4(2-hydroxy-3 methacryloyloxy-propyloxy)-phenyl-]-propane.
Some of the earlier materials also contained the lower weight monomer bis-MA to impart scratch resistance: the chemical formula for this material is:
2,2-bis(4-metacryloyloxy-phenyl)propane.

Since the introduction of the bis-GMA monomers, several commercial composites have been marketed which use urethane diacrylate in combination with bis-GMA (Craig 1981).

Other monomers have been evaluated as experimental materials. These monomers have all been modifications to the chemical structure of bis-GMA in an attempt to lower the viscosity of the resin or to make it more hydrophobic (Craig 1981).

B: Viscosity controllers.

Bis-GMA is a high molecular weight, viscous liquid. To improve its mixing and clinical handling properties, it is mixed with lower molecular weight monomers such as methyl methacrylate, ethylene glycol methacrylate and triethylene glycol methacrylate. The latter diluent is most commonly used.

C: Inhibitors.

To prevent premature polymerisation and therefore extend shelf life, an inhibitor is included in composite resins. 4-methoxyphenol and 2,4,6-tritertiarybutyl phenol can inhibit the polymerisation of the diacrylates. These materials are also responsible for the working time after mixing and before polymerisation.

D: Thermochemical Initiators.

In the original two paste composite systems, benzoyl peroxide was used as the initiator. This chemical is unstable and when subjected to heat, light or certain chemical groups, it can initiate the polymerisation of the composite resin. The free radicals produced from this chemical become incorporated into the polymer matrix and, therefore, should not be termed a catalyst.

E: Accelerators.

Tertiary aromatic amines can be used to interact with the initiator benzoyl peroxide and produce the free radicals required for chemically polymerising composites. Di-hydroxyethyl and di-methyl versions of para-toluidine may be used, although if the former is used, the colour stability of the resin is improved. Koblitz *et al* (1977) showed the colour stability of acrylic resins was influenced more by the level of benzoyl peroxide than tertiary amine. For this reason, the lowest concentration of accelerators and initiators should be used, commensurate with adequate physical and mechanical properties.

The tertiary amine accelerator in a two paste, chemically curing, system should be kept separate from the initiator by incorporating each in a different paste.

F: Photochemical Initiators.

Newer single paste composite resins can be initiated by light activation either from ultraviolet radiation at 365 nm. or by visible blue light of 470 nm.

Benzoin alkyl ether generates free radicals under the influence of ultraviolet light and can initiate the polymerisation reaction. In the currently used visible light curing systems, a diketone - camphorquinone - may be used which results in the production of free ion radicals.

G: Methods of Polymerisation.

The initiator contained within all resin systems either prevents premature polymerisation (in the case of chemically cured resins) or provides the composite with a prolonged shelf life (in the case of photocuring materials).

When the two pastes of a chemically cured material are mixed, the tertiary amine accelerator immediately begins to activate the benzoyl peroxide and produce free radicals. Polymerisation of the composite is initially prevented by a preferential reaction of the free radicals with the inhibitor. Once this is exhausted, polymerisation of the dimethacrylate resin monomers takes place, resulting in chains of resin and coated filler particles. This reaction continues during the setting time resulting in highly cross-linked filler and resin molecules. After initiation, the polymerisation process continues for many hours, but does not continue to completion with many methacrylate groups remaining unreacted (Asmussen 1982 and Rutyer & Svendson 1978). The chemically cured materials are easy to use and require no additional equipment (Sherer 1989), but air entrapment during mixing makes these materials more porous (Jones 1990).

Single paste materials are polymerised using light activation. These materials have unlimited working time, fast curing time, longer shelf life and less potential finishing (Raptis *et al* 1979). When ultraviolet light is used as an activator, the initiator benzoin methyl ether is added to the single paste restorative material. UV light has a wavelength of 365nm. and provides energy to the initiator until it is excited to the point where it generates free radicals for the polymerisation process.
In the third method of polymerisation, visible white light is used as an activator. The initiator - hydroquinone - absorbs energy from the blue range of white light (420 - 490nm.) until it is sufficiently excited to produce free radicals. Visible light curing systems have advantages over UV light polymerising methods, such as greater depth of cure (4mm. versus 2mm.), no warm up time for the bulb, constant energy out-put from the bulb and less potential for damage to the retina of the eye (Sȧlako & Cruikshanks - Boyd 1979).

In chemically activated materials, polymerisation occurs uniformly throughout the material and is unaffected by the bulk or thickness of composite. Light activated resin systems, however, polymerise only to a certain depth of cure dependant on the depth of light penetration, composition of the restorative material, light source and its intensity and exposure time (Salako *et al* 1979, Cook 1980 and Rutyer & Oysaed 1982).

Rutyer (1985) reported that the percentage of double bonds which may react could vary from as little as 35% up to 80%. Unreacted double bonds on pendant methacrylate chains make the set composite material susceptible to degradation in the oral environment (Jones 1990). The use of higher percentages of ultra fine filler (colloidal silica) makes the composite material more opaque, reducing the penetration of visible blue light and increasing the percentage of unreacted double bonds.

4.2.2 Filler Systems.

A: Classification of composite resins.

Composite restorative materials consist principally of reinforcing filler particles, both by weight and volume (Dogon 1990). Modern materials contain fillers of quartz, colloidal silica, lithium aluminium silicate, silica glasses containing barium, strontium and zinc (Craig 1981). More recently, fillers containing porous zirconia silica have been produced.

In 1983, Lutz and Phillips classified composite resin systems based upon particle filler size. This was subsequently modified by Watts & Paterson (1990a).

	Filler	% filled by weight	Properties
Large particle (Macrofill)	•Quartz *10-100μm*	75-80	•Fracture resistant •Non polishable •Surface plucking •Dull surface •Discolouration e.g. Adaptic Concise
Small particle	•Barium glass •Str. glass •Al silicate •Quartz •Ba Al borosilicate •Li Al silicate *Up to 8μm*	75-86	•Fracture resistant •Semi-gloss polish •Improved aesthetics over macrofilled e.g. Estilux Profile
Microfilled	•Colloidal silica *0.04μm*	36-79*	•Homogeneous •Very polishable •Non-load bearing •Shade selection difficult e.g. Heliomolar Silux
Hybrid: Type a (Blends)	•Barium glass •Ba Al silicate •Colloidal silica •Ground quartz •Sr Al borosilicate *0.04-3μm*	76-85	•Very strong •Polishable •Good aesthetics •Low thermal expansion e.g. Herculite XR Visiomolar
Hybrid: Type b (Resin bonded ceramics)	•Zinc glass •Barium glass •Quartz •Strontium glass •Silica, Zirconia •Ba Al borosilicate *0.04-50μm*** *ave. 3μm*	Up to 87.5	•Very strong •Limited shade range e.g. P30 P50 Occlusin

*** Includes organic filler   ** Most in range 1-10μm***

B: Large particle size composite.

It is the fillers which impart significant physical properties to the composite resin. Glass fillers contribute radiopacity to the restorative material, allowing the detection of secondary caries and overhanging edges at the margin of restorations. As glass particles are softer than quartz, the composite restoration is easier to polish. In a review of resin based restorative materials, Cook *et al* (1984) reported that all composite resins prior to 1977 contained inorganic filler particles of between 1μm and 100μm in diameter. Due to the size of these particles, they suffered from particle sedimentation, poor finishing and low resistance to wear.

C: Small particle size composite.

Efforts were concentrated on reducing the particle size and its distribution within the resin matrix. The introduction of newer synthetic fillers that could be manufactured with a particle size of 0.1 - 5 micrometers produced a smaller particle size composite with superior physical and mechanical properties (Dogon 1990). This was only possible due to the higher inorganic loading and also made it possible to achieve a superior surface finish than was possible with the large particle materials. The distribution of the particles within the resin was optimised to allow a thinner inter-particle layer (Okazaki & Douglas 1984 and Cross *et al* 1985), resulting in greater wear resistance.

D: Microfilled composite.

Use of colloidal silica, with a mean particle size of 0.04 micrometers, has been reported to result in marked improvement in polishability, surface texture and an even distribution of filler particles (Jorgensen & Asmussen 1978). The small size of the colloidal filler imparts the particles with a large surface area, resulting in a significant increase in the viscosity of the composite resin (Brunner & Schutte 1973). This limits the filler loading. The solution was to incorporate the inorganic colloidal silica filler into diluted bisGMA resin and polymerise it, before grinding into coarse **organic** particles of less than 50 micrometers, containing both resin and filler (Jacobsen 1981). Organic filler is then blended, under vacuum, with fresh monomer resin containing inorganic filler, to produce the final product which has a filler loading of just over 50%.

E: Hybrid Composite.

The blending of conventional sized filler particles with microfine and/or small particles produce bi-modal or tri-modal hybrid composites with close packing of particles. Filler particles of 10 - 20 micrometers are blended with particles of 2 - 5 micrometers and the interstitial spaces are filled with submicron particles of colloidal silica (Jones 1990). These materials are not as polishable as the microfilled composites and therefore are less suitable for use in anterior teeth. The advantages of this material are its high resistance to wear (Lutz 1983 and Christensen 1985a), making it suitable for restoration of posterior teeth, and its radiopacity which allows secondary caries and marginal overhangs to be seen on radiographs.

4.2.3 Filler-resin Coupling.

To impart good mechanical properties to a composite resin, transfer of stresses under loading must take place from the strong reinforcing filler to the more ductile polymeric resin matrix. For this to occur, a good bond must exist between the two phases of the composite material (Craig 1981). Additionally, it has been suggested that wear may be accelerated if hydrolytic degradation or crack formation occur between the two media (Dogon 1990). Two mechanisms have been described (Soderholm 1985): mechanical retention and chemical adhesion.

A: Mechanical retention.

Micromechanical retention was described by Ehrnford (1981 & 1983), where the glass is either sintered (Ehrnford 1976) or etched (Bowen 1963) to provide a porous structure into which the resin may flow and later polymerise.

B: Chemical Adhesion.

This is now the most frequently used means of bonding filler to matrix resin. Chemical bonding between the two media was reported by Bowen in 1963 when he described the formation of covalent bonds at the surface of the filler particles. This may be achieved by use of epoxy silane coupling agents first described by Bjorksten & Jaeger in 1952 and later by Sterman & Marsden in 1963. Examples include gamma - glycidoxypropyltrimethoxysilane *or* gamma-methacryloxypropyltrimethoxysilane. Silane treatment may be performed by aqueous solution or by dry-blending (Reinhart & Vahl 1977).

Recent work by Jones *et al* (1990b), demonstrated an increase modulus of elasticity in experimental composites using silane bonding between filler and resin. This work, using an ultrasonic method of investigation, showed many of the current materials available had insufficient adhesion between the organic and inorganic phases. Synthetic fillers of zirconia silica have been developed where the filler particles are sintered and their surfaces treated with silane to allow both mechanical and chemical bonding to occur (Creo & Steen 1987).

4.3.1 Properties of Composite Resins.

The composition of composites affects their physical and mechanical properties. Clinical trials using composite materials have shown that it may take several years for deficiencies in the materials to manifest themselves (Phillips *et al* 1973, Eames *et al* 1974 & Leinfelder *et al* 1975). It is prudent, therefore, to have some means of evaluating the properties of composite materials and predicting clinical performance.

4.3.2. Physical Properties

The volumetric contraction during polymerisation is typically 1.2 - 1.3%. The amount of contraction which takes place will depend on the type of monomer used and the filler loading of the material. Craig (1981) estimated that the volumetric contraction of the microfilled composite resins was much greater at 1.7 - 2.0%. Asmussen (1975b) concluded in his study on the wall to wall polymerisation contraction of composite resins, that the composition of the organic phase of composite resin was the principal factor. In an *in vitro* experiment he measured the wall to wall contraction of composite resins at the dentine walls of restored cavities and found a positive correlation between the size of gap and the amount of low viscosity monomer. Varying the amount of inorganic filler (up to 50% by volume) had no effect on gap formation.

Gjerdet & Hegdahl (1978) investigated the factors associated with porosity in composite materials and reported it to account for 1 - 2% by volume. He found encapsulated composite material contained more porosity than those supplied in bulk. The application of pressure to unpolymerised chemically cured composite paste greatly reduced the porosity: the extent of the reduction was a function of the viscosity of the mixed pastes.

The thermal expansion coefficient of composite resins is usually measured over the temperature range of 0 to 60^{0}C. The typical average value is 26 to 40 x 10^{-6} but microfilled materials have a greater amount of organic phase, resulting in values of 46 to 70 x 10^{-6}. Unfilled fissure sealants have values closer to that of the microfilled resins (80 to 90 x 10^{-6}). Tooth structure has a thermal expansion coefficient which is markedly lower than that of fissure sealants or composite resins (10 to 15 x 10^{-6}). Water sorption of composite resins is much lower than that which occurs with polymethylmethacrylate. This is due to the higher degree of cross linking between the chains of organic resin (Craig 1981).

Typical physical properties of composite resin materials:

Polymerisation contraction (% by volume)	1.2 - 1.6
Porosity (% by volume)	1.8 - 4.8
Thermal coefficient of expansion (x $10^{-6}/^{0}C$)	26 - 40
Water sorption (mgs/cm^2)	0.6 - 0.8

4.3.3. Mechanical Properties

In comparison to more traditional restorative materials, such as gold and amalgam, composite resins have demonstrated poor wear resistance in clinical testing, particularly when placed in positions of occlusal loading (Nuckles & Fingar 1975). Different methods of testing abrasion have been developed (Powers *et al* 1976, Jones *et al* 1972 and Heath & Wilson 1976) but it is uncertain how these may relate to clinical situations. Attempts to correlate wear with tensile strength or hardness have not been successful (Harrison & Draughn 1976).

In 1983, Leinfelder and Robertson demonstrated improved wear resistance with hybrid composite resins. Computerised methods of studying wear in the laboratory have been developed (DeLong *et al* 1985 & 1989), but the complex issues influencing wear still persist and were discussed by Bayne (1989). Wear rates vary with time depending on the tooth, size of the restoration, clinical procedure used during placement and operator variances. Leinfelder *et al* (1986) reported on the wear rates of nine composite resins over a three year period, by comparing the results using two methods of wear detection. In the first, he used the standard criteria issued by the US Public Health Service System, and in the second method, he used standardised, calibrated casts. The calibrated casts showed that wear reduced with time, while the conventional USPHSS system showed the opposite to be true. Current views are that wear is more rapid initially and then gradually decreases with time, but Dogon (1990) warns this may merely show that the restorations have moved out of occlusal contact and have become protected by the surrounding natural tooth structure. In 1981, the American Dental Association set standards for wear of less than 250 micrometers loss of restoration height over the first five years of service.

Restorations in permanent molar teeth wear more rapidly than those in premolar teeth (Lutz *et al* 1984) - the width and complexity of the restoration have been reported as having considerable influence (Taylor *et al* 1989a and 1989b). Wear is not only confined to areas of occlusal stress - the occlusal contact area - but also to the surrounding restoration surface - the contact free area (Kusy & Leinfelder 1977).

Fracture toughness is important if restorations are to be placed into areas of high stress (Jones 1990). Due to the lower fracture toughness of composite resins compared to unfilled methacrylate resins, crack propagation is not readily resisted. The fracture toughness of composite resins is also lower than that of dentine but superior to that of either enamel or glass ionomer cement. Fracture toughness of the microfilled materials is lower than that of the more highly filled composite (Smith *et al* 1983).

The modulus of elasticity for microfilled composites is lower than that for the conventional macrofilled materials. This can be explained by the lower filler volume (Rizkalla *et al* 1989). If a material has a low modulus of elasticity, the surrounding brittle tooth structure may fracture or there may be increased microleakage (Jones 1990). In 1989, Jones *et al* concluded that the higher the filler content of a composite resin, the greater is Young's Modulus and the more suitable the material is for restoration of high stress areas.

Equally, the indentation using the standard steel ball of 0.5mm. is greater for the microfilled materials although the percentage recovery after removal of the 30kg. loading, is similar for both materials.

The compressive strength of composites does not vary with filler type and load. The diametral strengths of the conventional composites and hybrid materials are greater than that of the microfilled restorative material.

The typical mechanical properties of composite resins are :

Wear (x 10^{-4} mm^3/mm travel)	6 - 7
Fracture toughness (kg - mm/mm^2)	0.01 - 0.05
Modulus of elasticity (GPa)	10 - 16
Indentation depth (μm)	55 - 70
Compressive strength (MPa)	170 - 260

4.4 Biocompatability of Composite Resins.

Adverse reactions to composite filling materials placed directly on to the dentine surface has been demonstrated histologically on pulp sections (Langeland *et al* 1965 & 1970, Suarez *et al* 1970, Brannstrom & Nyborg 1972, Stanley *et al* 1975 & 1979 and Glenn 1982). Some studies have shown a diminishing pulpal response with time and extreme incidence of pulpal necrosis (Heyes 1981). The use of a cavity lining, therefore, prior to insertion of the composite material has been recommended.

The biocompatability of these materials has also been reported to be associated with microleakage around the margins of the restoration (Mjor 1974, Brannstrom & Nordenvall 1978 and Brannstrom 1984). Etching enamel before placing composite filling materials reduces the invasion of bacteria between the cavity walls and the restorative material (Suarez *et al* 1970). Similarly, incremental placement of composite and the use of dentine bonding resins - where no enamel is present at the cavity margin - helps reduce microleakage and secondary caries (Dogon 1990).

The severest pulpal reactions take place in inadequately polymerised restorations. Free monomer resin can penetrate dentinal tubules to directly evoke an inflammatory response in the underlying pulp tissue (Dogon 1990).

Gingival response to composite resins is minimal when placed with care to eliminate overhanging margins or surface roughness on the restorations (Van Leeuween 1982).

4.5 Clinical Use.

Composite filling materials were introduced in the mid 1960's but, over the last 10 years, rapid progress has been made in improving these materials and they are now the material of choice for anterior restorations. The highly polishable microfilled materials may be used for intra-coronal restoration of class lll and V cavities. The stronger hybrid composite resins are ideal restorative materials for class IV cavity types involving the incisal edge where increased stress is applied to the restoration. The range of hue, value and chroma allow microfilled composites to closely match lost dentine and enamel (Cook *et al* 1984).

Hypoplastic or stained enamel, intrinsic staining, diastema closure and the alteration of mis-shapen teeth can be achieved by veneering the tooth with composite resins (Christensen 1985b). The increase in bucco-palatal thickness of a veneered tooth is a disadvantage which may make adequate plaque control problematic. Masking discoloured tooth structure with composite resins involves initial placement of a light shade of opaque resin over the discoloured enamel to assure reliable shade reproduction for the subsequent layers (Christensen 1985b). Pollack (1983) questioned the reliability of veneering mottled areas of enamel due to their high fluoride content, as this could interfere with the acid etch procedure.

Veneers may be made from composite or thin sheets of porcelain whose fitting surface has been etched using hydrofluoric acid. Veneers are placed at the chair-side using an acid etch composite luting system to produce good aesthetics, excellent gingival acceptance and minimal finishing at the chair-side (Calamia 1985) . Unfortunately, this is an expensive procedure requiring two visits.

Placement of composite veneers to mask anterior spacing is quick and economical. The length and width of the teeth, the size of the spacing and the condition of the gingival tissue have been reported as factors influencing the possibility of complete or partial closure of the space (Christensen 1985).

There has been debate over the suitability of posterior composite resins as a replacement for amalgam (Leinfelder 1985 and Roulet 1988). This has followed the recent controversy over the use of mercury (Hahn *et al* 1990) which has been shown

.3 concentrate in the kidney, gastrointestinal tract and jaw within four weeks of placement of amalgam restorations in monkeys. Conventional composite resins performed poorly when placed in posterior, teeth due to excessive wear on the occlusal surfaces (Eames *et al* 1974 and Phillips *et al* 1973) and the difficulty in achieving adequate contact points between the teeth (Leinfelder 1981). Research has concentrated on three fronts to overcome the problem of wear:

* New filler materials have been tested.
* Improved polymerisation systems have been developed.
* Filler loading has been improved with better particle size distribution (Dogon 1990).

In a review of composite resins, Dogon (1990) reports on personal communications with C.L. Davidson and W.D. Douglas who reported that newer composite resin technology had made it possible to achieve wear characteristics approaching that of amalgam. Pre-wedging of teeth about to be restored helps to overcome the problems of achieving adequate contact points which prevent food packing and periodontal inflammation.

Small composite restorations can be combined with the use of fissure sealant in the restoration of discrete, carious fissure lesions in posterior teeth (Simonsen & Stallard 1978 and Paterson *et al* 1991).

Resin retained bridgework may be used to restore missing anterior and posterior teeth.

Preparation of abutment teeth is conservative and of a reversible nature (Wood 1983) making this form of prosthesis ideal for the younger patient with large pulp chambers. The cast metal framework can be etched or sandblasted to produce a retentive surface suitable for use with composite luting cements. This type of restoration is not suitable in situations where patients are known bruxists or have parafunctional habits (Simonsen *et al* 1983).

Composite resin may also be used to splint traumatised teeth or to bond orthodontic brackets to etched enamel. In endodontic procedures, composite resins have been tested - with limited success - as retrograde filling materials (Palaniak 1985). Short term repairs to fractured acrylic and porcelain crowns and bridgework have been reported by Highton & Caputo (1979).

4.6 Future Developments.

To date, most development in composite resin technology has centred around the filler particle composition, size and loading. The weak link in the clinical performance of these materials is caused by the organic matrix: wear resistance is low and polymerisation shrinkage leads to marginal gap formation and increased microleakage.

Dogon (1990) discussed the possible use of alternative monomer resins to overcome the problems inherent in the current materials. Cook *et al* (1984) suggested the use of fluorinated dimethacrylate resins which would help reduce marginal gaps caused by the hydrophobic nature of bisGMA resin. They also reported a departure from the use of conventional resins by employing novel materials which expanded on setting, e.g. unsaturated spiro-orthocarbonates.

Two further problems were highlighted by Sherer (1989): the difference in thermal expansion coefficient between tooth structure and composite resins may lead to microleakage and stress the union between the resin and dentine adhesive systems; exact shade matching of composite resin to tooth structure is problematic yet vital to patient acceptance for use in aesthetic anterior restorations.

4.7.1 Bonding Systems.

Comprehensive kits of composite materials are now available containing various types of resins, etching and "bonding agents". The contents and the instructions provided with the kits frequently contain no information on the type of bonding system included: bottles are usually labelled "primer", "adhesive" or "bonding resin". The contents may contain cleansing solutions or more sophisticated bonding agents. Little guidance to the precise chemical contents or their mode of action are given. It is important to be able to select appropriate bonding agents for the material to be used in the restoration of the cavity and also to bond to the available surfaces i.e. enamel, dentine or glass ionomer cement.

4.7.2 Enamel Bonding.

Bonding to enamel is readily achieved by etching the surface with buffered phosphoric acid which produces micropores within the surface enamel to a depth of 10 - 40 micrometres. Resins with good surface wetting properties will be able to penetrate these pores and when cured, form resin tags to provide retention or bonding (Gwinnett & Buonocore 1965). Buonocore (1955) described this means of bonding as "micromechanical retention".

This type of bonding has enjoyed successful clinical use since the late 1960's with composite resins. The base resin system is either a bisGMA or urethane dimethacrylate depending on the composite resin selected. Early composite materials such as Adaptic (Johnson and Johnson) or Concise (3M) included an unfilled liquid resin in the kit for application to the etched enamel surface to improve surface wetting with the composite resin. Although the bond strength of the composite to etched enamel is not improved by application of the unfilled resin, the microleakage around the restoration margin is reduced (Hembree & Andrews 1976, Forsten 1978 and Brannstrom & Nordenvall 1978).

4.7.3 Dentine Bonding.

Reliable bonding of composite to dentine is difficult due to the nature of dentine and the production of a smear layer on its cut surface (Paterson & Watts 1990 and Watts & Paterson 1990b). The smear layer varies with the type of rotary instrument used and whether a water spray is employed during cavity preparation. Vital dentine contains fluid filled dentinal tubules which may wet the dentine surface if an acidic dentine cleanser is used. Acids remove the smear layer and not only open the tubule ends, but also alter the nature of the intertubular dentine. A stable bond can only be achieved in these circumstances if a *hydrophillic* bonding resin is used.

A number of different bonding mechanisms have been developed for use on dentine surfaces. Initially, these systems were classified according to a chronological order of development as 1st, 2nd and 3rd generation agents (Setcos 1988). In 1991, Watts *et al* considered a classification based on actual bonding mechanisms more acceptable as newer materials had incorporated *combinations of systems.*
All dentine bonding systems have the basic structure

$$M - R - X$$

where **M** is a methacrylate molecule which bonds to the composite resin.
R is an organic linking molecule.
X is a molecule which interacts with either the smear layer or the dentine surface.

Bonding to the dentine surface can take place by three methods:

A: Bonding with inorganic salts in dentine or smear layer.

Agents which work in this way will also bond to the calcium ion present in enamel and are therefore also known as the **dentine - enamel bonding agents**.

These bonding agents will also bond with glass ionomer cements (Causton & Sefton 1989). The exact mechanism of bonding to the cement has not been fully explained: originally, it was thought that bonding occurred to the metallic ions in the cement, but more recently, Hinoura *et al* (1989) suggested the excellent surface wetting of these agents allowed them to penetrate the irregularities of the cement surface, producing micromechanical retention. Acid etching of glass ionomer cements has been shown to produce alterations within the cement structure (Taggert & Pearson 1988 and Smith 1986) and to increase marginal leakage with some proprietary materials (Garcia - Godoy 1988a, Garcia - Godoy *et al* 1988b and Wexler & Beech 1988). The application of a dentine - enamel bonding resin to the unetched surface of the cement offers an alternative method of bonding composite resin to glass ionomer cement linings, or fissure sealant to glass ionomer cement restorations in the preventive resin or sealant restoration technique (Paterson *et al* 1991).

B: Bonding with the organic matrix of dentine.

According to Munksgaard & Asmussen (1985), these agents can bond with the organic matrix of dentine. As the organic matrix of enamel is inaccessible, these bonding resins cannot bond to this structure and therefore are frequently known as **dentine bonding agents**.

Dentine bonding systems normally have two components:

i/ A hydrophillic material which can polymerise when in contact with dentine - this reaction should occur in contact with moist dentine, but the materials do not form a bond with composite resins. In most kits this is known as the *primer liquid.*

ii/ A hydrophobic resin which bonds to both the primer and the composite resin. This material is usually labelled as *adhesive, sealer or bonding agent..*

Some dentine bonding kits contain cleansers, which remove the smear layer to allow bonding to take place with the collagen in the exposed intertubular dentine and on the walls of the opened tubules e.g. Gluma (Bayer) which contains a 17% EDTA as a cleanser. The *primer* consists of glutaraldehyde mixed with HEMA (hydroxyethyl methacrylate - a hydrophillic resin). The primer bonds to the collagen in the matrix but will not adhere to the composite resin. The *sealer* is an unfilled bisGMA resin (hydrophobic) which is applied to the surface of the primer and etched enamel to provide a bonding system for the composite resin.

In an attempt to reduce the number of clinical steps required, some manufacturers have incorporated acids in the primer solution e.g. Mirage Bond (Terec) and Scotchbond 2 (3M). In this way, simultaneous cleansing and priming of the dentine surface is achieved.

C: Bonding by entanglement or micromechanical means.

Studies on bond strength values obtained with different systems have suggested that bonding to either collagen or calcium ions may not be the sole means of attachment of resins to dentine (Erickson 1989). It has been suggested that the differences in bond strength magnitude may be accounted for by entanglement or micromechanical retention. This may occur in two different circumstances:

i/ With the ionic type agents, it has been suggested that the excellent surface wetting properties of these materials may allow resin penetration of the smear layer. This may give micromechanical retention by engaging around the components of the smear layer itself. Pashley (1984) suggested that total penetration of the smear layer by the resins allows bonding to the inorganic material lying in the dentine matrix.

ii/ The incorporation of acids into the primers of dentine bonding agents has been attempted (Setcos 1988). These acids are thought to act by removing both the smear layer and inorganic crystals from the collagen bundles of the dentine matrix. If the resins then flow into the irregularities in the collagen bundles, left after the removal of these crystals, then after curing, considerable micromechanical retention can be expected (Erickson 1989). It is also possible that chemical bonding may occur to the collagen itself (Asmussen & Munksgaard 1988).

Certain acidic primers also etch enamel with which they come into contact. At the present time, there is little data on the type of etching pattern produced by primers containing nitric acid (Berry *et al* 1990).

The exact mechanisms by which bonding agents function is confused. It seems likely that in many agents, a combination of chemical bonding and entanglement occurs.

4.7.4 Bond Strengths to Dentine.

The literature on testing of bond strengths achieved with the many different agents reports a wide range of values and there is no general agreement on an ideal bond strength. Figures of at least 10MPa (Asmussen & Munksgaard 1988) and 20 MPa (Finger 1988) have been proposed, but no clear rationale has been given. It may be reasonable for some restorative procedures to aim to equal or exceed the cohesive strength of dentine. This has been stated to be as high as 40 - 50 MPa (Bowen & Rodrigues 1962 & Lehman 1967), but in shear bond strength tests involving dentine bonding systems (Retief & Denys 1989) many dentine specimens fractured at a mean shear bond strength of 14.8 MPa. Bond strengths of this magnitude would be inappropriate for orthodontic brackets or any situation where an appliance may have to be subsequently removed. It would be sensible to suggest that products should be developed to produce varying bond strengths specifically for different applications .

Bond strength data obtained with the same bonding agents vary considerably in different centres. This is possibly the result of the variations in the dentine surfaces used in these studies e.g. roughness, the presence or absence of the smear layer, and the site from which the dentine was selected. Further variables which could be expected to influence bond strength include the storage medium for the specimens, the duration of application of the test load, the degree of curing of the resin system and thermocycling regime. Many experimental studies have been carried out using bovine dentine which may not be directly comparable to human dentine (Finger 1988). These variations are in marked contrast to the values obtained with etched enamel, where reliable bonding is readily obtained, with values in excess of 20 MPa being regularly reported (Gwinnett 1988, Stanford 1985 and Chalkley & Jensen 1984).

Bond strength values are commonly quoted by the manufacturers in their advertising material as proof of the clinical merit of their product. The wide variations in the reported values reflect the lack of standardisation of testing methods (Finger 1988, Retief *et al* 1988 & Gwinnett 1988b).

The method commonly used is to take dentine test pieces from sound extracted teeth. Depending on the proximity to the pulp, considerable variation will occur in the number and diameter of the dentinal tubules and the area of intertubular dentine available. Some workers (Stanford 1985 and Causton 1984) consider that the principal site of adhesion of the dentine bonding agents is to intertubular dentine and higher values for bond strength have been shown with the more superficial dentine, where the tubules are smaller in diameter and spaced further apart.

There is little evidence of any investigation of bond strengths achieved to dentine from carious teeth (McInnes-Ledoux *et al* 1987). Most operators recognize caries in dentine by the presence of staining and softening. Common clinical practice is to ignore staining on the pulpal floor and to excavate until the dentine is "hard". Investigations have shown that softened dentine extended, on average, 484 micrometers after bur excavation, and 706 micrometers after hand excavation (Terashima *et al* 1969). More detailed microscopic studies (Fusayama *et al* 1966) have demonstrated the changes associated with the progress of caries through dentine. It is clear from these that the dentine remaining after investigation will be partially demineralised and the organic matrix may be disrupted. The effects of the application of further acid to this surface, or the bond strengths which may be achieved if the collagen matrix is disrupted, must be open to question.

One of the main difficulties with composite resins as restorative materials is the polymerisation shrinkage. Even with the most recently developed materials a shrinkage of 1.7 - 5.7% volumetric and 0.2 - 0.9% linear have been reported (Liu *et al* 1990). In clinical practice, where dentine bonding agents are being used, the volumetric shrinkage will be more relevant than the linear component. When composite resin is attached with experimental bonding agents to dentine test pieces in the laboratory only linear contraction will occur. This could be expected to produce limited contraction forces during polymerisation. These may have limited effect on the bond strength achieved to dentine. In the clinical situation where polymerisation contraction is volumetric, the much greater contraction may produce forces which may partly disrupt the bond of the composite to the dentine, resulting in a much lower bond strength being achieved. Modern cavity preparation for composite resins emphasises the importance of saucer shaped cavities to minimise the effects of volumetric polymerisation contraction forces (Asmussen & Munksgaard1988 and Davidson *et al* 1984).

4.7.5 Conclusions on Dentine Bonding.

A wide range of bonding agents is now available to the dental practitioner for use with composite resins. The best approach when selecting a proprietary material is to consider the mode of action of the product.

One of the most difficult topics on which to reach a decision is whether or not the smear layer should be removed. Removal results in the opening of the tubule ends which allows the egress of tissue fluid and possible invasion by bacteria. Fluid movement within the tubules has been associated with dentine sensitivity (Brannstrom 1981) and bacterial invasion with adverse pulpal response (Watts 1979). These effects will be greatest when the cavity floor is in close proximity to the pulp where the tubules are wide. In relatively superficial cavities, these effects will be much less significant. In cases of non carious tooth surface loss, the dentine is usually exposed and then removed slowly. In many instances deposition of calcific material in the tubules and further deposition of reparative dentine will provide adequate pulp protection.

The ideal properties of a dentine bonding agent (Watts 1990c) are:

a/ Non toxic to pulp.

b/ Hydrophillic to allow bonding in many clinical situations where moisture is present.

c/ Good wetting agent to achieve intimate contact with the dentine surface.

d/ Long term stability.

Many of the materials currently in use have not been tested for prolonged periods. Earlier systems which showed initial promise failed due to hydrolysis of the bonding agent (Retief & Denys 1989 & Causton 1984).

Watts *et al* (1991) agreed with Franquin & Broullet (1988) that in deeper cavities systems requiring the complete removal of the dentine smear layer should be viewed with some caution. Their main value is in the cementation of porcelain inlays and etch retained restorations where the preparations extend into dentine. They are also useful in abrasion cavities where there is usually very little enamel available for bonding.

The older enamel bonding resins (see group 4 in Tables 1 & 2) are still supplied in many proprietary kits. These have been used successfully for many years. The bond strengths reported are lower than for the more recent dentine-enamel and dentine bonding agents. It should be remembered that the long term stability of the newer materials has yet to be demonstrated. Watts *et al* (1991) considered that the use of enamel bonding agents can be justified in class lll cavities where bond strength is not paramount and the main concern is the reduction of microleakage.

The following tables show a classification of many of the proprietary products which are currently available.

	Enamel Bonding	***Dentine Bonding***	***Entanglement***
Group 1 a	Ionic to calcium	Ionic to calcium	To the surface of dentine smear only
1 b	Covalent to hydroxyapatite	Covalent to hydroxyapatite	To the surface of dentine smear only
Group 2 a	Ionic to calcium	Ionic to calcium	Both groups leave the dentine smear layer in position.
2 b	Micromechanical to etched enamel	Micromechanical to collagen matrix	The smear layer is penetrated and bonding occurs to underlying dentine.
Group 3 a	No bonding	Covalent to collagen matrix of dentine	Both groups remove the dentine smear layer.
3 b	Micromechanical to etched enamel	Micromechanical to collagen matrix	Entanglement with demineralised collagen fibrils of dentine matrix.
Group 4	Micromechanical to etched enamel	None	No entanglement in dentine.

Table 4. 1 Bonding mechanisms to tooth structure.

(Refer to Table 4. 1 for mode of action).

Group 1.

a	b
Bondlite (Kerr) J & J dentine bonding agent Aristobond original (Wright) Prisma Universal (Caulk)	Dentin Protector (Ivoclar) [formerly Adhesit]

All of the above bonding resins have bonding potential to both enamel and dentine.

Group 2.

a	b
Aristobond 2 (Wright) Dual Cure Scotchbond (3M) Prisma Universal Bond 2 - primer + adhesive* (Caulk) Tripton (ICI) XR Bond (Kerr)	Kulzer Adhesive Bond

* *Prisma adhesive may also bond covalently.*

All of the above bonding resins have bonding potential to both enamel and dentine

Table 4. 2 Proprietary bonding agents.

Group 3.

a Dentine bonding potential	b Dentine and enamel bonding potential
Gluma Primer (Bayer)	Scotchbond 2 (3M) Superbond (Sun Medical) Mirage Bond (Terec) Tenure*

* Tenure may also bond ionically.

Group 4.

Enamel bonding agents.
Coltene Margin Bond
Coltene Duobond
Occlusin Enamel Bond (ICI)
Concise Enamel Bond (3M)
Gluma Sealer [formerly Resin L] (Bayer)
Heliobond (Ivoclar)
J & J Light Curing Bonding Agent
Durafill Bond (Kulzer)
Visiobond (Espe)
Degufill Bond (Degussa)
Profile Bonding Agent (S.S.White)
Scotchbond 2 Adhesive Liquid (3M)
Visar Seal (Den Mat)

Group 4 materials are enamel bonding agents only, i.e. unfilled bisGMA or dimethacrylate.

Table 4.2 (Contd) Proprietary Bonding Agents.

Group 1. Dentine enamel bonding agents which bond to the surface of the smear layer.

a Ionic type - bond to calcium ions in hydroxyapatite	
Bondlite (Kerr)	Phosphorylated methacrylate ester Dual curing.
J & J Dentine Bonding Agent	Phosphorylated ester of bisGMA Chemically cured.
Aristobond (orig) (Wright)	Carboxylic acid/methacrylate Light cured.
Prisma Universal (Caulk)	Polymerisable oligomers Phosphated ester Light cured.
b Covalent type - bond to hydroxyl group of hydroxyapatite	
Dentine Protector [formerly Adhesit]	Methylene chloride Pre-polymerised urethane Self cured

Uses: Ionic bonding types.

* class 1 cavities (sealant restorations).
* minimal class 11 cavities for composite resin where there is little dentine uncovered after lining.
* class 111 cavities.
* class 1V cavities (fractured incisors).

Covalent bonding types.

* class V cavities where sensitivity is considered a problem.

Table 4. 3. Constituents and uses of proprietary bonding agents.

Group 2. Dentine enamel bonding agents which penetrate the dentine smear layer.

a <u>ionic type</u> - bond to calcium ions in hydroxyapatite	
Aristobond 2 (Wright)	Carboxylic acid methacrylate Light cured.
Scotchbond Dual Cure (3M)	Halophosphorus esters of bisGMA Dual cured.
Prisma Universal Bond 2 *	<u>Dentine primer</u> is HEMA and PENTA (phosphorylated monomer in ethanol) <u>Adhesive</u> acrylic resins, phosphate esters, >1% glutaraldehyde. Light cured.
Tripton (ICI)**	<u>Dentine primer</u> polyhexamethylene biguanide <u>Universal bond</u> "Novel" phosphate methacrylate monomer Triethylene glycol dimethacrylate Urethane dimethacrylate Light cured.
XR Bond (Kerr)	<u>XR Primer</u> phosphonated - dimethacrylate ester. Light cured. <u>XR Bond</u> phosphonated dimethacrylate ester. Urethane dimethacrylate Aliphatic dimethacrylate Light cured.
b <u>Micromechanical retention.</u>	
Kulzer Adhesive	A mixture of methacrylates with Bond silanised silica in a vehicle of acetone. Light cured.

* Stated to bond ionically to hydroxyapatite and covalently to collagen.

** Claimed to bond ionically to calcium via phosphate methacrylate and to collagen via biguanide.

Uses: Group 2a and b have similar uses to those listed for group 1a.

Table 4.3 (continued) Constituents and uses of proprietary bonding agents

Group 3. Dentine bonding agents which require the dentine smear layer to be removed

a <u>Covalent type</u>	
Gluma system* (Bayer)	<u>Cleaner</u> 17% EDTA <u>Primer</u> glutaraldehyde HEMA (Hydroxyethylmethacrylate) <u>Sealer</u> unfilled bisGMA Light cured.
b <u>Micromechanical retention.</u>	
Scotchbond 2	<u>Scotchprep (dentine primer)</u> maleic acid, HEMA. <u>Adhesive</u> bisGMA, HEMA. Light cured.
Superbond** (Sun Medical)	4 META (4-methacryloxy trimellitate anhydride)
Mirage Bond (Terec Group)	<u>Part 1.</u># <u>Dentine /enamel Primer</u> NPG (N phenyl glycine) 2.5% Nitric acid. <u>Part 2</u> <u>Dentine/enamel Primer</u> PMDM(Pyromellitic acid dianhydride) HEMA In *acetone solvent.*
Tenure (Den Mat)	<u>Dentine/enamel conditioner</u> Aluminium oxalate 2.5% Nitric acid. <u>Solution A</u>. NTG-GMA (N-tolylglycine-glycidyl methacrylate) *In acetone solvent.* <u>Solution B</u>. PMDM

* Gluma system cleanser removes smear layer.
Primer bonds to amino groups in collagen.
May entangle.
Sealer applied to primed dentine and etched enamel.

** Superbond kit contains citric acid used to remove smear layer.
Micromechanical bonding to etched enamel and dentine collagen matrix.
Bonds chemically to metal frameworks.

\# Part 1 of Mirage Bond removes smear and etches enamel before the application of Part 2.

Table 4. 3 (continued)

Uses: Materials from both groups 3a and b appear to be more useful in cavities where dentine predominates e.g. cervical abrasion cavities. They are also indicated in the luting of porcelain inlays and other etch retained restorations where dentine has been exposed during preparation.

Table 4.3 (Continued) Constituents and uses of proprietary bonding agents.

Group 4

Enamel bonding agents.
Coltene Duobond
Coltene Margin Bond
Concise Enamel Bond (3M)
Degufill Bond (Degussa)
Durafill Bond (Kulzer)
Gluma Sealer (Formerly Resin L) (Bayer)
Heliobond (Ivoclar)
J & J Light Curing Bonding Agent
Occlusin Enamel Bond (ICI)
Profile Bonding Agent (S.S. White)
Scotchbond 2 Adhesive Liquid (3M)
Visar Seal (DenMat)
Visiobond (Espe)

Group 4 materials are enamel bonding agents only i.e. unfilled bisGMA or dimethacrylate.

Table 4.3 **Constituents and uses of proprietary bonding agents.**

4.8 A Field Trial of Composite and Fissure Sealant and Glass Ionomer Cement, Composite Resin and Fissure Sealant (i.e. Laminate or Sandwich Restorations) used in the Management of Fissure Caries in the Community Dental Services in Glasgow and Lanarkshire.

4.8.1 INTRODUCTION.

The use of minimal composite restorations for the treatment of fissure caries and the results after one year were reported by Simonsen and Stallard in 1977. It was not until 1987 that these restorations were available under the Health Service regulations in the U.K. The following year, the regulations were substantially modified. In Scotland 240,00 sealant restorations were placed (Dental Practice Board, Edinburgh). No information is available on the performance of this form of treatment in the management of fissure caries in the conditions of General Dental Practice. Since pit and fissure caries now accounts for the majority of new caries lesions, monitoring of this management option is an important consideration.

In 1987, a symposium on the topic of "Criteria for Placement and replacement of dental Restorations" was held in the United States. A series of conclusions and recommendations regarding restorative dentistry were made. The conservation of tooth structure was of prime importance: the use of fissure sealant or the " sealant restoration" technique was advocated in the management of active pit and fissure lesions and in sites where the presence of a lesion was in doubt or where the activity of the lesion was questionable.

In this section of the study, the materials and methods used to place both composite and fissure sealant restorations and larger laminate restorations (glass ionomer base, composite filling and fissure sealant covering) in the restoration of fissure lesions, will be examined and the results of sealant retention and performance of the composite filling after six months, one year and 2 years will be reviewed.

4.8.2 MATERIALS AND METHODS.

The methods used in the field trial for recording materials and techniques employed during sealant restoration placement are described in Chapter 3.

The review examination techniques adopted by the external examiners after 1 year were as follows:

The teeth were cleaned, dried, isolated and examined under good lighting conditions using a mirror and standard right angled probe. The presence of white, light-cured fissure sealant was easily seen but the detection of clear, auto-polymerising sealant was more difficult and required the use of a dental probe to detect the presence of the composite surface and the edge of the surrounding fissure sealant.

A subjective measurement of the width and extent of fissure involvement by the composite filling was recorded diagrammatically. The width and extent of the composite restorations were then transcribed to a numerical score:

i/ extent of fissure pattern involved

1. <1/3 of fissure pattern (Small).
2. Between 1/3 and 2/3 (Medium).
3. >2/3 of fissure pattern (Large).

ii/ lateral width across cavity

1. Up to 1mm (Narrow).
2. 1 - 3mm (Moderate).
3. >3mm (Wide).

On the same diagram, missing areas of fissure sealant were shaded in a contrasting ink.

The restorations were examined separately by two calibrated examiners who conferred after seeing each patient and, in the event of a disagreement, re-examined the patient before agreeing the final rating. A record was kept of the very small number of changes in each examiner's decisions.

The following data were recorded at the examination one year after placement:

Sealant: *A. Retention.*

1. Sealant completely retained.
2. Sealant entirely missing.
3. Sealant partially missing

B. Missing Zone.

1. Over restoration.
2. Occlusal fissure pattern.
3. Buccal fissure.
4. Palatal fissure.

Restoration: A - *Presence / absence*

1. Present and covered with fissure sealant.
2. Present but with no fissure sealant covering.
3. Restoration absent.

B - *Marginal integrity.* (assessed if sealant missing)

1. Probe catches but no visible crevice.
2. Visible crevice but no dentine visible at base.
3. Dentine exposed but restoration not mobile/fractured/missing.
4. Dentine exposed at base: restoration missing/ fractured/mobile.

C - *Marginal discolouration.* (assessed if sealant is missing)

1. No discolouration at margins.
2. Discolouration extending around less than 1/3 of the margin.
3. Discolouration extending between 1/3 and 2/3.
4. Discolouration extending around more than 2/3 of the margin.

The criteria used by the author in deciding the need for addition of further fissure sealant was reached by either the presence of exposed fissures containing stain **and** decalcification or the presence of more than 2 other active caries lesions in the dentition.

The level of patient cooperation and the type of fissure pattern in the treated tooth were subjectively assessed and noted on the monitoring form. The criteria used to grade the three levels of cooperation were decided with the Community Clinical Dental Officer and have been described in Chapter 3.

The procedures adopted for two-year review of the restorations were similar to those used for assessment after one-year. Further attempts were made to recall patients who had failed to attend for the one-year review. Patients were only excluded if they failed to attend for three review appointments which were sent by letter. Attempts were made to review patients who had failed to attend the one-year reviews by inviting them for further examination at the Community Dental Clinics.

The data collection document used to record details of the clinical performance of the sealant restoration after 24 months was similar to that used for the one-year review, but at this stage, the life expectancy of the restoration was estimated.

Three categories of response were used:

Requires immediate replacement

- *loss of restoration or the presence of secondary caries associated with the composite filling were considered justification for replacing the restoration.*
- *where treatment to a new primary caries lesion would require removal of the original composite filling.*

Life expectancy 1 - 2 years

- *where additions of fissure sealant were required for sealant restorations due to either the presence of staining* ***and*** *decalcification in the exposed fissures*
- *where the patient had sound exposed fissures but more than two other active lesions in the dentition they were considered at risk of new lesions developing in exposed fissures.*

Life expectancy more than 2 years

- *where restorations were completely intact at the two-year review.*
- *where some fissure sealant was missing but it was not considered that it required to be replaced due to the absence of caries in the fissure or the low caries risk of the patient.*

All data were recorded by number i.e. the Dental Officers were not identified by name and were given the specific assurance that no data relating to their work would be disclosed without their prior knowledge and consent.

Data from the registration cards and the monitoring forms used by the calibrated examiners were entered on the data base programme Survey It! (Conway Information Systems Ltd, Version 4.0, 1991) and was analyzed on micro-computer using the statistical package C-Stat (Oxtech Ltd 1991). Chi-square test was employed to show differences between tested groups with the level of significance set at 5%.

4.8.3 RESULTS.

A: Use of the materials and techniques.

Five hundred and twenty sealant restorations were placed by the group of participating Community Dental Officers. One hundred and fifteen composite and fissure sealant restorations and 163 laminate restorations were placed - 22.2 and 31.3% respectively of all sealant restorations registered.

The distribution of the restorations is graphically shown in Figure 4.1. 78.3% of composite and sealant restorations and 76.1% of laminate restorations were placed in first permanent molar teeth while the corresponding percentages for second molar teeth were 16.5 and 22.7% respectively. These restorative techniques were seldom used in premolar teeth - only seven restorations were placed. There was generally an even distribution of restored teeth by quadrant.

94.7% of the teeth were functional at the time of restoration placement with only fourteen non-functional teeth.

The mean ages of patients receiving composite and fissure sealant restorations and laminate restorations were not dissimilar. The distribution of restorations by age in the first and second molars are shown in Tables 4.4 and 4.5. Only 42.4% of the patients were male.

B: Cavity preparation.

Information on the use of local analgesia during cavity preparation was not provided for fourteen (12.1%) of the smaller intra-enamel type cavities and for nine (5.5%) of the larger laminate cavity types. In Table 4.6 use of a local analgesic was confined to 24.7% of intra-enamel cavities and 70.8% of the larger cavity types involving dentine preparation.

A comparison of the burs used during preparation of the cavity types is shown in Table 4.7. In the smaller intra-enamel cavities, round friction grip burs were predominantly used while there was an increase in the proportion of fissure burs used during preparation of the larger cavity types. Diamond burs were used almost twice as frequently as tungsten carbide burs.

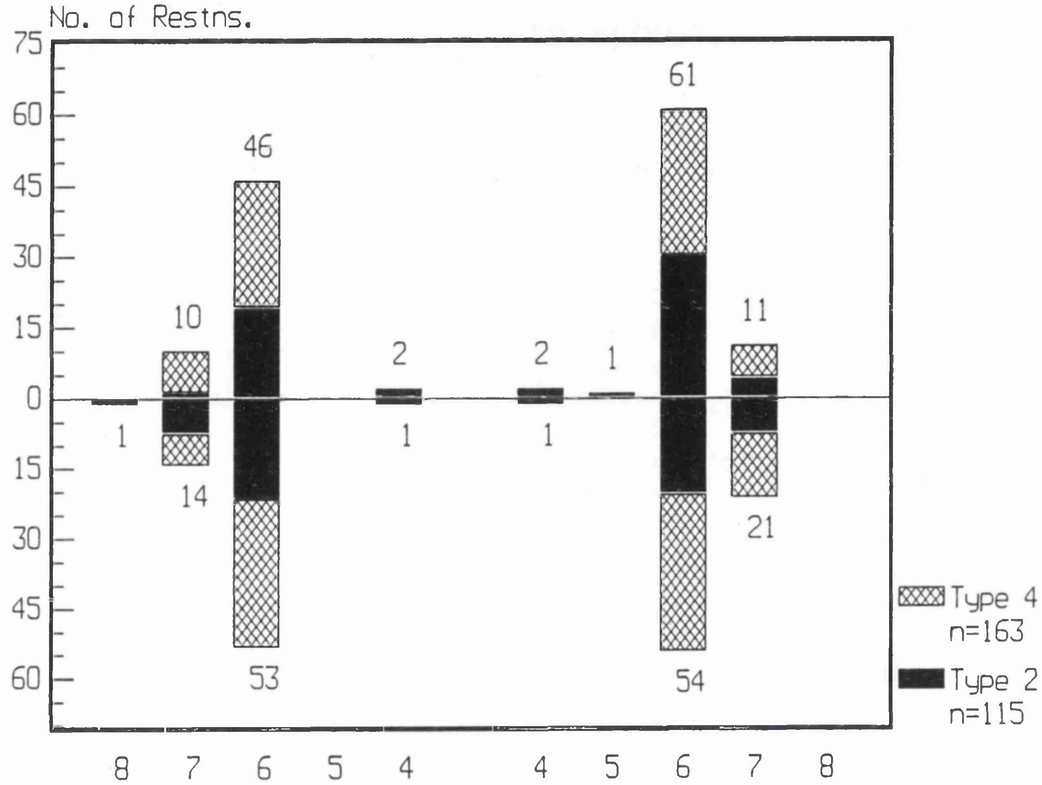


Figure 4.1 **Distribution of intra-enamel and laminate sealant restorations placed by the community Clinical Dental Officers in the field trial.**

Age of patient	Number & Percentage of intra-enamel restorations	Number & Percentage of laminate restorations
6.0 - 6.9	5 (5.6%)	6 (5.1%)
7.0 - 7.9	10 (11.2%)	9 (9.7%)
8.0 - 8.9	22 (24.7%)	12 (10.3%)
9.0 - 9.9	15 (16.8%)	17 (14.6%)
10.0 - 10.9	9 (10.1%)	18 (15.5%)
11.0 - 12.9	17 (19.0%)	32 (27.5%)
13.0 - 15.9	9 (9.9%)	22 (18.9%)
16.0 and over	2 (2.2%)	0

Mean ages - composite+fissure sealant (type 2 restns) - 10.07 years (S.D. 2.48 yrs)
laminate restorations (type 4 restns) - 10.79 years (S.D. 2.31 yrs)

Table 4.4. **Age distribution of patients receiving composite and fissure sealant and laminate restorations in first permanent molar teeth (n=205).**

Age of patient	Number & Percentage of intra-enamel restorations	Number & Percentage of laminate restorations
8.0 - 8.9	0	1 (3.2%)
9.0 - 10.9	0	2 (6.4%)
11.0 - 12.9	5 (27.7%)	3 (9.6%)
13.0 - 13.9	6 (33.3%)	6 (19.3%)
14.0 - 14.9	3 (16.6%)	10 (32.2%)
15.0 - 15.9	1 (5.5%)	3 (9.6%)
16.0 and over	3 (16.6%)	6 (19.3%)

Mean ages composite+fissure sealant (type 2 restns) - 14.01 years (S.D. 2.18 yrs)
laminate restorations (type 4 restns) - 14.14 years (S.D. 2.52 yrs)

Table 4.5 **Age distribution of patients receiving composite and fissure sealant and laminate restorations in second permanent molar teeth n=49.**

	Number of type 2 restorations (% answered)	Number of type 4 restorations (% answered)
L.A. used	25 (24.7%)	109 (70.8%)
No L.A. used	76 (75.3%)	45 (29.2%)
No information	14 (--------)	9 (------)

Table 4.6 **Use of local analgesia during the preparation of cavities for type 2 and type 4 sealant restorations (n=278).**

	Number & Percentage in type 2 restorations (% answered)	Number & Percentage in type 4 restorations (% answered)
Shape		
round	86 (76.8%)	86 (62.8%)
fissure	26 (23.2%)	51 (37.2%)
not specified	14 (--------)	50 (-------)
Material		
diamond	58 (63.7%)	111 (69.4%)
t. carbide	33 (36.3%)	49 (30.6%)
not specified	26 (--------)	12 (-------)
Size		
008	14 (17.1%)	7 (5.5%)
010	19 (23.2%)	22 (17.2%)
012	35 (43.2%)	35 (27.3%)
larger	14 (17.1%)	64 (50.0%)
not specified	33 (-------)	35 (-------)

Table 4.7 **The shape, size and bur type used during the preparation of the cavities for the two types of composite sealant restoration (n=278).**

Between 20 and 28% of operators did not state the size of bur used during the preparation of the cavity. Only 5.5 to 17.1% of cavities were prepared using the recommended size of bur (008), while there was a strong preference for using burs of an ISO 012 or greater (1.2mm in diameter).
Isolation of the cavity was achieved using cotton wool rolls and an aspirator during the placement of 52.7 to 65.5% of the restorations. In Table 4.8 all methods of isolation are shown. During the placement of the laminate sealant restorations, significantly more were isolated with rubber dam ($P < 0.05$).

C: Materials.

In Table 4.9 the reported use of composite resins in the restoration of type 2 and type 4 sealant restorations by the Community Dental Officers are shown by filler type and distribution. The most popular composite resin used was the urethane based material "Occlusin" (I.C.I.) which was used to restore the cavities in 47.1% of all composite sealant restorations. 57.9% of all restorations placed used urethane based composite filling materials. According to the criteria suggested by Lutz & Phillips (1983), the majority of the composite resin used was suitable for restoration of posterior teeth (62.2%) while in 34.9% of the sealant restorations, a composite resin was used which is manufactured as an anterior filling material.

Fissure sealant usage is also shown in Table 4.9 Delton (Formerly Johnson and Johnson, now De Trey/Dentsply) was used to seal 92.8% of all restored teeth. Opaque sealants were used during the placement of 61.1% of all composite sealant restorations while a clear, auto-polymerising resin was preferred by fewer operators (31.6%). The ratio of self cured to light cured fissure sealants was 1 : 2.6.

Information on the length of light curing received by the composite and fissure sealant materials was available for 245 restorations.

	Number and Percentage in type 2 restorations	Number and Percentage in type 4 restorations
Cotton wool rolls	36 (31.9%)	35 (23.6%)
C/W rolls + aspirator	74 (65.5%)	78 (52.7%)
Rubber dam	3 (2.6%)	35 (23.6%)
not specified	2 (------)	15 (-------)

Type 2 restorations n=113 (specified isolation technique)
Type 4 restorations n=148 (specified isolation technique)

Table 4.8 Methods of isolation employed during type 2 and 4 sealant restoration techniques with composite and fissure sealants.

Composite Resin.

Type	Product	% Using	Suitable for
Hybrid	Occlusin*	131 (47.1%)	Post. Restns
	Herculite	80 (28.8%)	Ant. Restns
	Fulfil	5 (1.8%)	Post. Restns
	Degufill H	7 (2.5%)	Post. Restns
Microfilled	Heliomolar*	30 (10.8%)	Post. Restns
Fine particle	Prismafil	17 (6.1%)	Ant. Restns
(other)	(not stated)	8 (2.9%)	

* Urethane diacrylate based materials

Fissure Sealants.

Sealant	% Using	Curing Method	Colour	Filler
Delton	170 (61.2%)	Light-cured	Opaque	Unfilled
Delton	88 (31.6%)	Self-cured	Clear	Unfilled
Helioseal	15 (5.4%)	Light-cured	Opaque	Unfilled
Prismashield	5 (1.8%)	Light-cured	Opaque	50% Filled

Table 4.9 Reported use of fissure sealants and composite resins in type 2 and type 4 sealant restorations placed in the field trial (n= 278).

Curing times are shown in Table 4.10 which demonstrate that the smaller intra-enamel restorations were generally cured for shorter periods than the larger laminate restorations. Over 75% of the operators preferred to expose the laminate restoration to visible blue light for at least one minute in comparison to 57% of the smaller composite restorations which were cured for a similar time.

In cavities where the carious lesion has reached dentine, placement of a lining or base is recommended to protect the pulpal tissue underlying the cavity floor. Eleven percent of restorations were lined using a setting calcium hydroxide material (Dycal, Caulk). The remainder were lined using the glass ionomer cements shown in Table 4.11. Radio-lucent glass ionomer cements, developed as restorative materials, were placed below 58.6% of composite restorations while only 35.6% of the cements were radio-opaque and manufactured as lining materials.

Etching of the glass ionomer cement linings was performed in 35.2% of restorations: 76.6% of which were etched using a gel formulation of material applied for 30 to 45 seconds (66.8%).

Information on the type of etchant and etching times employed were given for all restorations and are presented in Tables 4.12.1 and 4.12.2. There were no differences between the two cavity/restoration types relating to the use of the etching materials or the etch times. Gel etchants proved to be more popular than liquids. 66.8 to 70.1% of the restorations were etched for 31 to 45 seconds while 25.4 to 26.3% were etched for times in excess of 45 seconds.

D: Performance of sealant restorations after six months.

After six months, 85 of the smaller intra-enamel sealant restorations were reviewed and 126 laminate restorations - a recall rate of 73.9 and 77.3% respectively. Restricting the number of restorations reviewed to those who were also seen after twelve months (68 and 109 patients respectively) allowed direct comparison of the performance of the two types of sealant restoration with that achieved after one year.

Curing times	Frequency of use in type 2 restorations	Frequency of use in type 4 restorations
1 - 15	0	0
16 - 20	0	0
21 - 30	6 (6.1%)	4 (2.7%)
31 - 40	22 (22.4%)	25 (17.0%)
41 - 50	14 (14.2%)	7 (4.7%)
51 - 60	56 (57.1%)	111 (75.5%)
60 and greater	0	0
	n=98	n=147

Table 4.10 **Information on the length of light curing time given for the placement of 245 composite sealant restorations.**

Name of base or lining material	Frequency of use in laminate (type 4) restorations.
ChemFil 2	85 (52.1%)
Baseline	43 (26.4%)
Dycal	18 (11.0%)
Ketacbond	15 (9.2%)
not specified	2 (1.2%)

Table 4.11 **The materials used as bases or lining materials in laminate sealant restorations (n = 163).**

Etch materials	Frequency of use in type 2 restorations	Frequency of use in type 4 restorations
liquid	17 (14.7%)	35 (21.4%)
gel	98 (85.2%)	125 (76.6%)
mixture	0	3 (1.8%)
no data	0	0
	n=115	n=163

Table 4.12.1 **Etchant materials used during the placement of two types of composite sealant restorations.**

Etch times	Frequency of use in type 2 restorations	Frequency of use in type 4 restorations
0 - 15	0	0
16 - 30	5 (4.3%)	11 (6.7%)
31 - 45	80 (70.1%)	109 (66.8%)
46 - 60	29 (25.4%)	43 (26.3%)
61 and greater	0	0
	n=114	n=163

Figure 4.12.2 **Etch times employed by the operators during the placement of the two types of composite sealant restorations.**

No difference could be shown between the retention rate of fissure sealant in the two groups of teeth restored with the two types of composite sealant restoration ($P>0.05$). In Table 4.13, the retention rate of fissure sealant at six months is shown: 24.7 to 27.8% of sealants were completely retained and 4.8 to 8.2% had been lost entirely from all pit and fissure surfaces and from over the surface of the composite restorations.

The performance of the composite fillings after six months is shown in Table 4.14. The larger laminates exhibited more surface wear and marginal discolouration than the smaller intra-enamel restoration. The retention rate of the composite fillings was similar in both types of restoration while similar caries status was recorded for both. The loss of fissure sealant from the surface of the composite restoration or from the fissures of the restored teeth allowed 9 new caries lesions to develop in the teeth reviewed after six months. Only one of the teeth restored with a laminate restoration had shown any sensitivity after the placement of the sealant restoration and this had subsided before the six monthly review.

In Table 4.15 the treatment that the two reviewing examiners considered necessary after the initial clinical recall is shown. The complete replacement of 4 composite fillings was indicated where they had been entirely lost. In the nine teeth where new caries lesions developed on the occlusal surface (three primary and six secondary lesions), five teeth were eliminated from further review as amalgam restorations were found to be necessary after further investigation. An investigative cavity and insertion of an adhesive filling material was required in the remaining four teeth before resealing the surfaces. These teeth were also excluded from further review.

In 90% of the restorations reviewed, either no treatment was considered necessary or only small additions to areas of lost sealant. In total, 13 teeth were eliminated from the trial at this time due to new caries requiring investigation in pit and fissure surfaces (5 teeth) or the presence of class ll lesions (8 teeth).

Fissure sealant retention in all teeth reviewed after 6 months.

Fissure sealant retention	Frequency of occurrence type 2	Frequency of occurrence type 4
Fully retained	21 (24.7%)	35 (27.8%)
Partially retained	57 (67.1%)	85 (67.4%)
Completely missing	7 (8.2%)	6 (4.8%)
	n=85	n=126
	recall rate 73.9%	recall rate 77.3%

Statistical Comparison: *difference in sealant retention between type 2 and 4 restorations. $Chi^2 = 1.176$ $DF = 2$ $P > 0.05$ Not Significant*

Sealant retention after 6 months in patients also seen after 1 year

Fissure sealant retention	Frequency of occurrence type 2	Frequency of occurrence type 4
Fully retained	13 (19.1%)	32 (29.4%)
Partially missing	48 (70.6%)	72 (66.0%)
Completely missing	7 (10.3%)	5 (4.6%)
	n=68	n=109

Statistical Comparison: *difference in sealant retention between type 2 and 4 restorations. $Chi^2 = 3.86$ $DF = 2$ $P > 0.05$ Not Significant*

Table 4.13 **Fissure sealant retention after six months in all teeth reviewed with type 2 and type 4 sealant restorations.**

• Restoration retained	- yes	83 (97.6%)	
	- no	2 (2.4%)	n=85
• Occlusal wear present	- yes	1 (1.2%)	
	- no	84 (98.8%)	n=85
• Marginal discolouration	- yes	5 (5.9%)	
	- no	80 (94.1%)	n=85
• Caries present	- new primary	2 (2.4%)	
	- new secondary	3 (3.5%)	
	- no caries	80 (94.1%)	n=85

Table 4.14.1 Performance of type 2 composite fillings after 6 months (n=85).

• Restoration retained	- yes	124 (98.4%)	
	- no	2 (1.6%)	n=126
• Occlusal wear present	- yes	14 (11.1%)	
	- no	112 (88.9%)	n=126
• Marginal discolouration	- yes	11 (8.7%)	
	- no	115 (91.3%)	n=126
• Caries present	- new primary	1 (0.8%)	
	- new secondary	3 (2.4%)	
	- no caries	122 (96.8%)	n=126

Table 4.14.2 Performance of type 4 composite fillings after 6 months (n=126).

Type 2.

- no modification - 35 (40.7%)
- modification - 43 (51.6%)

39 addition of ***fissure sealant***

4 ***composite*** *and* ***fissure sealant***

- eliminated restorations - 7 (7.7%)

(n=85 restorations)

35 + 39 = 74 restoration (87.1%) required either no treatment or simple addition of fissure sealant resin.

Type 4.

- no modification - 71 (56.8%)
- modification - 49 (38.9%)

45 addition of ***fissure sealant***

4 ***composite*** *and* ***fissure sealant***

- eliminated restorations - 6 (4.3%)

(n=126 restorations)

71 + 45 = 116 restorations (92.1%) required either no treatment or simple addition of fissure sealant resin.

Statistical comparison between treatment requirements of type 2 and 4 restorations:

$Chi^2 = 4.952$ $DF = 3$ $P > 0.05$

Not Significant

Table 4.15 **Modifications required to composite and sealant restorations after 6 months.**

E: Results after 1 year.

After 1 year, the participating Community Dental Officers successfully recalled 209 of 278 sealant restorations placed involving the use of composite resin and fissure sealant - a recall rate of 75.2%.

One hundred and sixty two restorations reviewed (77.5%) had been placed in first permanent molar teeth and 44 (21.1%) in second molars: only 3 premolar teeth were restored using the sealant restoration technique. There was an even distribution of reviewed molar restorations placed by quadrant.

F: Treatment required after 12 months.

In Table 4.16 the treatment that the external assessors considered necessary is presented. No treatment or the simple addition of further fissure sealant was required for 85.9% of the restorations to allow them to continue in clinical service. In 7 restorations (3.3%), the composite filling was lost. Following the loss of fissure sealant, 12 new primary lesions developed in exposed pits and fissures and in 4 teeth secondary caries was present around the composite restoration. These 23 teeth, therefore, required further investigation and placement of new composite resin and overlying fissure sealant.

Caries in a previously sealed surface occurred in 16 teeth: an overall new caries prevalence of 7.6% of the reviewed sample. When these patients were matched both in age and tooth type, they had a DMFT of 6.08 and PCS (the **P**roportion of **C**arious **S**urfaces to all surfaces in the permanent dentition) of 4.77. The corresponding figures for patients who had lost fissure sealant but who had not developed new caries lesions was 4.24 and 1.25 respectively.

Treatment required at 12 months.	No. of restns.
No treatment:	93 (44.5%)
Addition of fissure sealant:	85 (41.4%)
Additions of composite and fis. seal:	23 (11.0%)
Placement of a class ll restoration:	7 (3.3%)

n=209

Table 4.16 **Treatment required for the 209 sealant restorations after 12 months clinical performance. Addition of composite and further fissure sealant was required if the original restoration were lost, new primary caries developed or secondary caries occurred at the margins of the original composite filling.**

G: Fissure sealant retention.

In Table 4.17 a comparison is presented for the retention of fissure sealant to the small "intra-enamel" sealant restorations and to the larger laminate restorations. No difference in sealant retention could be demonstrated between the two types of restoration ($P=0.66$). In Table 4.18, areas of lost and retained fissure sealant are given for all first and second permanent molar teeth by tooth surface and restorative material. No differences in sealant retention were found between first and second molar teeth ($P > 0.05$): the apparently superior sealant retention to occlusal and buccal fissures in second molars fell just below the level of statistical significance. Sealant retention to occlusal fissures was significantly better than to the surfaces of urethane based composite resin ($P < 0.01$). No statistical difference in sealant retention could be demonstrated between occlusal fissures and bisGMA composite resin surfaces. The retention of bisGMA pit and fissure sealant to the surfaces of urethane based composite restorations (29% retained) was significantly poorer than that achieved when the fissure sealant was placed over a composite resin based on a similar resin system (51% retained) to that used in the pit and fissure sealant ($P < 0.01$).

Significant differences in sealant retention to the various tooth surfaces were also noted ($P < 0.01$): retention of sealant in the buccal fissure was significantly poorer than to all other surfaces while sealants in the occlusal and palatal fissures performed best.

H: The effect of the age of the patient at time of placement

Table 4.19 shows the retention of fissure sealant from restorations in first molar teeth in three different age groups. Statistical comparison shows improved retention in the children aged 12 years or older ($P < 0.01$).

I: The effect of patient's level of cooperation.

In Table 4.20, the effect of patient cooperation was considered. When the results were restricted to the 162 restorations placed in first molar teeth, only 17 patients were considered to have cooperated poorly. Cooperation was a significant factor in improving retention to the buccal and occlusal fissures ($P < 0.05$). No significant improvement could be demonstrated in the palatal fissure or to the surface of the composite restoration ($P > 0.05$).

	Type 2 Restoration "Intra-enamel"	**Type 4 Restoration "Laminate"**
Completely retained	14 (17.3%)	24 (18.7%)
Partially retained	62 (76.5%)	97 (75.8%)
Entirely missing	5 (6.2%)	7 (5.5%)

Statistical comparisons.

Type 2 v Type 4 $Chi^2 = 0.105$ $DF = 2$ $P > 0.05$

Not significant

Table 4.17 **Percentage fissure sealant retention for the two types of composite sealant restorations which were reviewed after 1 year.**

i/ first permanent molars

	RESTORATION Urethane	bisGMA	OCCLUSAL	BUCCAL	PALATAL
LOST	67 (71%)	33 (49%)	66 (41%)	57 (73%)	29 (35%)
RETAINED	28 (29%)	34 (51%)	96 (59%)	21 (27%)	55 (65%)
	n=95	n=67	n=162	n=78	n=84

Statistical Comparisons

Urethane based v bis GMA	*Chi2=21.3*	*DF=1*	*P < 0.01*	**
Urethane based v Occlusal fissure	*Chi2= 7.3*	*DF=1*	*P < 0.01*	**
Buccal v Occlusal fissure	*Chi2=22.0*	*DF=1*	*P < 0.01*	**
Palatal fissure v Buccal fissure	*Chi2=24.1*	*DF=1*	*P < 0.01*	**
Other comparisons	*not significant*			

ii/ second permanent molars

	RESTORATION Urethane	bisGMA	OCCLUSAL	BUCCAL	PALATAL
LOST	19 (66%)	4 (27%)	11 (25%)	15 (54%)	7 (44%)
RETAINED	10 (34%)	11 (73%)	33 (75%)	13 (46%)	9 (56%)
	n=29	n=15	n=44	n=28	n=16

Statistical Comparisons

Urethane v bis GMA	*Chi2=5.98*	*DF=1*	*P < 0.05*	*
Urethane based v Occlusal fissure	*Chi2=11.8*	*DF=1*	*P < 0.01*	**
Buccal v Occlusal fissure	*Chi2=6.05*	*DF=1*	*P < 0.05*	*
Other comparisons	*not significant*			

Table 4.18 **Areas of lost and retained fissure sealant on all permanent molar teeth after 1 year.**

i/ Lost and retained surfaces in restorations placed in 45 children ***aged 6-8 years.***

	RESTORATION	OCCLUSAL	BUCCAL	PALATAL
LOST	25 (56%)	20 (44%)	17 (77%)	14 (61%)
RETAINED	20 (44%)	25 (56%)	5 (23%)	9 (39%)
	n=45	n=45	n=22	n=23

ii/ Lost and retained surfaces in restorations placed in 67 children ***aged 9-11 years.***

	RESTORATION	OCCLUSAL	BUCCAL	PALATAL
LOST	46 (69%)	31 (46%)	31 (97%)	11 (31%)
RETAINED	21 (31%)	36 (54%)	1 (3%)	24 (69%)
	n=67	n=67	n=32	n=35

iii/ Lost and retained surfaces in restorations placed in 42 children ***aged 12 years or over.***

	RESTORATION	OCCLUSAL	BUCCAL	PALATAL
LOST	23 (55%)	10 (24%)	14 (70%)	2 (9%)
RETAINED	19 (45%)	32 (76%)	6 (31%)	20 (91%)
	n=42	n=42	n=20	n=22

Statistical Comparisons.

Age 6-8 v Age 9-11	*Chi ^{2}=12.01*	*DF=7*	*$P > 0.05$*	
Age 9-11 v Age 12+	*Chi ^{2}=19.15*	*DF=7*	*$P < 0.01$*	**
All age groups	*Chi ^{2}=30.03*	*DF=14*	*$P < 0.01$*	**

Table 4.19 **Areas of lost and retained sealant in first permanent molar teeth over three age groups.**

*i/ Lost and retained surfaces in restorations placed in 85 children who **co-operated well.***

	RESTORATION	OCCLUSAL	BUCCAL	PALATAL
LOST	56 (66%)	30 (35%)	32 (78%)	13 (30%)
RETAINED	29 (34%)	55 (65%)	9 (22%)	30 (70%)
	n=85	n=85	n=41	n=43

*ii/ Lost and retained surfaces in restorations placed in 61 children who **co-operated satisfactorily.***

	RESTORATION	OCCLUSAL	BUCCAL	PALATAL
LOST	40 (66%)	32 (53%)	31 (97%)	12 (41%)
RETAINED	21 (34%)	29 (47%)	1 (3%)	17 (59%)
	n=61	n=61	n=32	n=29

Statistical Comparison.

Good v Satisfactory - *Occlusal* $Chi^2=4.28$ *DF=1* $P < 0.05$ *

- *Buccal* $Chi^2=5.40$ *DF=1* $P < 0.05$ *

- *other surfaces not significant.*

Table 4.20 **Retention of fissure sealant to the various tooth and restoration surfaces dependant on the level of patients co-operation.**

J: The Effect of isolation method.

The effect of isolation is shown in Table 4.21 Few restorations were placed with rubber dam isolation. During the placement of 37 restorations, cotton wool rolls were used as the only means of isolation while an aspirator was also used during a further 86 fillings. The method of isolation did not significantly influence sealant retention ($P > 0.05$).

K: The Effect of the size of the composite filling.

In Table 4.22.1, the bucco-lingual width and extent of fissure pattern involvement is shown. There was a trend for the extent of the fissure pattern involvement to increase as the width of the composite restoration became greater. As the restoration increased in width and extent (see Table 4.22.2), sealant retention was shown to become significantly poorer ($P < 0.05$).

L: Results after 2 Years.

After two years, 53.9% (n=62) of the smaller intra-enamel composite sealant restorations and 61.3% (n=100) of the larger laminate restorations were successfully reviewed.

Table 4.23 outlines the details of the number and percentage of the reviewed restorations with intact, partially missing or completely missing fissure sealant. No difference in sealant retention could be demonstrated between the intra-enamel and larger laminate restorations ($P > 0.05$) at two years. Only 9.7 to 19% of the sealants were considered by the two assessors to be completely intact, while the majority of restorations had partially missing sealant (76 to 85.5%). When the number of reviewed restorations was restricted to those that had also been successfully reviewed after one year (Figure 4.21.2), a direct comparison of sealant retention was possible. No statistical difference could be shown between the restricted and unrestricted reviews ($P > 0.05$). Overall, fissure sealant retention in type 2 and 4 restorations was not different from that observed after 12 months (Type 2 restorations $Chi^2=2.59$ DF=2 $P>0.05$ and type 4 restorations $Chi^2=0.034$ DF=2 $P>0.05$).

i/ Lost and retained surfaces in 37 restorations placed using ***only cotton wool roll isolation.***

	RESTORATION	OCCLUSAL	BUCCAL	PALATAL
LOST	24 (65%)	13 (35%)	17 (90%)	5 (28%)
RETAINED	13 (35%)	24 (65%)	2 (10%)	13 (72%)
	n=37	n=37	n=19	n=18

ii/ Lost and retained surfaces in 86 restorations placed using isolation achieved witth ***cotton wool rolls and aspirator .***

	RESTORATION	OCCLUSAL	BUCCAL	PALATAL
LOST	56 (65%)	46 (53%)	38 (95%)	19 (41%)
RETAINED	30 (35%)	40 (47%)	2 (5%)	27 (59%)
	n=86	n=86	n=40	n=46

Statistical Comparison:
No statistical differences between similar surfaces with the two methods of isolation ($P > 0.05$)

Table 4.21 Surface retention of fissure sealant to first permanent molar teeth dependant on the method of isolation.

Extent of restoration	Width of composite restoration <1mm	1-3mm	> 3mm
< 1/3 fissure	**72.2%**	27.7%	0
1/3-2/3 fissure	2.9%	**93.4%**	3.6%
> 2/3 fissure	0%	29.0%	**70.9%**

Table 4.22.1 Distribution of composite restorations by width and extent.

	<1/3	**1/3-2/3**	**>2/3**	**<1mm**	**1-3mm**	**>3mm**
LOST	17 (47%)	85 (62%)	24 (77%)	12 (40%)	93 (63%)	21 (78%)
RETAINED	19 (53%)	52 (38%)	7 (23%)	18 (60%)	54 (37%)	6 (22%)
	n=36	n=137	n=31	n=30	n=147	n=27

Table 4.22.2 Retention of the sealant over the composite filling dependant on its width and extent.

Statistical Comparisons.

Sealant retention v restoration width $Chi^2=7.37$ $DF=2$ $P < 0.05$ *

Sealant retention v restoration extent $Chi^2=9.09$ $DF=2$ $P < 0.05$ *

Table 4.22 Retention of the overlying fissure sealant dependant on the width and extent of the composite restoration.

Fissure sealant retention.	Intra-enamel composite sealant restorations.	Laminate sealant restorations.
Completely retained	6 (9.7%)	19 (19%)
partially missing	53 (85.5%)	76 (76%)
completely missing	3 (4.8%)	5 (5%)
Totals	62 (100%)	100 (100%)

Statistical comparisons.

Differences between the sealant retention in the two types of composite sealant restoration:

Chi^2=2.59 DF=2 P>0.05

Table 4.23.1 Sealant retention in restorations reviewed after 2 years.

Fissure sealant retention	Intra-enamel composite sealant restorations.	Laminate sealant restorations.
Completely retained	5 (8.9%)	17 (17.9%)
partially missing	49 (87.5%)	73 (76.8%)
completely missing	2 (3.6%)	5 (5.3%)
Totals	56 (100%)	95 (100%)

Statistical comparisons.

Differences between the sealant retention in the two types of composite sealant restoration:

Chi^2=2.66 DF=2 P>0.05

Table 4.23.2 Sealant retention in composite sealant restorations reviewed after one and two years.

Areas of partially/completely missing and completely retained fissure sealant are shown in Table 4.23.2 Sealant retention in the buccal fissure still proved to be significantly poorer than that to all other surfaces ($P < 0.05$) while the retention of the fissure sealant to the surface of the composite restorations was significantly poorer than that to the adjacent pits and fissures of the occlusal surfaces. The performance of the sealant in the palatal fissure was not dissimilar to that noted for the occlusal surface ($P > 0.05$). Differences in the missing areas of fissure sealant were not significantly different from that observed after 12 months ($P > 0.05$). The poorer retention of fissure sealant in the palatal fissures after 24 months, compared to that after 12 months, fell just below the level of significance.

It was estimated that between 45.2 and 52% of the restorations would survive at least another two years before further treatment was required. The tabulated results are shown in Table 4.25 No difference could be demonstrated in the predicted life expectancy between the two types of composite sealant restoration ($P > 0.05$).

In Table 4.26 the factors associated with the performance of the composite filling are shown. No differences in performance could be shown between the smaller and larger composite fillings ($P > 0.05$) with regard to: sealant retention to the composite surface; marginal integrity of the filling to tooth interface; marginal discolouration around the composite periphery and surface wear of the filling material. Marginal discolouration around the periphery of the larger laminate restorations occurred in 16% of all restorations reviewed while only 9.6% of smaller composite fillings showed similar staining - the difference was not significant. Similarly, surface wear was not significantly different despite the greater number of laminate restorations (7%) showing loss of surface contour compared to smaller composite fillings (1.6%).

Although only 9.7 to 19% of the sealant restorations had completely intact fissure sealant, the assessors considered that only 46.7 to 51% of the composite sealant restorations required no treatment to allow them to continue in clinical function. After 24 months, 8.1 to 11% of the restorations required replacing due to either primary or secondary caries. The simple addition of further fissure sealant to previously sealed surfaces was found necessary in 38 to 45.2% of restorations. Treatment requirements for the two groups of composite sealant restorations shown in Table 4.27 were found to be statistically similar ($P > 0.05$).

	Restoration	Occlusal	Buccal	Palatal
Retained	63 (38.9%)	95 (58.6%)	25 (29.4%)	36 (49.3%)
Lost	99 (61.1%)	67 (41.4%)	60 (70.6%)	37 (50.7%)
	n=162	n=162	n=85	n=73

Statistical comparisons.

Differences between sealant retention and loss by surface for all composite sealant restorations after 24 months.

Restn v Occl. $Chi^2=12.65$ $DF=1$ $P < 0.01$

Bucc v Occl $Chi^2=19.07$ $DF=1$ $P < 0.01$

Pal v Occl $Chi^2= 1.77$ $DF=1$ $P > 0.05$

Bucc v Pal $Chi^2= 6.56$ $DF=1$ $P < 0.05$

Differences between the areas of sealant loss after 12 and 24 months.

$Chi^2= 4.76$ $DF=7$ $P > 0.05$

Table 4.24 **Areas of lost and completely or partially retained fissure sealant after 2 years.**

Life expectancy	Type 2	Type 4
immediate replacement	5 (8.1%)	11 (11%)
1 - 2 years	29 (46.8%)	37 (37%)
more than 2 years	28 (45.2%)	52 (52%)
	n = 62	n = 100

Statistical comparisons

life expectancy between type 2 and type 4 restorations

$Chi^2 = 5.878$ $DF=2$ $P > 0.05$

Table 4.25 Prediction of the estimated future life of the sealant restorations after 24 months.

	Type 2	Type 4
Presence of restoration:		
covered with sealant	37 (59.6%)	53 (53%)
no sealant covering	25 (40.4%)	47 (47%)
Marginal integrity:		
explorer catch	61 (98.4%)	98 (98%)
visible crevice - dentine not exposed	1 (1.6%)	2 (2%)
Marginal discolouration:		
no discolouration	56 (90.3%)	84 (84%)
around < 1/3 margin	3 (4.8%)	11 (11%)
between 1/3 and 2/3	1 (1.6%)	3 (3%)
around > 2/3 margin	2 (3.2%)	2 (2%)
Surface wear:		
absent	61 (98.3%)	93 (93%)
present	1 (1.6%)	7 (7%)

Statistical comparisons between type 2 and type 4 restorations.

Sealant over restoration $Chi^2 = 0.691$ $DF=1$ $P > 0.05$

Marginal integrity $Chi^2 = 0.035$ $DF=1$ $P > 0.05$

Marginal discolouration $Chi^2 = 2.389$ $DF=1$ $P > 0.05$

Occlusal wear $Chi^2 = 2.366$ $DF=1$ $P > 0.05$

Table 4.26 **Comparison of the performance of the composite restorations in the two composite sealant restoration types after 24 months.**

	Type 2	Type 4
No treatment required Addition of f. sealant. New restoration required.	29 (46.7%) 28 (45.2%) 5 (8.1%) n=62	51 (51%) 38 (38%) 11 (11%) n=100
Reason for new restoration Secondary caries Primary class 1 Primary class 11	 2 (40%) 1 (20%) 2 (40%) n=5	 3 (27.3%) 2 (18.2%) 6 (54.5%) n=11

Statistical comparisons between type 2 and type 4 restorations.
$Chi^2 = 3.65$ $DF=3$ $P > 0.05$

Table 4.27 Treatment requirements after 24 months.

4.8.4 DISCUSSION.

A: Introduction.

The data collected in this trial differ from that reported in carefully controlled clinical trials, where usually a single operator places restorations under ideal conditions of practice following a strict clinical protocol. In this field trial, the summated data from 14 Community Clinical Dental Officers is presented as a typical example of the performance of sealant restorations placed in the Community Dental Services. Seventy five percent of patients were successfully recalled after 1 year, during a time when the Service was being actively encouraged to have patients register with General Dental Practitioners on a capitation scheme. Paterson *et al* (1990) reported the wide acceptance of the sealant restoration technique among General Dental Practitioners for the management of pit and fissure caries.

In the current study, first permanent molar teeth contributed significantly to the total caries experience. Stamm (1984) observed that carious lesions in children under the age of 12 years occurred virtually exclusively in first permanent molars. Thereafter, lesions in second permanent molars became increasingly prevalent. The occlusal surfaces of teeth in the permanent dentition account for only 12.5% of all the available surfaces, yet this surface receives 60% of all new restorations placed (Wendt & Koch 1988).

B: Use of composite sealant restorations.

The combination of composite resin and fissure sealant in the management of fissure caries has expanded the available treatment options. Under the classification described in "Trends in the Management of Fissure Caries" (Scottish Home and Health Department, 1989), composite resin may be used in two types of sealant restoration. In the first, small cavities remaining in enamel can be restored with composite and fissure sealant, while in the second type, larger lesions involving dentine caries may be restored by placing a structural lining of glass ionomer cement followed by a composite and fissure sealant. The principal difference between the two restorations relates to the size of the composite filling. For this reason it was considered that these two restoration types could be considered together.

It could be argued that the small intra-enamel composite sealant restoration could be managed by placement of a fissure sealant alone (Dental Strategy Review

Group, 1981), but diagnostic uncertainty exists on the involvement of dentine by the carious lesion and the presence of occult caries. As few of the Community Dental Officers use radiographic examinations on a regular basis (see Chapter 1), minimally invasive techniques will improve their diagnostic certainty. If the caries lesion is found to be limited to enamel only, the technique can be abandoned at an early stage (Elderton 1985) with no lack of restorative benefit (Simonsen 1980).

The original technique presented by Simonsen and Stallard (1977) described the removal of only the carious lesion and restoration of the cavity with a diluted anterior composite resin (Concise, 3M). In a review of the Preventive Resin Restoration in 1992, Ripa and Wolff stated that lesions detected radiographically were too large to be restored using this technique. It could be argued, however, that improvements in the performance of composite resins make the laminate sealant restoration suitable for larger occlusal caries where cavity preparation - with minimal extension - would still leave fissures surrounding the cavity margins. Restoration of such minimally extended cavities using amalgam would result in imperfect margins in the region of the fissures. The provision of a laminate sealant restoration avoids the need to extend the cavity margins which would further weaken the tooth.

General Dental Practitioners responding to a postal questionnaire (Paterson *et al* 1990) showed the use of small composite and larger laminate sealant restorations to have been placed by 51% and 44% of the respondents. Returns to the Scottish Dental Practice Board during the six months period from October 1988 to March 1989 showed sealant restorations placed using composite and fissure sealant and laminate restorations to account for 28.2% and 13.1% of all restoration types involving the enamel biopsy or investigative cavity technique. In the current field trial involving the Community Dental Services, 22.1% and 31.3% respectively of similar restoration types were placed.

The mean ages of patients, in whom the two restorative techniques involving placement of composite were used, did not differ significantly and indeed did not differ from the group of patients receiving glass ionomer and fissure sealant restorations.

It is difficult to explain the similarity in the age groups over the three investigative techniques - particularly as one of the restoration types was limited to caries remaining localised within enamel. It may be that operators examining children of similar age groups will be suspicious of the presence of decalcified fissures occurring in children in an area of high caries prevalence. When therapeutic sealants were placed, the mean age of patients was approximately eighteen months younger which may have made the operators believe that caries would have been limited to enamel.

C: Materials and techniques employed.

As in the glass ionomer fissure sealant restorations, few intra-enamel sealant restorations were placed using a local anaesthetic. In the larger laminate restorations, local anaesthetic was administered on just over 70% of occasions: this implies that no local anaesthetic was used during the placement of approximately 30% of these restorations which extended into dentine.

The low use of local anaesthetic in the smaller cavity types would suggest that operators were sure of their ability to accurately estimate the extent of the lesion. In chapter 1, the accuracy of cavity size estimation showed that small type 2 cavities were accurately estimated in approximately 70% of occasions. In view of the good estimation of cavity size, it is more difficult to explain why dentists are unhappy to manage fissure caries by the application of a fissure sealant. It would appear that sealant restorations provide a minimally destructive technique which dentists find not only reliable but also allows them to eliminate the possibility of sealing caries within the tooth (Gift *et al* 1975 and Frazier 1984).

The use of diamond burs was favoured by 64 - 69% of operators for cavity preparation. Over 63% of each cavity type was prepared using round burs: in the larger type, however, there was a greater use of fissure burs. This is not surprising, as larger areas of unsupported enamel overlying the dentine lesion would require removal. Similarly, the use of larger diameter burs in larger cavity types is explainable by virtue of the greater amounts of tooth structure which require removal. Only 17.1% of the smaller intra-enamel cavities were prepared using ISO 008 diameter burs.

In the Community Dental Services a single ordering source exists for purchase of materials. This may explain the high reported use of Occlusin and Herculite in the restorations placed. Anterior composites were used during the placement of 34.9% of the restorations and may reflect either, use of the technique as originally described by Simonsen and Stallard (1977), or simply a limited stock of composite resin materials. Light cured fissure sealants were used significantly more than the self cured variety. This is in contrast to the findings in the glass ionomer sealant restorations and show the preference for this form of polymerisation where curing lights are available.

In the restoration of the larger laminate sealant restoration, 11% of the fillings placed were lined with a setting calcium hydroxide as recommended in the original descriptions of the preventive resin restoration (Simonsen and Stallard, 1977). Problems with the diagnosis of recurrent caries below laminate restorations on radiographic examination are to be expected because 58% of the laminate restorations were lined using a radiolucent glass ionomer cements. As in the glass ionomer and fissure sealant restorations, 35% were etched before applying the composite restoration. The problems of etching recently placed glass ionomer cements will be discussed in Chapter 5. No differences in etchant materials or times were noted among the two types of composite or glass ionomer sealant restorations. Following etching, mechanical interlocking of the composite resin to the prepared enamel will reduce gap formation between the cavity walls and the restorative material, making microleakage unlikely (Ripa & Wolff 1992). The presence of the fissure sealant over the filling, its margins and adjacent fissures will reduce leakage still further. The effect of omitting the etch regime and diluting the composite filling material was investigated by Raadal (1978). He reported that diluting the filling material did not increase microleakage, provided that the cavity walls were etched.

D: Performance of composite sealant restorations after six months.

The retention of fissure sealant in teeth restored with composite sealant restorations was found to be slightly better than that reported for the glass ionomer sealant restoration. As with the glass ionomer sealant restorations, the presence of a filling reduces the retention rate of the sealant. This may have arisen due to the longer treatment time required to place such restorations: with increased operative time, patient cooperation frequently reduces and there is an increased risk of contamination of the etched enamel surfaces. Although the time taken to place a laminate restoration would be longer than that required for placement of a small intra-enamel composite sealant restoration, no difference was found in the sealant retention. In the group of patients receiving laminate restorations, a local analgesic was commonly given: this may be responsible for the continued patient cooperation when discomfort is minimised.

The retention of sealant after six months is disappointingly poor compared to other published results (Simonsen & Stallard 1977 and Simonsen 1980). In the carefully controlled trial by Simonsen & Stallard (1977), the selected teeth were rejects from a preventive fissure sealant study where the teeth were noted to have minimal caries lesions.

After only six months clinical performance, surface wear of the larger laminate restorations was noted. As these restorations are wider and more extensive, wear in the occlusal contact areas is possible (Roulet 1988), particularly with the high reported use of composite resins more suited to anterior restorations. Walls *et al* (1988) reported loss of anatomical contour on the surface of small composite restorations in 2.8% of their treated teeth after two years. The 5-year results of the same group of patients were published by Welbury *et al* (1990) and showed surface wear in 9.7% of the composite restorations: surface wear resulting in need for replacement of the filling was noted in one restoration after only eight months. The restorations in the latter study that exhibited surface wear occupied on average 13% of the occlusal surface, compared to 5% for those restorations not showing signs of loss of anatomical form. These results would then be in accordance with the higher wear rates noted in the current field trial with the larger laminate restorations.

Composite sealant restorations need either minimal or no treatment after six months to allow them to continue in clinical function. The repair of fissure sealants during a clinical trial has been shown to still provide a high success rate in reducing caries (Bagramian *et al* 1978 & 1979, and Rantala 1979). Walls *et al* (1988) warns of the dangers in interpreting low levels of new caries, as early diagnosis of new primary fissure lesions is difficult in the shorter term.

The greatest problem appeared to be the need for replacement of the restorations as part of a cavity extension while treating approximal caries. After six months, eight caries lesions became clinically evident on an approximal tooth surfaces. Greater use of regular radiographic screening for approximal caries lesions would prevent placement of restorations, localised to only the occlusal surfaces, when approximal lesions are also present. Further operative treatment to the tooth would not be necessary within a short period.

E: Results after 1 year: treatment required after one year.

After 1 year, Simonsen and Stallard (1977) reported complete retention of fissure sealant over all restorations placed in a carefully controlled clinical trial. In the current field trial using multiple operators, 85% of the restorations required either no treatment or the simple addition of small amounts of fissure sealant after one year. It was considered that further additions of fissure sealant were required where there was stain and decalcification in exposed fissures, or if there were more than 2 or more other active lesions elsewhere in the dentition, indicating a high risk of further caries.

Seven composite fillings (3%) were lost in the reviewed sample and this probably represents a failure in operator technique. This could be due to contamination of the etched cavity surfaces, failure to use a bonding resin on the etched cavity walls and floor, or failure to adequately cure composite increments of greater than 2mm. thickness (Wilson 1990).

F: Factors influencing fissure sealant retention to restorations and fissures in composite sealant restorations .

Raadal (1978b) reported that the presence of a restoration did not reduce fissure sealant retention. This finding is in direct contrast to the current study, where a significantly greater loss of sealant occurred from the surface of urethane composite restorations than from the adjacent occlusal pits and fissures. In the current study, however, no difference was observed between the retention to the surface of bisGMA composite and that to the adjacent occlusal pits and fissures.

Loss of sealant from the surface of urethane based composite resins was significantly greater than that from surfaces of bisGMA composite resins. The data from the laboratory investigations described in Chapter 6 show significantly lower mean shear bond strength values when resin systems in the filling and fissure sealant are mismatched. Although urethane resins contain methacrylate groups, there is a reduction in bond strength when resin systems are mixed. Alternatively, differing thermal expansion co-efficients may stress the union between the two materials leading to their adhesive failure.

The size of the composite filling influences the retention of the fissures sealant: as the bucco-lingual width of the filling increases, a smaller area of enamel will be present on the cusp slopes to which the unfilled fissure sealant resins may micromechanically retain. This may reduce the retention of the fissure sealant and, should it flex over the composite filling (due to different thermal expansion co-efficients), it could be lost leaving a defined margin around the periphery of the composite filling. Neither the age nor the cooperation of the patient influenced the retention of the sealant to the surface of the composite restoration. Where fissure sealant was lost from the surface of a composite resin filling, a definite edge could be detected which coincided exactly with the surfocaval margin of the restoration. This would indicate clearly that wear of the sealant was not responsible for this observation.

It would appear that failure of the bond to the restoration surface, combined with the known excellent bond strength of sealant resin to etched enamel, has resulted in an area of stress between these two surfaces.

Retention of sealant to the buccal fissure appears to be problematic. Operators were asked to ensure sealant was extended into adjacent occlusal and buccal/palatal fissures. As the mean age of the patients who had sealant restorations placed in first permanent molar teeth was over 10 years, these teeth should have been fully erupted and not precluded the placement of sealant in the buccal fissure. This surface is easily contaminated by saliva, yet no difference in sealant retention was found between operators using cotton wool rolls alone and those who also used a saliva ejector or aspirator as a means of isolation. In a report by Straffon *et al* (1985), sealant retention was unaffected by placement under rubber dam or when placed using cotton wool roll isolation. Sixty one per cent of the additions of further sealant in his study were to mandibular molar teeth.

The age of the patient at the time of restoration placement and their likely ability to cooperate with the operator were significant factors in achieving improved retention to buccal fissures. These factors may indirectly influence the ability to maintain a dry working field which can result in early failure of fissure sealant. Retention of sealant in the palatal fissures of maxillary molar teeth was better than to all other tooth surfaces. Isolation of this surface is easier to achieve, as the operator may shield it from salivary contamination by the tongue using the dental mirror or aspirator. This might explain why improved levels of sealant retention to palatal fissures were obtained even in the mouths in children where cooperation was limited.

G: Caries incidence in the trial group.

Interestingly, the DMFT and proportion of carious surfaces (PCS) were higher in patients who developed cavitated lesions in previously sealed fissures. Mitchell and Murray (1987) found 3.1% of previously sealed surfaces in 3017 teeth from 486 children attending Newcastle Dental School developed new caries. In the current study, the comparable prevalence of new caries was 7.6%. The difference between the caries prevalences can be explained by the dissimilarity in the protocol of the studies and in the caries rates endemic in the two areas. In the Mitchell and Murray study, the patients came from an area supplied with fluoridated water and each had multiple fissure sealants placed as a preventive measure. In the current study, only one restorations was placed per patient. These patients all lived in the non-fluoridated West Coast of Scotland which has the highest level of caries prevalence in mainland Britain (Pitts and Davies 1992). By restricting the number of restorations placed per patient, the individual caries experience of patients will not significantly influence the overall caries prevalence. The caries prevalence in the Newcastle study represents a 59% reduction in caries compared to the non-fluoridated West Coast of Scotland.

H: Performance After Two Years: factors influencing recall rate after two years.

Although only 53.9 to 61.3% of the composite fissure sealant restorations were reviewed after 2 years, the reviewed number of restorations was still sufficiently high to place confidence in the results obtained. It may be argued that the remaining patients may be more highly motivated and more regular attenders. However, over the past two years there has been considerable movement of patients away from the areas of previous domicile, due to closure of steel mills and the general high redundancy prevailing in Strathclyde Region. In addition, in parts of Glasgow, refurbishment of homes in the mainly social class IV and V areas has been progressing, resulting in the decanting of families to other areas of the city. It has been the experience of the Community Clinical Dental Officers that patients may be lost from recall for up to a year, but some will return when the family unit is reunited. Zoitopoulos and Jenner (1991) reported that 16.5% of previously well motivated patients were lost from recall when they were referred to the General Dental Services. In the current study, the patient group did not all consist of well motivated dental patients and, therefore, the fall in attendances following social upheaval is likely to be considerable greater.

I: Retention of fissure sealant after two years.

Overall fissure sealant retention between the two types of composite sealant restoration was similar, despite the difference in size of the composite filling ($P > 0.05$). It was interesting that the performance of the fissure sealant was not dissimilar from that observed after six months or after one year ($P > 0.05$). It would appear, therefore, that sealant failure occurs predominantly in the first six months following placement - this would support the view that incorrect attention to detail during the placement of the sealant is of paramount importance for its long term retention. Walls *et al* (1988) discussed the importance of simultaneous cure of fissure sealant and composite resin to avoid stressing the junction between the two materials when they are polymerised consecutively. These authors recommended the use of composite and fissure sealant materials from the same manufacturer to ensure complete compatibility. It is likely that salivary contamination has resulted in early loss of sealant from the buccal fissures of molar teeth in the current study, but the higher loss of sealant from the surface of the composite resin than from the adjacent fissures surrounding the restoration, is more difficult to explain but has been addressed already .

J: Performance of the composite resin restoration after two years.

The performance of the composite filling itself was satisfactory, with only up to 16% of the restorations showing signs of marginal discolouration and 7% surface wear. Neither problem was of sufficient magnitude to consider replacement of the restoration. Wilson *et al* (1986) discussed the problem of marginal discolouration and suggested that this could be due to factors other than microleakage. In the context of the current study, loss of sealant from the surface of the composite filling will leave a ledge where plaque could collect. Wilson *et al* (1986) discussed that marginal stain was more common in patients with poor oral hygiene and who had a tendency to form extrinsic staining of the teeth. It could follow, therefore, that the observed staining around the periphery of the composite sealant restorations could be due to extrinsic staining.

The small number of composite fillings which showed loss of anatomical contour after two years all belonged to the laminate sealant restoration group. These fillings were, therefore, greater in width and extent than the smaller intra-enamel restorations. Walls *et al* (1988) found a low incidence of surface wear in a series of small composite sealant restorations placed in a carefully controlled dental hospital environment. The two restorations that these authors reported as being affected by surface wear occupied a greater surface area than the others in the group. In the present study, only 1 restoration exhibited surface wear in the small intra-enamel sealant restoration group, while 7 composite fillings in the laminate group had suffered the same consequence. The rate of wear in the study was lower than that anticipated and most probably reflects the minimal nature of the cavity preparation which serves to protect the composite surfaces from *in vivo* wear.

K: Maintenance / expected survival of composite and fissure sealant restorations after two years.

At regular recall visits, it has been observed that there is a need for routine maintenance of sealant restorations. This consisted of additions of small additional amounts of fissure sealant - a procedure that can be quickly and painlessly performed. Using the re-treatment criteria suggested i.e. replacement of fissure sealant where the previously sealed fissure is now decalcified or where there are more than two other active caries lesions in the dentition, has shown a conservative life expectancy where 45.2 to 52% of the composite sealant restorations were expected survive another two years. The main reason for excluding restorations from further recall after 2 years was due to the development of new primary caries affecting the approximal surfaces of permanent molar teeth following the eruption of the premolar teeth.

4.8.5 CONCLUSIONS.

1. The mean age of patients receiving composite and sealant restorations in first permanent molars was 10.07 - 10.79 years i.e. 4 years after tooth eruption. Similarly, in second molars the mean age of placement was 14.01 - 14.14 years.

2. Local anaesthetic was used during the placement of only 71% of the laminate restorations.

3. Round diamond burs were favoured for the enamel biopsy technique. Bur diameters of greater than 1.2mm were preferred.

4. All of the fissure sealant materials used by the CDOs were based on bisGMA resins while 57.9% of the restorations placed used a urethane based composite resin. There was a strong preference for the light cured fissure sealants which were cured for longer than 40 seconds on 71.3-80.2% of occasions.

5. Only 36.5% of laminate restorations were placed using a radio-opaque glass ionomer lining cement. This may result in future problems with the radiographic diagnosis of recurrent caries using radiographs.

6. Only 4.3 - 6.7% of teeth were etched for less than 30 seconds. Most operators etched for 31-45 seconds,

7. After 6 months only 24.7 - 27.8% of restorations had intact fissure sealant and in 4.6 - 10.3% of restorations the sealant was completely lost.

8. No difference in the treatment needs could be demonstrated between the two composite resin and fissure sealant restoration types.

9. After 12 months clinical service, 85% of composite fissure sealant restorations required either no treatment or minor additions of fissure sealant.

10. Caries occurred in 7.6% of teeth where fissures had been exposed by loss of sealant.

11. Improved retention of sealant was found with increasing age of patient at time of restoration placement and with good levels of patient cooperation.

12. Problems were observed with the retention of bisGMA fissure sealant to the surface of urethane composite restorations and also in buccal fissures of mandibular molar teeth.

13. Loss of sealant from the surface of composite fillings was influenced by the size of the restoration.

14. Sealant retention after 2 years was not dissimilar to that observed after 6 & 12 months.

15. After 2 years, the larger laminate restorations showed a higher rate of marginal discolouration.

16. The principal reason for the elimination of composite resin and fissure sealant restorations from the field trial was the diagnosis of approximal caries in the treated tooth.

17. A conservative life expectancy of 3-4 years was observed in 37 - 46.8% of composite resin sealant restorations, while 45.2 - 52% had a life expectancy greater than 5 years.

Chapter

5

A Field Trial of Glass Ionomer (Polyalkenoate) Cement and Fissure Sealant Restorations in the Management of Pit and Fissure Caries in the Community Dental Service.

Chapter 5

Literature Review.

5.1 Development of glass ionomer cements.

The Laboratory of the Government Chemist (see Wilson and Kent 1971 and 1972) developed a new dental cement - glass ionomer cement - for the restoration of teeth. The official International Standards Organisation (ISO) terminology for this cement is glass polyalkenoate cement. The cement was developed further for clinical use by McLean & Wilson (1974) and Crisp *et al* (1975). The objective of this newly developed cement was to combine the advantageous properties of the two parent materials: dental silicate and zinc polycarboxylate cements.

McLean & Wilson (1978) described the best attributes of the silicate cements as the properties of low thermal expansion, high resistance to abrasion in the absence of an acidic environment and their cariostatic affect due to release of the fluoride ion. Smith (1968) reported on the hydrophillic properties of polycarboxylate cements which also had a reasonable adhesion to tooth structure. The material was also reported to be "bland" on biological testing. The polyalkenoate cements have been shown by McLean (1977a) to have a similar strength as dental silicate cements. Adhesion to tooth structure is by physicochemical means via polar and ionic bonding.

5.1.1 Development of the glass.

Glass composition varies greatly but all are based on a calcium aluminium fluorosilicate. Barry *et al* (1979) reported on one of the original glass compositions which principally contained silica, aluminium oxide and calcium fluoride. Walls (1986) reviewed the literature and listed the composition of the glass as containing quartz, alumina, cryolite, fluorite, aluminium trifluoride and aluminium phosphate.

Kent *et al* (1979) found the ratio of alumina and silica to be critical in the production of a glass which would be susceptible to acid attack. When the alumina content is increased, the compressive strength of the glass is increased but with the accompanying disadvantage of the glass becoming opaque.

The constituents of the glass are fused at a temperature of between 1100^{0}C and 1500^{0}C before quenching in water and grinding to a particle size of 50 micrometers for restorative materials and around 20 micrometers for luting cements (Wilson & McLean 1988). Fusion at high temperatures produces a more reactive glass which is virtually unusable because of a limited working time (Barry *et al* 1979).

Sced & Wilson (1980) described the incorporation of alumina fibres or amalgam powder into the cement with varying effects on the flexural strength. Resistance to abrasion was found to be poor and the aesthetics were adversely affected. McLean & Gasser (1985) developed the cermet-ionomer cements in an attempt to improve abrasion resistance and strength. In this type of cement, precious metals are fused with the calcium fluroaluminosilicate to produce a glass which imparts the cement not only with improved abrasion resistance but also better flexural strength.

5.1.2 Development of the acid.

The polyalkenoate acids used in glass ionomer cements were described by Wilson & McLean (1988) as polyelectrolytes. Such substances are both polymers and electrolytes and as such are soluble in water. Crisp *et al* (1980a) described the polyacids as being either homopolymers **or** copolymers of unsaturated mono-, di-, and tri-carboxylic acid. The most effective acrylic acid copolymers are those with itaconic acid and those with some of the alkenoate acids - maleic and fumaric principally.

Originally, a 50% solution of acrylic acid was used but found to be unstable on storage due to gelation in a time period of 10 - 30 weeks. Crisp *et al* (1975) reported this to be due to slow but continual hydrogen bonding which produced cross linking between the polymer chains. Crisp *et al* (1977) reasoned that if the polymer chains could be made less regular they would not cross link. Initial attempts failed when it was found that, clinically, cements stained when methylation of the polymer had been utilised to disorder the acid chains. The incorporation of copolymers with acrylic acid also had the desired effect of disrupting the organised chain pattern and this produced a stable and marketable cement.

Prosser *et al* (1986) reported that increased molecular weight and acid concentration were important factors in producing a cement with good physical properties. When either is increased, however, the viscosity of the liquid is markedly raised making the cement paste more difficult to mix and manipulate. Freeze drying of the polyacid and its incorporation into the powder were methods used to overcome mixing difficulties - distilled water or a solution of tartaric acid could be used to achieve a workable cement mix.

Initial studies with glass polyalkenoate cements were disappointing due to the minimal working time and sluggish setting characteristic of the cement. In 1976, Wilson *et al* discovered that small amounts of tartaric acid added to the polyacid solution resulted in an increased and adequate working time, with a shorter and sharper set. Walls (1986) reported this "chelating comonomer" to be present in all commercially available cements and its discovery had made the polyalkenoate cements commercially viable.

Previously, in an attempt to obtain adequate handling characteristics, the fluoride concentration of the glass had been increased but this produced a cement with poor translucency.

5.2 The setting reaction.

Overall, the setting mechanism is an acid base reaction between the weak polyalkenoate acid and the basic ion-leachable glass. The setting reaction is complicated by the presence of two markedly dissimilar ions in the glass: calcium and aluminium. Crisp & Wilson (1974a & 1976c) described the setting reaction as occurring in two distinct phases: dissolution and gelation.

5.2.1 The dissolution phase.

The polyalkenoate acid degrades the surface of the glass particles resulting in the release of calcium, aluminium and fluoride ions (Crisp & Wilson 1974a). The glass breaks down into a salicic acid which is left on the surface of the glass powder. The resulting cement sol which forms around the glass cores has a greater concentration of calcium ions, because the aluminium ions which are released form more stable complexes with the fluoride.

Acid attack on the glass surface is not uniform, but occurs at sites which are rich in calcium (Barry *et al* 1979). Walls (1986) also postulated that the diffusion of aluminium ions into the sol would be slower due to its trivalent nature and its greater ionic radius.

5.2.2 The gelation phase.

Ions released from the glass accumulate in the sol before being removed in precipitation with the polyalkenoate acids. After a certain stage, the cement sets, but there is still a continual precipitation which is responsible for the increase in hardness. Barry *et al* (1979) showed that the initial set was due to the formation of calcium polyacrylate, while Crisp & Wilson (1974b) demonstrated a predominance of aluminium polyacrylate in the final set.

Mount & Makison (1982) reported that although the cement may have reached an initial set, many cement forming ions were still in solution and may be lost from the cement if it were to be contaminated with water at an early stage. This would result in a weaker cement with an opaque surface. In an attempt to reduce the vulnerability of the initial set cement, Schmidt *et al* (1981) attempted to remove calcium ions by washing the glass surface of the powder in acids. This was found to delay initial set but still provided the mix with excellent working and setting characteristics.

Hardening and precipitation of ions continue for approximately twenty-four hours, during which time there is a slight expansion of the cement and an improvement in translucency. Crisp *et al* (1976b) reported that the strength of the cement increased logarithmically for approximately a year - a phenomenon Wilson *et al* (1981) attributed to a gradual hydration of the cement.

Walls (1986) described four mechanisms responsible for the rate of reaction:

a/ **Temperature:** The temperature of the substrates influences the rate of the reaction. Mount & Makison (1978) described a method to increase the working time by cooling the mixing slab.

b/ **Powder liquid ratios:** The ratio of powder to liquid and the surface area of the powder are important in determining the law of mass action. Crisp et *al* (1979a) showed the working and setting times were reduced in cements with small glass particle sizes.

c/ **Fluoride ion:** Low fusion temperature glasses have a large moiety of fluoride ion which is released when the glass is attacked by acid (Barry *et al* 1979). As this results in more ions in solution at a lower pH, the workability of the cement is maintained for a longer period before it undergoes a rapid and sharp set.

d/ **Tartaric acid:** Wilson *et al* (1976) described the role of tartaric acid as acting as an acidic chelating agent which could hold metallic ions in solution and prevent the ionisation and unwinding of the polyacid chains. Tartaric acid preferentially attacks the glass and results in a more rapid extraction of aluminium ions which it can hold in solution as complexes with fluoride ions (Prosser *et al* 1982). The greater the concentration of tartaric acid, the longer the working time and the lower the concentration of fluoride that need be incorporated in the glass. This results in better working characteristics and improved translucency of the set cement.

5.3 Structure of the cement.

Brum and Smith (1982) described the set cement as containing unreacted glass particles surrounded by a silicious hydrogel containing few aluminium ions. The glass cores are embedded in a polyalkenoic acid matrix which is cross linked with metallic ions. In the fully set cement, aluminium ions predominate. The bond between the hydrogel and the glass core is weak (Wilson & McLean 1988). These authors also reported that smaller glass filler particles were degraded entirely by the action of the acid to form siliceous hydrogel.

5.4 Physical properties.

In the mouth, glass ionomer cement sets in three to five minutes to form a material which chemically adheres to tooth structure. The cement is generally described as brittle in nature but when immature, it will deform under load in a plastic manner. At 24 hours, these materials have a high compressive strength of between 164 and 175 MPa but a low tensile strength of between 11.7 and 13 MPa (Crisp *et al 1975*). The compressive strength of some of the newer encapsulated materials is lower than that of the corresponding hand-mixed versions. Gee & Pearson (1993) suggested this could be due to the use of lower molecular weight polyacrylic acids necessary for incorporation into the encapsulated system.

Four factors appear to affect the physical properties of the set material:

A: Variations in powder formulation.

If particle size is reduced, the specific surface area is increased with a correspondingly faster rate of set to produce a cement with improved strength. Wilson & McLean (1988) attempted to replace the calcium ions with those of barium, strontium or lanthanum to provide radio-opacity and found that only strontium could replace the calcium without producing a cement with poor translucency.

When Prosser *et al* (1986) increased the proportion of dispersed phase in the glass, the flexural strength of the cement could be doubled. Suitable material for disperse phasing could include corundum, baddeleyite and rutile.

The incorporation of alumina fibres into the cement was attempted with limited success by Sced & Wilson (1980). Although the flexural strength could be significantly increased, the abrasion resistance was found to be poor. The latter workers also described the incorporation of amalgam alloy into the mix in an attempt to improve the physical properties, but Moore et *al* (1985) found that this reduced the abrasion resistance of the cement.

McLean & Gasser (1985b) described the cermet-ionomer cements which were unlike the mixtures of amalgam alloy into the glass ionomer powder: they consisted of gold or silver sintered with the calcium fluroaluminosilicate glass to produce a powder which retained its characteristic properties. Additionally, the cermets had improved handling properties and a low porosity due to the more rounded glass powder. The cermets have dramatically improved abrasion resistance which McKinney *et al* (1986) postulated was due to a lubricating effect which the silver particles imparted to the cement surface. An alternative suggestion by McLean & Gasser (1985b) was that the sintered metal in the glass lowered the coefficient of friction.

B: Variation in powder/liquid ratios

When the amount of powder in the cement mix is increased, the working and setting times of the cement are decreased, but it provides both an early increase in hardness and ultimate compressive strength (Crisp *et al* 1976c, 1977). The same group of workers also found that when the molecular weight of the polyacids was increased, a similar decrease in working and setting times was obtained. This produced a set cement with increased compressive strength.

C: Hydration of the cement.

On setting, the matrix and hydrogel are hydrated with the water content in two forms: "loose" and "tight" water. The latter is tightly bound within the matrix structure and cannot be subsequently lost (Elliot *et al* 1975), while the former can be lost through desiccation (Saito 1978) or absorbed through an unprotected surface producing an alteration in surface colour and roughness (Phillips & Bishop 1985). Hornsby (1980) stated that loosely bound water was labile and that the cement was only stable in 80% relative humidity. He also reported that this effect could be advantageous as water absorption, in the conditions of high humidity in the oral cavity, would result in hydroscopic expansion exceeding the setting contraction.

Paddow & Wilson (1976) described an increase in the ratio of tightly bound water as the cement ages. They attributed the increase in strength to this change.

Water also plays an important role in the setting reaction and structure of the cement because it is the medium into which the released ions are liberated and where they may react with the polyacid chains. Loss of water from the set cement is equally damaging through desiccation - Philips & Bishop (1978) observed that different cements showed variation in the time of vulnerability. Damage may also be caused by early contact of the initial set cement with water resulting in surface disruption (Causton 1981). If the surface is protected for the first 60 minutes following placement of a restoration, the problem of surface roughness should not occur (Mount & Makison 1982). Earl *et al* (1985) reported that there was no ideal material to coat the surface of the recently set cement: copal ether varnishes were not entirely effective and the application of a petroleum jelly was not suited to all clinical situations. The best solution appeared to be the application of a light cured resin.

Causton (1981) described an increase in cement strength as the specimens aged. This was thought to be due to alteration in the ratio of tight bound water, as the loose water was lost.

D: Porosity within the Cement.

Smales & Joyce (1978) found set glass ionomer cement to be four times more porous than a two paste chemically cured composite resin. They concluded that within a brittle material, the porosity would produce stress foci which would ultimately result in fracture of the cement below its tensile strength.

5.5 Solubility and erosion.

The dissolution or solubility of the glass ionomer cements in aqueous solutions does not appear to have the consequences of similar dissolutions in other acid base reaction cements. Crisp *et al* (1980b) showed that the majority of ions lost in the first 24 hours were not ions responsible for matrix formation. Aluminium ions were shown to dissolve from immature cement on immersion during the first hour following initial set. Thereafter, however, virtually no matrix forming ions were leached.

Oilo (1984) reported on the high susceptibility of the glass ionomer cements during the first 5 to 10 minutes. On exposure of the cement to eroding solutions, there is a loss of all matrix forming ions. The severity of erosion is dependant on the pH of the solution and the stability of the complexes formed between the matrix ions and the anions in the acid (Beech & Banyopadhyay 1983).

There appears to have been little research on erosion of glass ionomer cements in the alkaline conditions that can be experienced in the oral cavity following tooth brushing with certain dentifrices. McCabe (1982) reported an increased erosion under agitated conditions at a pH of 11.5.

5.6 Fluoride release.

Lind *et al* (1964) described the "elution" of fluoride ions from dental silicate cements and it has been found that the amount of fluoride released from the glass ionomer cements is of an even greater magnitude (Forsten 1977, Causton 1981). Provided eluted ions do not form part of the matrix of the set cement, there does not appear to be any detrimental effects and indeed the release of fluoride ions locally may have a cariostatic affect.

The literature would appear to indicate that not only is there a greater amount of fluoride released, in comparison to dental silicate (Forsten 1977), but that the rate of elution is greater under acidic conditions (Matsuya *et al* 1984).

Kuhn & Jones (1982) suggested that glass ionomer cements could take up fluoride from the local environment in a similar manner to dental silicate cements. This was said to occur when the fluoride ion gradient was in the correct direction. Fluoride released from glass ionomer cement may have an effect on the tooth structure neighbouring the cavity walls (Wesenburg & Hals 1980). Although released fluoride appears to result in the precipitation of calcium and phosphate ions in the cavity walls, the fluoride becomes bound within the enamel. Retief *et al* (1984) showed that with cementum, a similar binding did not take place as fluoride was gradually lost again with time.

Garcia & Charbeneau (1981) showed that plaque formed in normal quantities on the surface of glass ionomer restorations while Jenkins (1978) reported that the formed plaque could concentrate fluoride. Plaque fluoride levels rise following the use of a fluoride containing rinse or toothpaste (Birkeland *et al* 1971) and this led Walls (1986) to reason that glass ionomer cement could act as a fluoride reservoir. Recent unpublished work by Strang *et al* showed that the potential for fluoride uptake and subsequent release is far greater than had originally been anticipated.

5.7 Bonding reaction and bond strength to tooth structure.

Glass ionomers, like polycarboxylates have the ability to form permanent bonds with both enamel and dentine. When bonding to enamel, it is uncertain if the cement bonds directly to the enamel or to surface pellicle: when bonding to dentine, the cement has been shown to bond with the smear layer. Glass ionomer cements have been shown to bond with polar substrates such as base metals.

Aboush & Jenkins (1986) reported that 80% of the bond strength is developed within the first 15 minutes, while Powis *et al* (1982) found the strength to continue to increase slowly over a few days. Wilson & McLean (1988) argued that the adhesive bond to tooth structure is due to chemical means and sited the decreased bond strength to dentine as evidence of its increased moiety of collagen.

Smith (1968) postulated that the polyacid chelated with the calcium ions in tooth structure but this was refuted by Beech (1973) who claimed that this would involve the formation of an eight membered ring which is unstable. Wilson (1974) suggested that when the cement is applied to the cavity in its fluid and unset state, hydrogen bonds would form between the free carboxyl groups on the acid chains. He then stated that these bonds would be replaced with ionic bonding as the cement aged. This work was confirmed by Beech (1973) who, using infra-red spectrometry, indicated an ionic bond formed between the polyacrylate and apatite of tooth structure.

In 1983, Wilson *et al* postulated that the polyacrylate could enter the apatite crystal and replace phosphate groups. In a complex series of reactions, both phosphate and calcium ions were displaced from the tooth structure and formed an intermediate layer of aluminium and calcium phosphates on the interface between tooth and restorative material.

The literature on glass ionomer bonding to dentine has no definite agreement: Beech (1973) postulated the presence of only ionic bonding to calcified tooth structure while Wilson (1974) proposed hydrogen bonding to the carboxyl and amino groups on the collagen in the dentine matrix. More recent work by Jackson (1986) failed to demonstrate any bonding to collagen.

5.8 Biocompatability.

As these materials must be brought into intimate contact with the calcified tooth structure to which they will bond, it is imperative they exhibit good biocompatability. Biocompatability studies have been reported both *in vitro* and *in vivo.*

Two groups of workers, Dahl & Tronstad (1976) and Meryon *et al* (1983) found freshly mixed cement was cytotoxic to cell cultures, while the work by Kawahara *et al* (1979) did not support this view. The latter authors, however, found that there was inhibition of cellular proliferation. Meryon *et al* (1983) reported an exaggerated response when luting glass ionomer cements were used but qualified their results by showing the cellular response was modified when dentine was placed between the cement and the cell culture.

In animal studies using ferrets and monkeys, Tobias *et al* (1978) and Kawahara *et al* (1979) reported only mild pulpal responses comparable with those seen when zinc oxide and eugenol were employed. In 1987, Paterson & Watts reported on work involving use of germ-free rats. When rat molars were exposed and pulp capped using glass ionomer cement, there appeared to be an area of aseptic necrosis with inhibition of repair from the surrounding tissue.

Tobias *et al* (1978) and Plant *et al* (1984) reported on studies involving placement of glass ionomer restorations in caries free premolar teeth. Subsequent extraction and histological sectioning revealed an inflammatory response greater than that produced with zinc oxide and eugenol, but less than that reported when zinc phosphate cement was employed. In 1983, Meryon *et al* reported data which confirmed previous work by Cooper (1980), where luting glass ionomers appeared to exhibit greater cytotoxicity. The response of the gingival tissue to placement of glass ionomer restorations in the cervical third of the tooth structure has been reported by Garcia & Charbeneau (1981). These authors found no difference between the test and control sites.

In a review of the literature in 1986, Walls discussed the reasons why there did not appear to be a marked pulpal response to the low pH of the cement. He postulated that the large polyacid molecules would not permeate the dentinal tubules, due not only to their large size, but also the ability of these acids to bind to calcified tooth structure. He cited the work of Lindemann *et al* (1985) who showed the smaller acid molecules of EDTA did not penetrate the tubules as they had the ability to chelate with the calcified tooth structure.

The literature would appear to suggest that there is no need for a lining to be placed below below glass ionomer restorations except where the cavity is deep - a sublining of a setting calcium hydroxide should be used in these circumstances. Dentine pre-treatment would not appear to be advocated. In animal studies, Tobias *et al* (1978) noted that irreversible pulpitis occurred only in cases where acidic pre-treatment had been employed.

5.9 Clinical performance and usage.

The manner in which operators use materials and the variations in patient cooperation may result in poorer clinical performance than would be anticipated from the results of *in vitro* laboratory testing.

Although manufacturers recommend a powder:liquid ratio of 3:1, Mount & Makison (1978) found marked variation in the ratio employed by dentists when using a powder/liquid glass ionomer cement. In a subsequent paper, the same researchers recommended the use of encapsulated forms of cement to achieve consistent results (Mount & Makison 1982). Mention has already been made of the need to protect freshly placed glass ionomer to prevent a reduction in their physical properties and the development of surface roughness and opacity. McLean & Wilson (1977b) advocated the application of varnish while Saito (1979) also recommended the application of cocoa-butter. Earl *et al* (1985) found most proprietary agents supplied by the manufacturer reduced water movement to and from the glass ionomer cement during setting and restorative procedures.

The matching of both colour and translucency has been disappointing. Knibbs *et al* (1986) reported two year data on class lll ChemFil restorations and found only 57% had good colour match and 61% had acceptable opacity match. Colour match with dentine does not appear to prove problematic (Crisp *et al* 1979b). Asmussen (1983) reported that the opacity of darker shades of cement was greater than that found with lighter shades. He also demonstrated that early contamination of the cements with water increased their opacity.

Hembree & Andrews (1978) and Kidd (1978) investigated microleakage around glass ionomer restorations placed in class V cavities. The abrasion cavities produced by Hembree & Andrews showed no marginal leakage at either the enamel or dentine side of the restoration, unlike the control specimens placed using a composite resin. The cavities produced by Kidd were prepared with all margins placed in enamel. Results from this study, involving the use of an artificial caries gel, showed only a small amount of leakage with evidence of caries inhibition around the restoration. Kidd reported that as glass ionomer cements adhered to tooth structure, this finding was to be expected. Alperstein *et al* (1983), however, was able to demonstrate significant marginal leakage using a dye penetration regime. Pre-treatment of the cavity with 50% citric acid did not appear to reduce the amount of dye penetration. Controls were placed using composite resin and amalgam: half the specimens in each group were pre-treated using an acid etch regime and bonding resin or the application of two coats of varnish. Results indicate that glass ionomers restorations leak more than those of composite or amalgam even where careful pre-treatment aimed at reducing microleakage had been performed. The authors concluded that the preparation of definite margins on the cavities may have resulted in marginal defects, unlike those from other research workers who prepared abrasion cavities with no confining walls.

The release of fluoride into the surrounding tooth structure, with a demonstrated reduction in size of enamel caries lesions in an *in vitro* model, was described by Kidd (1983). Fuks *et al* (1983) failed to show any deterioration in marginal integrity of class ll glass ionomer restorations examined under scanning electron microscope, following a thermocycling regime between 15^{0}C and 62^{0}C.

The results from a dye penetration study by Garcia-Godoy (1989) showed only 8.3% of glass ionomer and fissure sealant restorations leaked and he cited his earlier work on leakage with composite and fissure sealant restorations as a control (Garcia-

Godoy 1987), where up to 25% of the specimens exhibited dye penetration along the cavity walls. Significant leakage in fissure sealants, previously demonstrated by Hicks & Silverstone (1982), made this finding appear promising for the future of small, non load bearing glass ionomer fissure sealant restorations.

5.10 Clinical usage of glass ionomer cements.

5.10.1 Cervical abrasion cavities.

The use of glass ionomer cements for the restoration of cervical abrasion cavities has the advantage of better aesthetics than amalgam and exhibits improved resistance to microleakage along cavity walls placed in dentine (Hembree & Andrews 1978). There has been debate over the preparation of a butt joint at the margin of such restorations in an attempt to eliminate desiccation and fracture of the brittle cement. McLean and Wilson (1977c) reported a failure rate of only 9% after three years. Results from other groups of researchers show a failure rate of 8 to 17% when no cavity preparation had been performed (Flynn 1977 and Tyas & Beech 1985). In the short term, Knibbs *et al* (1986b) found no difference in the performance of the restorations placed both with a butt joint and those without.

Smales (1981) reported a high failure rate (42.7% at 1 year and 71.8% at 3 years) when hand mixed cements were used in a Dental Hospital environment. The author concluded that this was due to the lack of abuse tolerance of the material and the lack of clear instructions from the manufacturer. With experience in the use of glass ionomer cement, Low (1981) reported higher retention rates.

Dentine is exposed during the formation of cervical abrasion cavities - this, in turn, leads to sensitivity. Hypersensitivity is reduced on placement of cervical glass ionomer restorations even when the restoration is partially or entirely lost (Low 1981).

5.10.2 Restoration of deciduous teeth.

McLean and Wilson (1977b) suggested that glass ionomer cement was suitable as a restorative material for the deciduous dentition provided cavity design allowed sufficient bulk of material. The avoidance of shallow keyways and the preparation of mechanical undercuts in larger cavities was considered essential. Saito (1979) expressed concern about the difficulty in using this material in children with the strict requirement for protecting the recently placed restoration from saliva.

Reports from a clinical trial (Plant 1977 *et al* and Vliestra *et al* 1978) comparing a non undercut modification of a conventional cavity design which employed a chamfer finish for areas of low occlusal stress, showed 75% of restorations intact at one year. There did not appear to be any difference between the modified cavity and the conventional design in respect of marginal adaptation, contour and surface finish.

5.10.3 The Class III cavity.

Although glass ionomer cement can be used to restore approximal cavities, its use in the more extensive restoration is limited because of its inferior aesthetics compared to composite resins (Mount & Makison 1978). A clinical trial of the performance of class III cavities restored with glass ionomer cement has been reported by Knibbs (1986) who found acceptable results during a 42 month trial period.

5.10.4 The Class I cavity.

Results from Saito (1979) and Smales (1981) indicate that the performance of glass ionomer cement restorations in class I cavities was poor with an increase in both surface roughness during the first year following placement and clinically perceptible wear by the third year of function. The performance of glass ionomer cement restorations in combination with fissure sealant has not been reported in the literature, despite its widespread use in the General Dental Services (Paterson *et al* 1990).

5.10.5 Fissure sealants.

The use of glass ionomer cement fissure sealant was first described by McLean & Wilson in 1974. They considered that success was achieved when the cement was applied to patent fissures: if applied to fissures with narrow orifices, the material is lost through erosion and abrasion. McLean & Wilson (1974) reported on the performance of glass ionomer cement placed in fissures over a two year period: only 10% of the restorations were lost during the first year and a further 4% in the second year. In 1984, Mount reported the presence of glass ionomer in the depth of fissures, six years after application.

Reports in the literature would appear to indicate that the retention of glass ionomer cement fissure sealants are poor. Smales (1981) found retention to be excellent after one year, but by the end of the second year, the retention rate had fallen to 14.3%. Williams & Winter (1976) placed glass ionomer fissure sealants after etching the teeth with phosphoric acid. Even with this regime, they reported only

21.1% retention after two years. Interestingly, however, they reported no apparent difference in caries incidence between the sample teeth and those treated with a conventional bisGMA fissure sealant.

The opening of narrow fissures using a small tapered fissure bur was advocated by McLean & Wilson (1974 & 1977b) as a means of improving the retention of the glass ionomer cement. The fissure widening procedure was also reported to have the advantage of allowing the inspection of the fissure walls and base for the presence of caries before sealing. Where dentine caries was found, the cavity could be restored in glass ionomer before sealing the fissures with the same mix of cement.

5.10.6 Other applications.

The use of glass ionomer cement in small class I and II cavities in the permanent dentition has been advocated by Knight (1984), Hunt (1984) and Paterson *et al* (1991). In these small cavities, the occlusal contact areas are not involved and, therefore, allow the remaining natural tooth structure to provide protection for the restorative material.

The advantages of glass ionomer as a lining material can be combined with the aesthetics achievable with composite resin. McLean *et al* (1985) advocated the use of glass ionomer cement as a lining material under composite: replacement of the lost dentine with a material having a thermal expansion co-efficient similar to that of dentine and having the ability to release fluoride while still exhibiting minimal microleakage and adhesion to tooth structure. Causton *et al* (1986) reported that the bond strength between cement and composite depended on the type of cement and the etching procedure used.

Use of glass ionomer cement with sintered metallic particles was described by McLean (1985b). He advocated its use on badly broken down teeth before crown preparation.

Glass ionomer has also been used as a luting cement and found to compare favourably with other luting materials for crown and bridge cementation (Reisbick 1981, McComb 1982 and McComb *et al* 1984). These materials have a finer grain size and are mixed with a lower powder/liquid ratio. Luting glass ionomer cements form a bond with noble metal surfaces but not with porcelain or precious metals. Holtz *et al* (1977) reported on the effect of tin plating the fitting surfaces of precious metal castings to permit formation of weak bonds.

5.11 Glass ionomer cement and fissure sealant restorations: Materials and techniques used during the placement of restorations and initial results on clinical performance.

5.11.1 INTRODUCTION.

The prevalence of dental caries has been shown to reduce by approximately 50% when fluoride is added to the public water supply. The maximum reduction in caries occurs in smooth surfaces (Blinkhorn *et al* 1981), while the pits and fissures of molar and premolar teeth remain the most susceptible (Lewis & Hargreaves 1975 and Ripa *et al* 1988a). It has been estimated that pits and fissures are eight times more susceptible to caries than smooth surfaces (Harris 1991).

It had been reported that the time since tooth eruption does not influence the susceptibility of fissure surfaces to caries (Ripa *et al* 1988a). This observation was supported by Arthur and Swango (1987) who reported a high incidence of occlusal caries among U.S. navy recruits in their late teens and early twenties.

Glass ionomer and fissure sealant restorations were added to the list of available treatment under General Dental Services in 1987. Subsequently the regulations were revised substantially in 1988 (Statement of Dental Remuneration, 1988) under section 6 of the National Health Service fee scale for General Dental Practitioners. To date, there has been no direct clinical results on the performance of glass ionomer fissure sealant restorations. In a postal survey of all General Dental Practitioners working in Greater Glasgow and Lanarkshire Health Board areas, Paterson *et al* (1990) reported that 81% of dentists in these areas were providing sealant restorations and the most popular combination of materials for this technique was glass ionomer cement and fissure sealant resin. This combination was used by 85% of the operators responding to the questionnaire. Seventy four percent of the dentists correctly identified the criteria for use of these materials.

The rapid development and improvement of materials have extended the Preventive Resin Restoration as described by Simonsen and Stallard (1977), to include glass ionomer cements. An entire series of 'sealant restorations' now exist for the treatment and management of early enamel lesions and caries which extends into dentine.

In 1974, McLean described a technique and reported on the two year results of ASPA ll - a glass ionomer cement - used as a fissure sealant and fissure filling material. When used as a sealant, fissures between 100 and 350µm only were suitable. Where 'sticky fissures' were present, the lesion was investigated using a 008 fissure bur and providing dentine was not involved "to any great extent", could be restored using glass ionomer and the surrounding fissures sealed using the same material. After one year, only 84% of the cement sealants were intact and after a further year, another 6% had been lost. Despite these results using early glass ionomer cements, this material has not been widely accepted as suitable for sealing fissures. Mejare and Mjor (1990) compared retention rates of two unfilled pit and fissure sealant resins with a glass ionomer cement developed for fissure sealing (Fuji lll). After twelve months, these authors found that 61% of the glass ionomer sealants had been lost and after three years they reported 84% loss. By contrast, 90% of the bisGMA sealants were still completely retained after 5 years.

The restoration of teeth with minimal caries lesions extending just into dentine, but whose margins are not in occlusal contact, was described by Garcia-Godoy (1986). He suggested that the cavity should be restored using glass ionomer cement formulated as a lining material. This could simultaneously be etched, along with the surrounding fissures, using a buffered phosphoric acid solution. The addition of a resin sealant could be used over the filling and into the adjacent fissures.

The restoration of minimal fissure caries using these materials was also advocated by the authors of the Scottish Home and Health Department Publication "Trends in the Management of Fissure Caries". This cautioned dentists on the practice of etching glass ionomer cements and advocated that the surface of the cement should be protected from etching materials by the application of an enamel dentine bonding resin which would also provide adhesion to the overlying fissure sealant.

A comparison of the size of cavities prepared for glass ionomer cement and those prepared to receive amalgam restorations was made by Welbury *et al* (1991). They reported that amalgam restorations occupied 28% of the occlusal surface area of deciduous molar teeth, while the corresponding surface area occupied by glass ionomer cement restorations was 16%. The undoubted savings in tooth preparation and tooth strength is evidenced by this data.

In this section of the study, the materials and methods used to place glass ionomer fissure sealant restorations in the restoration of fissure lesions, will be examined and the initial results of sealant retention and performance of glass ionomer filling after 6, 12 and 24 months will be reviewed. Factors influencing sealant retention will be investigated and their relevance evaluated.

5.11.2 MATERIALS AND METHODS.

Fourteen Clinical Community Dental Officers from Greater Glasgow and Lanarkshire Health Boards participated in the field trial by placing glass ionomer and fissure sealant restorations in patients attending the Community Dental Services for treatment. All glass ionomer restorations placed over a one year period were recorded on a registration card providing information on patient details, tooth, materials and techniques used for their application (see Chapter 3).

The selection criteria for patients were explained to the CDO's at the outset of the field trial. The suggested choice of restorative material was that described by Paterson *et al* (1991) i.e. that enamel biopsies extending just into dentine but whose cavity margins were not in occlusal contact could be restored with a glass ionomer cement and the surface of the cement and the adjacent fissures sealed with a pit and fissure sealant.

Patients were recalled to the Community Dental Clinics after six months, at which time the restorations were reviewed independently by the Community Dental Officer who placed the sealant and by the author and another calibrated examiner (GBG and RCP). In the event of a disagreement on the scoring between the two examiners, the patient was re-examined and a final score agreed (for details of the features examined during the scoring procedure see Chapter 4). The data presented in this section is that from the two external examiners - the scoring by the Community Dental Officer has been discussed in Chapter 2.

Examinations were carried out under good lighting conditions using standard operating lamps and with the aid of a compressed air supply to dry the operating field. Standard right angled probes were used to detect the presence and extent of fissure sealant. No attempt was made to influence the Community Dental Officer as to the need for modification of the restoration by the addition of further sealant. Where the surface of the glass ionomer filling had been exposed due to the loss of sealant, this was then examined for the presence of wear, marginal stain and secondary caries.

The procedures adopted for two-year review of the restorations were similar to those used for assessment after one-year. Further attempts were made to recall patients who had failed to attend for the one-year review. Patients were only excluded if they failed to attend for three review appointments which were sent by letter. Attempts were made to review patients who had failed to attend the one-year reviews by inviting them for further examination at the Community Dental Clinics.

When patients attended for review, the teeth were dried and isolated with cotton wool rolls before details of the performance were recorded. Before completing the review assessment, any teeth with marked plaque deposits or those exhibiting extrinsic staining were carefully cleaned using a rubber cup and prophylaxis paste. To avoid altering the restorations during this procedure, only light operating pressure was employed.

The data collection document used to record details of the clinical performance of the sealant restoration after 24 months was similar to that used for the one-year review but also included an estimate of the life expectancy of the restoration (see Chapter 4).

The data was analysed on microcomputer using a Database programme (Survey it!, Conway Information Systems Inc. 1991. Version 4.0) and was analysed on micro-computer using the statistical package C Stat (Oxtech Ltd 1991). Chi square test was employed to show differences between tested groups with the level of significance set at 5%.

5.11.3 RESULTS.

A: Use of the techniques.

The group of participating Community Dental Officers placed 520 sealant restorations. A glass ionomer cement and fissure sealant combination was used during the placement of 146 sealant restorations - 28.1% of all restorations registered.

The distribution of the restorations is graphically displayed in Figure 5.1. One hundred and thirteen of the glass ionomer fissure sealant restorations (77.4%) were placed in first permanent molar teeth, while only 30 second molar teeth (20.5%) were similarly restored. This restorative technique was seldom used in premolar teeth - only three restorations were placed. There was a generally even distribution of restored teeth by quadrant. It was noted, however, that thirteen more restorations had been placed in maxillary right first permanent molar teeth. At the time of restoration placement, 97.1% of the teeth were functional - with only four teeth non-functional - and in the registration of seven restorations, no information was provided by the operators. Patients receiving glass ionomer sealant restorations in first permanent molar teeth had a mean age of 10.08 years with a standard deviation of 2.52 years, while those with similar restorations placed in second permanent molar teeth were 13.63 years with a standard deviation of 1.63 years. The data in Tables 5.1 and 5.2 show the mean ages of the two groups of patients. Male patients accounted for 51.3% of the sample.

B: Cavity preparation.

Information on the use of local analgesia during cavity preparation was not provided in ten of the restorations registered. In Table 5.3 use of a local analgesic was confined to only 52.9% of restorations. During cavity preparation, round friction fit burs were most popular (82.8% of cavities prepared with round burs) with diamond versions being used in 85.6% of occasions and tungsten carbide in 11.6%. The size of bur used was not specified in 29.4% of restorations while the diameter of those used are shown in Table 5.4. Isolation of the cavity was achieved using cotton wool and an aspirator during the placement of 84.2% of the restorations. In Table 5.5 all methods of isolation are shown.

C: Materials.

In Table 5.6 the glass ionomer cements used by the dentists are shown in order of reported preference. Only 3.3% of the glass ionomer cement restorations were

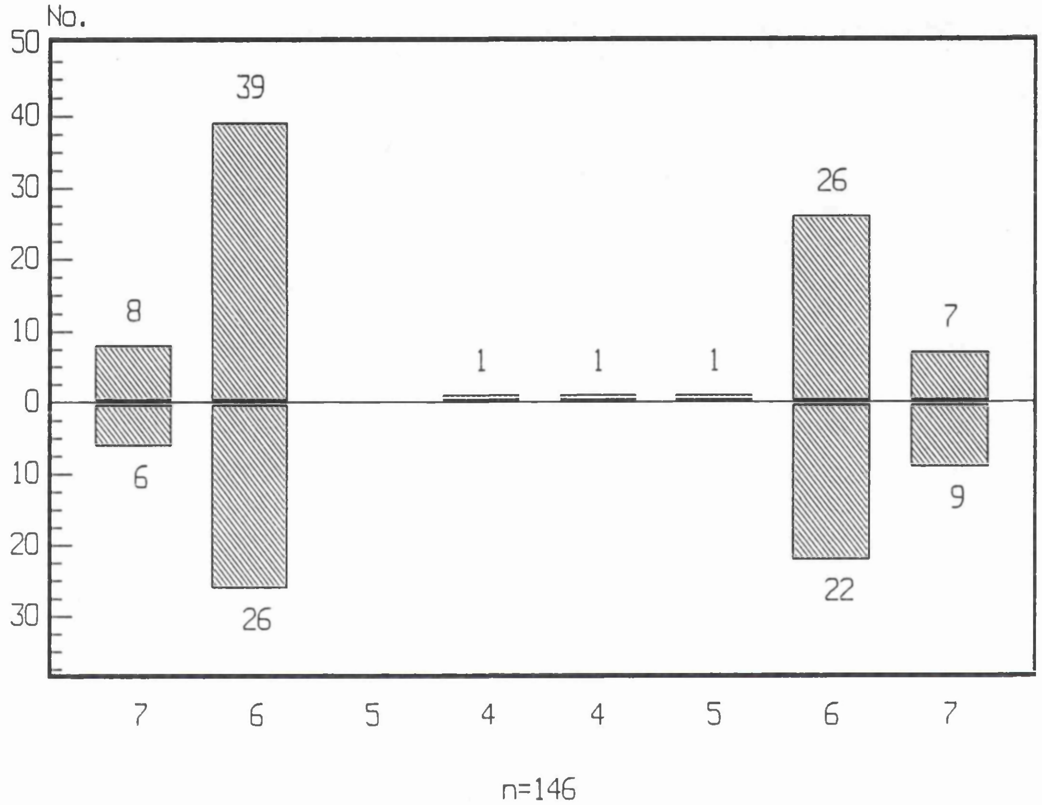


Figure 5.1 **The distribution of teeth restored with glass ionomer cement sealant restorations placed in the Community Dental Service (n = 146).**

Age of patient	Number of restorations	Percent of total
6.0 - 6.9	10	8.8
7.0 - 7.9	13	11.5
8.0 - 8.9	19	16.8
9.0 - 9.9	22	19.4
10.0 - 10.9	17	15.0
11.0 - 12.9	11	9.6
13.0 - 15.9	18	15.8
16.0 and over	3	2.5

mean age 10.08 years (standard deviation 2.52 years)

Table 5.1 Age distribution of patients receiving glass ionomer sealant restorations in first permanent molar teeth (n=113).

Age of patient	Number of restorations	Percent of total
8.0 - 8.9	0	0
9.0 - 10.9	2	6.6
11.0 - 12.9	6	19.9
13.0 - 13.9	9	30.0
14.0 - 14.9	8	26.6
15.0 - 15.9	2	6.6
16.0 and over	3	9.9

mean age 13.63 years (standard deviation 1.63 years)

Table 5.2 Age distribution of patients receiving glass ionomer sealant restorations in second permanent molar teeth (n=30).

	Number of restorations (% answered)
L.A. used	72 (52.9%)
No L.A. used	64 (47.1%)
No information	10 (-------)

n=146

Table 5.3 Use of local analgesia during the preparation of cavities for glass ionomer sealant restorations.

	Number of restorations (Percentage)
008	3 (2.0%)
010	28 (19.1%)
012	35 (23.9%)
larger	37 (25.3%)
not specified	43 (29.4%)

n=146

Table 5.4 Bur sizes used during the cavity preparation for glass ionomer sealant restoration.

	Number of restorations (Percentage)
Cotton wool rolls	21 (14.3%)
C/W rolls + aspirator	123 (84.2%)
Rubber dam	1 (0.6%)
other	1 (0.6%)

n=146

Table 5.5 Methods of isolation employed during the sealant restoration technique with glass ionomer cements and fissure sealants.

Glass Ionomer Cement	**Number of Restoration (Percentage)**
ChemFil ll	140 (95.8%)
Baseline	4 (2.7%)
Opus	1 (0.6%)
Ketacbond	1 (0.6%)

n=146

Use of radio-opaque glass ionomer cement - 3.3%

Use of radio-lucent glass ionomer cement - 96.7%

Table 5.6 Glass ionomer cements used during placement of filling for sealant restoration.

placed using a radio-opaque material. Surface etching of the glass ionomer cement was carried out in 32.9% of all restorations.

Use of fissure sealant is shown in Table 5.7. Opaque versions were used during the placement of 28.8% of the glass ionomer sealant restorations while an auto-polymerising resin was preferred by most operators. Ratio of light cured to auto-polymerising fissure sealants was 1 : 2.4. Forty-three restorations were placed using light cured sealant materials: information regarding the length of curing time was available for only 29 teeth. Curing times are shown in Table 5.8 which demonstrate that most operators prefer to expose the sealant to visible blue light for at least one minute.

Information on the type of etchant and etching times employed were given for all restorations and are presented in Tables 5.9.1 and 5.9.2. Gel etchants proved to be more popular than liquids. Seventy one percent of the restorations had been etched for 30 to 45 seconds, while 10% were etched for times longer than 45 seconds.

D: Performance of sealant restoration after six months.

After six months, one hundred and twenty-four patients were successfully recalled - a review rate of 84.9% (Table 5.10.2). If the number of reviews are restricted to those who were also seen at twelve months (103 patients), direct comparison of the performance of sealant and glass ionomer filling is possible.

In Table 5.10.1 the retention rate of fissure sealant at six months is shown: 21.3% of sealants were completely retained and six sealants (5.8%) had been entirely lost from all fissure and glass ionomer cement surfaces. The performance of the glass ionomer cement sealant restorations after six months is shown in Table 5.11: only one cement filling had been lost, while of those remaining, six showed surface wear and in twelve fillings marginal discolouration was discernable. Following the loss of fissure sealant, four fissure lesions had cavitated while seven lesions were discovered on an approximal tooth surface. Immediately following placement of the glass ionomer sealant restoration, two teeth were sensitive to thermal stimuli but after six months only one tooth continued to demonstrate thermal sensitivity.

Fissure Sealant	Number of Restoration (Percentage)
Delton - self cure	103 (70.5%)
Delton - light cure	40 (27.3%)
Helioseal	2 (1.3%)
ICI Bond	1 (0.6%)

n=146

Use of opaque fissure sealant - 28.8%
Use of clear fissure sealant - 71.2%

Ratio of light to self cured fissure sealants 43:103 (1 : 2.4)

Table 5.7 Fissure sealant materials used during placement of glass ionomer sealant restorations.

Curing times	Frequency of use	
1 - 15	2	6.8%
16 - 20	5	17.2%
21 - 30	1	3.4%
31 - 40	8	27.5%
41 - 50	0	0%
51 - 60	0	0%
60 and greater	13	44.8%

Table 5.8 Forty-three restorations were placed using light cured fissure sealant but only 29 restorations contained complete data on curing time.

Etch materials	Frequency of use	
liquid	62	42.4%
gel	83	56.8%
no data	1	0.6%

n = 146

Table 5.9.1 Etchant materials used during the placement of glass ionomer sealant restorations.

Etch times	Frequency of use	
0 - 14	1	0.6%
15 - 29	26	18.0%
30 - 44	102	70.8%
45 - 60	15	10.4%
61 and greater	0	0%

Table 5.9.2 Etch times employed by the operators during the placement of glass ionomer sealant restorations (n=144 restorations with complete data).

Fissure sealant retention	**Frequency of occurrence**
Fully retained	22 21.3%
Partially retained	75 72.8%
Completely missing	6 5.8%

Table 5.10.1 Fissure sealant retention in teeth reviewed after six months and also after 12 months (n=103).

Fissure sealant retention	**Frequency of occurrence**
Fully retained	27 21.7%
Partially retained	89 71.7%
Completely missing	8 6.5%

Table 5.10.2 Fissure sealant retention in all teeth reviewed after 6 months (n=124).

• Restoration retained	- yes	123	(99.2%)	
	- no	1	(0.8%)	n=124
• Occlusal wear of glass ionomer cement	- yes	6	(4.9%)	
	- no	116	(95.1%)	n=122
• Marginal discolouration of filling	- yes	12	(9.8%)	
	- no	110	(90.2%)	n=122
• Caries present	- new primary	4	(3.2%)	
	- new secondary	7	(5.7%)	
	- no caries	112	(91.1%)	n=123

Table 5.11 Performance of the glass ionomer sealant restoration after 6 months (n=124).

In Table 5.12 the treatment that the two review examiners considered necessary after the initial clinical review is shown. The complete replacement of one glass ionomer cement was indicated where this had been entirely lost. In the eleven teeth where caries lesions had cavitated (four primary and seven secondary lesions), two teeth were eliminated from further review as amalgam restorations were found to be necessary after further investigation. An investigative cavity and insertion of an adhesive filling material was required in four of the other nine teeth before resealing the surfaces. In the remaining five teeth, fissure sealant alone was considered adequate for the management of the early enamel caries. In 88.7% of the restorations reviewed, either no treatment was considered necessary or only small additions to areas of lost sealant. In total, 9 teeth were eliminated from the trial at this time due to cavitated caries lesions requiring investigation in pit and fissure surfaces (2 teeth) or the presence of class ll lesions (7 teeth).

E: Performance after one year

After one year, 98 glass ionomer cement restorations were reviewed - a successful recall rate of 77%.

A comparison of the overall fissure sealant retention is presented in Table 5.13. The results after 6 and 12 months are shown: no significant difference could be demonstrated between the two review appointments. Only 12 (12.2%) of the glass ionomer cement sealant restorations had completely intact fissure sealant after 12 months and in 4 teeth (4.1%) the sealant was completely missing.

- no modification - 49 (39.5%)

- modification - 66 (53.2%) 61 addition of **fissure sealant**
  5 **glass ionomer** and **fissure sealant**
  (4 with primary or secondary caries and 1 with restoration lost)

- eliminated restorations - 9 (7.2%) 7 teeth - class ll cavity
  2 teeth - class I requiring amalgam

(n=124 restorations)

49 + 61 = **110 restoration** (88.7%) required either no treatment or simple addition of fissure sealant resin.

Table 5.12 Requirement for modification after 6 months.

	Completely Retained	Partially Retained	Completely Missing
Six months	22 (21.3%)	75 (72.8%)	6 (5.8%)
Twelve months	12 (12.2%)	82 (83.7%)	4(4.1%)

n = 98

Statistical comparison.

Differences between 6 month and 12 month fissure sealant retention:

Chi ^{2} = *3.531* *DF* = *2* $P > 0.05$

Table 5.13 Retention of fissure sealant in 98 sealant restorations reviewed after 6 and 12 months after placement. No significant differences could be demonstrated between the two review scores (P > 0.05).

In Table 5.14, the retention of the sealant is shown to the various pit and fissure surfaces and to the surface of the glass ionomer cement surface. Significant differences exist among the retention rates to the different surfaces ($P < 0.01$). Retention of the sealant to the surface of the glass ionomer cement was significantly poorer than to the adjacent pits and fissures on the occlusal surface ($P < 0.05$). Retention to the buccal fissure was significantly poorer than to other surfaces ($P < 0.01$), while the retention to the palatal fissure was better than that demonstrated for all other surfaces ($P < 0.05$). The greatest loss of fissure sealant was from the buccal fissure of the permanent molar teeth and from the surface of the glass ionomer cement restoration.

When the overall fissure sealant retention was considered for maxillary and mandibular molar teeth and for those teeth on the right and left sides of the dentition (Figures 5.2 and 5.3), no significant differences in retention could be demonstrated ($P > 0.05$).

Light cured Delton had been used to seal the surfaces of 21 teeth, while the self cured material had been used to seal the remaining 77 teeth reviewed. In Figure 5.4, areas of lost sealant for each tooth surface and material are shown. Although there would appear to be improved retention of the self cured material to the buccal fissure, this was not significant ($P > 0.05$). No difference in sealant retention could be shown between the two versions of the sealant. ($P > 0.05$).

During the placement of 33 restorations, the surface of the glass ionomer cement was etched before the fissure sealant was applied. The effect of etching the restoration surface is shown in Table 5.15 This practice did not improve sealant retention ($P > 0.05$). No difference in sealant retention to glass ionomer cement surfaces could be demonstrated when the cement surfaces were etched using gel or liquid etchant material ($P > 0.05$).

Extending the etch time for greater than 30 seconds did not significantly improve the sealant retention. In Figure 5.5, the percentage of surfaces where sealant was lost is compared for the two etch time groups. The apparently improved retention shown for the buccal fissures which were etched for more than 30 seconds was not significant ($P > 0.05$).

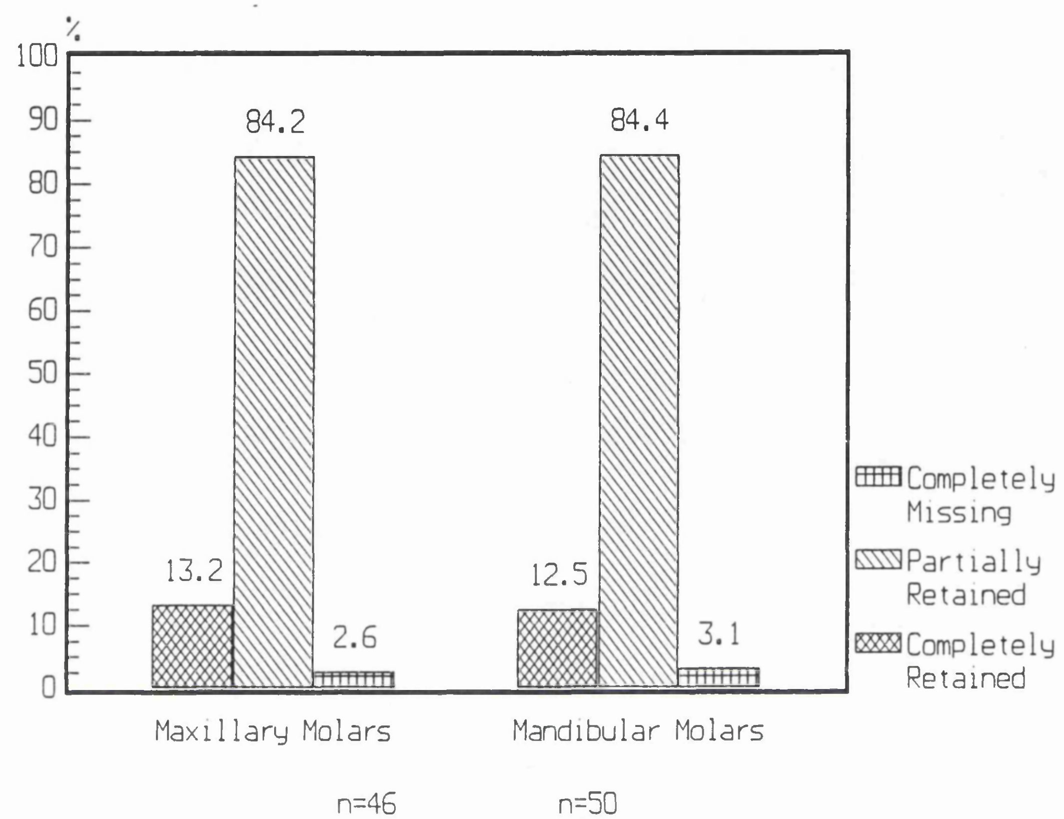
Areas of lost and retained sealant from various surfaces

	Restoration	**Occlusal**	**Buccal**	**Palatal**
Retained	31 (31.6%)	47 (48%)	6 (13%)	34 (69%)
Lost	67 (68.4%)	51 (52%)	41 (87%)	15 (31%)

Statistical comparisons.

Restoration v Occlusal fissures	*$Chi^2 = 5.45$*	*DF = 1*	*$P < 0.05$ **
Buccal v Occlusal fissures	*$Chi^2 = 16.97$*	*DF = 1*	*$P < 0.01$ ***
Palatal v Occlusal fissures	*$Chi^2 = 6.06$*	*DF = 1*	*$P < 0.05$ **
Buccal v Palatal fissures	*$Chi^2 = 31.64$*	*DF = 1*	*$P < 0.01$ ***
Restoration v Buccal fissure	*$Chi^2 = 5.95$*	*DF = 1*	*$P < 0.05$ **
Restoration v Palatal fissure	*$Chi^2 = 18.88$*	*DF = 1*	*$P < 0.01$ ***
Among all surfaces	*$Chi^2 = 37.46$*	*DF = 3*	*$P < 0.01$ ***

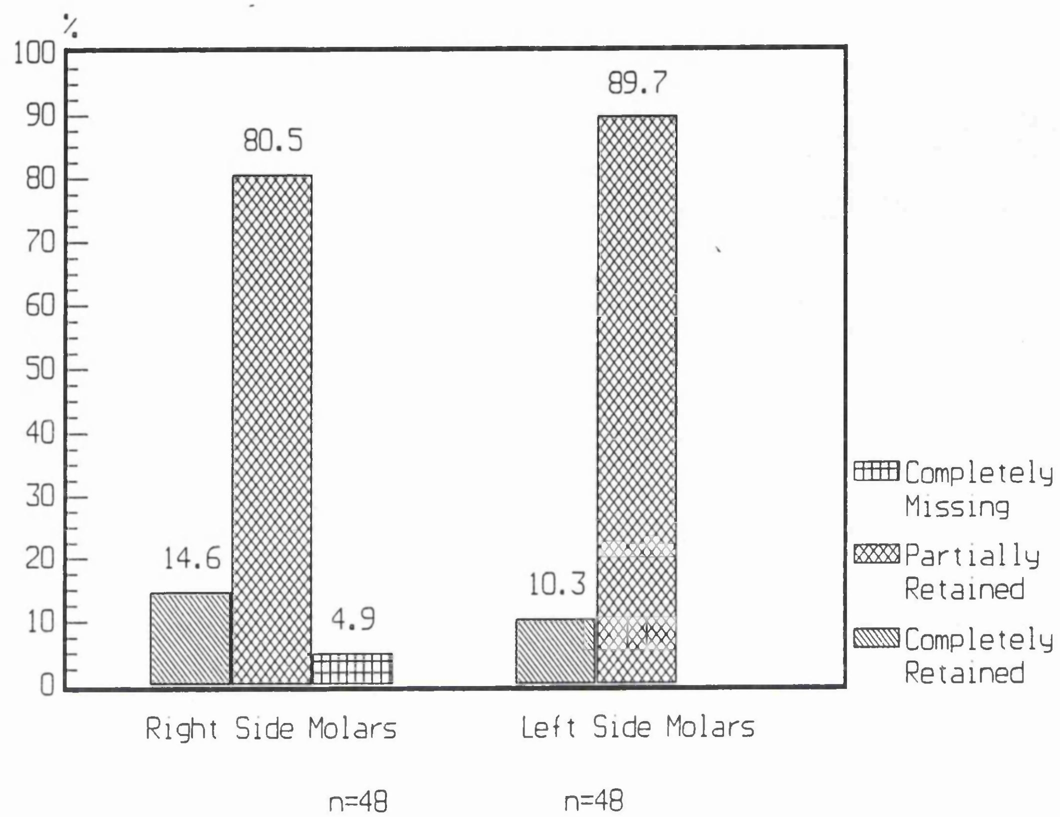
Table 5.14 Retention of fissure sealant on glass ionomer cement restorations and adjacent fissures after 1 year.



<u>Statistical comparison:</u>

Maxillary v Mandibular teeth $Chi^2 = 0.007$ $DF = 1$ $P > 0.05$

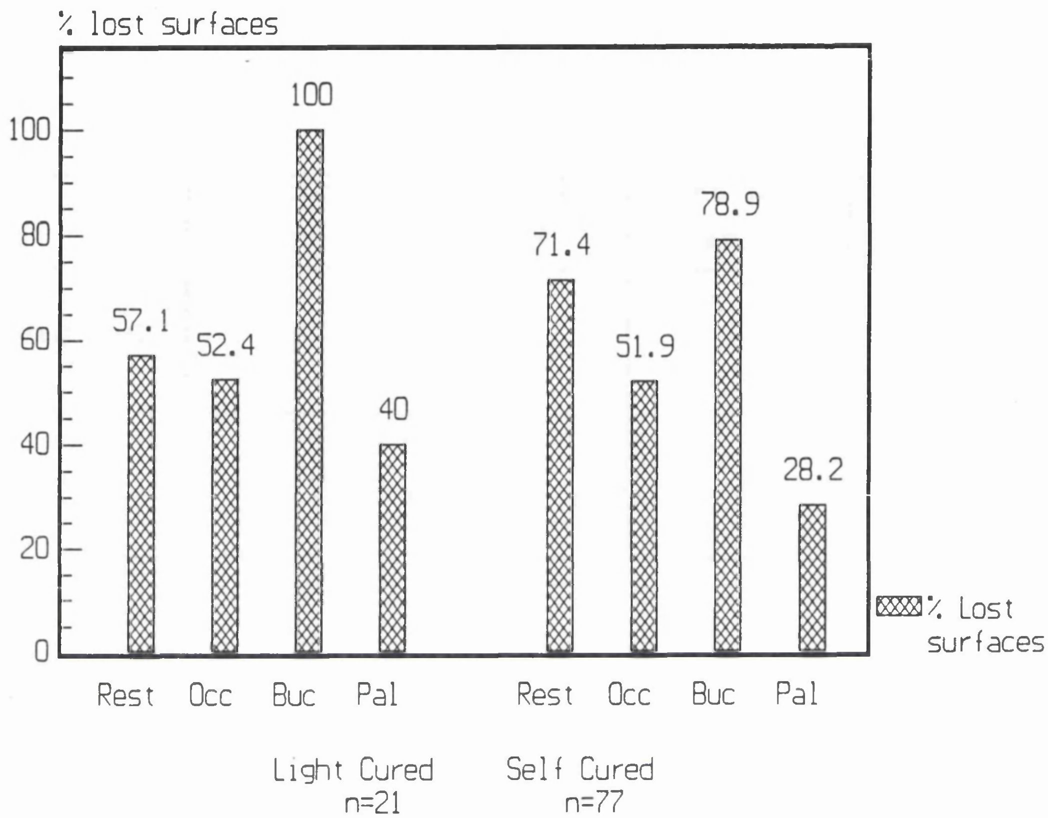
Figure 5.2 **Fissure sealant retention on maxillary and mandibular molar teeth after 1 year.**



Statistical comparison:

Right v Left molar teeth $Chi^2 = 0.280 \quad DF = 1 \quad P > 0.05$

Figure 5.3 **Fissure sealant retention in right and left molar teeth after 1 year.**



Statistical comparisons:

Light v Self cured sealant	*Restoration:*	$Chi^2=1.560$	$DF=1$	$P>0.05$
	Occlusal:	$Chi^2=0.001$	$DF=1$	$P>0.05$
	Buccal:	$Chi^2=2.770$	$DF=1$	$P>0.05$
	Palatal:	$Chi^2=0.520$	$DF=1$	$P>0.05$

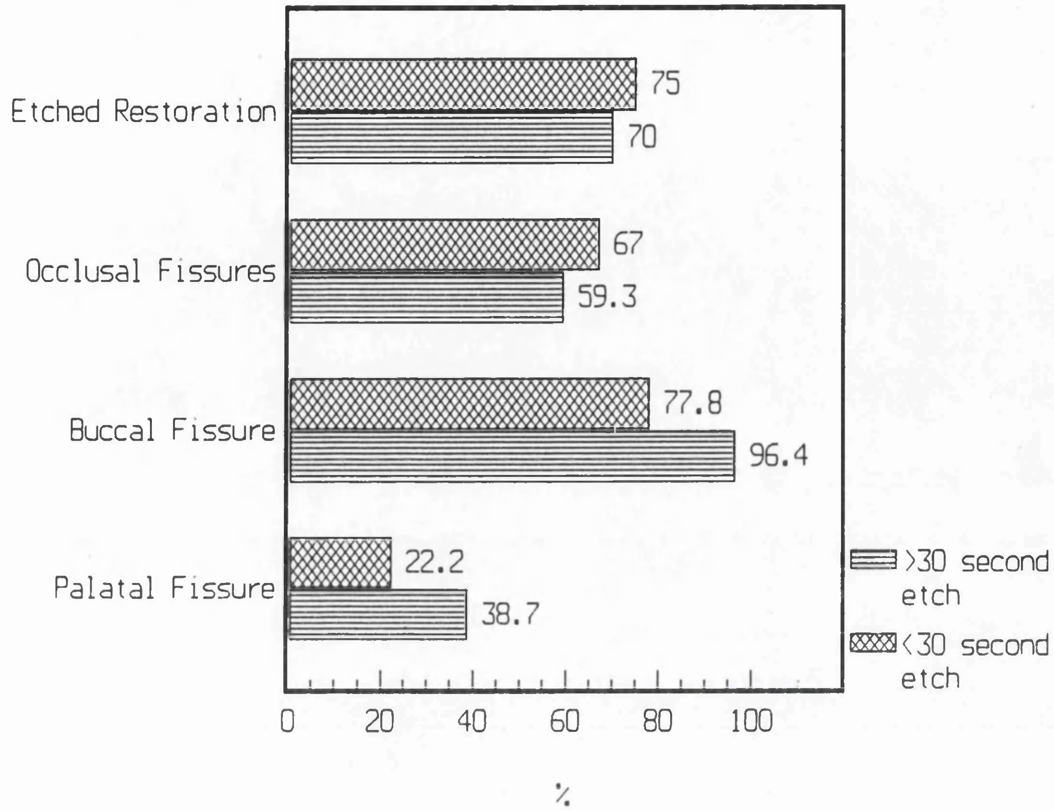
Figure 5.4 **Fissure sealant retention in light and self cured resin after 1 year.**

	Etched Liquid	Etched Gel	Etched Total	Not Etched
Retained	3	8	11	19
Lost	10	12	22	39

Statistical comparisons:

Etched v non-etched $Chi^2 = 0.003$ $DF = 1$ $P > 0.05$
Liquid v Gel etchants $Chi^2 = 1.015$ $DF = 1$ $P > 0.05$

Table 5.15 Effect of etching glass ionomer cement surfaces on fissure sealant retention.



<u>*Statistical comparisons:*</u>

< 30 secs v > 30 secs	*Restoration:*	*Chi^2=0.007*	*DF=1*	*P>0.05*
	Occlusal:	*Chi^2=0.300*	*DF=1*	*P>0.05*
	Buccal:	*Chi^2=3.810*	*DF=1*	*P>0.05*
	Palatal:	*Chi^2=0.831*	*DF=1*	*P>0.05*

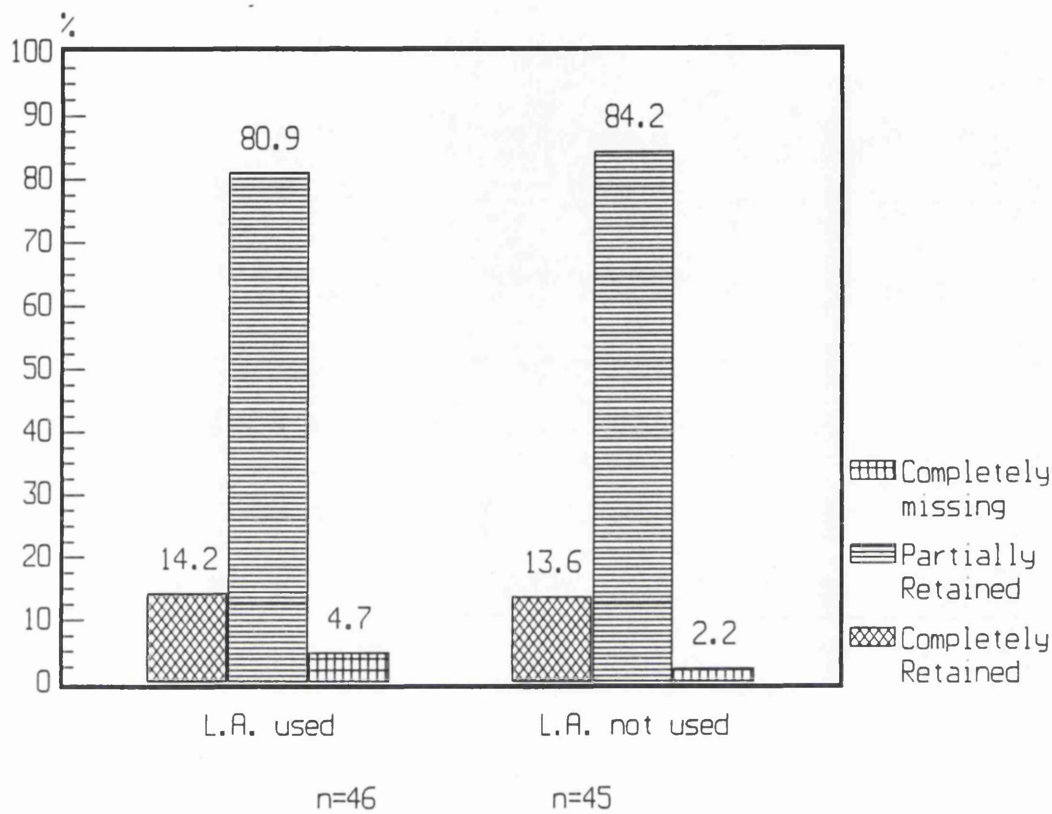
Figure 5.5 **Surface areas from which fissure sealant has been lost in restorations subjected to varying etching times.**

No information was available about the use of local anaesthetic at the time of placement of 7 restorations. In the remainder, local anaesthetic was administered in exactly 50% of cases. The relationship between the administration of local anaesthetic and the retention of fissure sealant is shown in Figure 5.6. No differences could be demonstrated between the teeth treated with and without local anaesthetic ($P > 0.05$).

Only 1 restoration was placed using rubber dam isolation. The remaining restorations were placed using either cotton wool rolls alone or in combination with an aspirator. In Figure 5.7, areas of lost sealant are compared using the two different methods of isolation. Retention of fissure sealant in the problematic buccal fissure was significantly improved when an aspirator was used in addition to cotton wool roll isolation ($P < 0.05$). The improvement in the retention of sealant in the palatal fissure was just below the level of significance.

Table 5.16 illustrates the bucco-lingual width and extent of fissure involvement in the glass ionomer cement restorations placed in the 96 molar teeth reviewed after one year. The majority of the restorations (62%) were between 1 and 3mm wide and occupied between 1/3 and 2/3 of the fissure. In only 13 restorations (14%) was the width less than 1mm. Generally, the greater the width of the restoration the greater was the extent of fissure involvement.

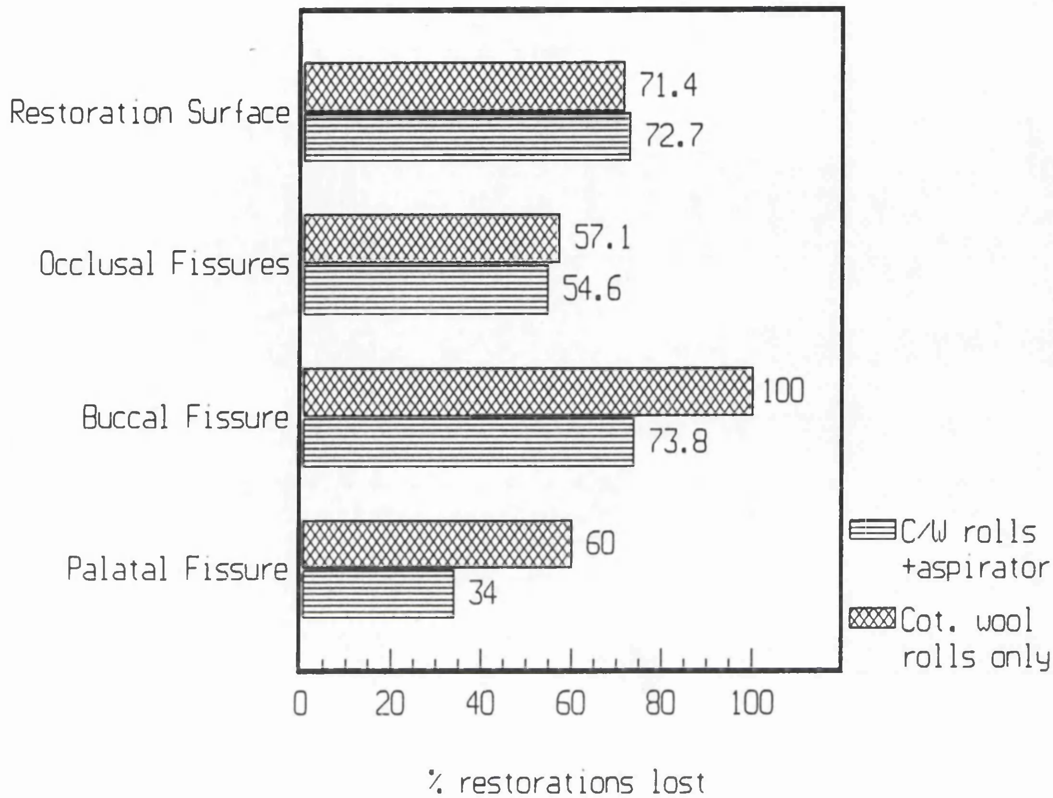
Table 5.17 shows the retention of the sealant related to the bucco-lingual width and the extent of the fissure involved in the glass ionomer cement restoration. The results indicate that the retention of the sealant was not significantly related to the width of the restoration ($P > 0.05$) but was significantly related to the extent of the fissure involvement ($P < 0.05$). There was a general trend towards poorer retention as both the width and extent of the glass ionomer cement restorations increased.



Statistical comparison:

LA v no LA $Chi^2 = 0.008$ $DF = 1$ $P > 0.05$

Figure 5.6 **Retention of fissure sealant in glass ionomer fissure sealant restorations when local analgesic was used at the time of restoration placement.**



<u>*Statistical comparisons:*</u>

Cotton wool rolls v cotton wool rolls and aspirator

Restoration:	*Chi^2 = 0.008*	*DF = 1*	*P > 0.05*
Occlusal:	*Chi^2 = 0.010*	*DF = 1*	*P > 0.05*
Buccal:	*Chi^2 = 3.950*	*DF = 1*	*P < 0.05 **
Palatal:	*Chi^2 = 2.630*	*DF = 1*	*P > 0.05*

Figure 5.7 **Surface areas from which fissure sealant has been lost dependent on method of isolation.**
Thirty restorations were placed using cotton wools rolls alone and 67 restorations with the addition of aspiration.

Width of glass ionomer cement restoration

Extent of Fissure involved	< 1mm	1 - 3 mm	> 3 mm	Total
< 1/3	**11**	14	0	25
1/3 to 2/3	2	**59**	0	61
> 2/3	0	6	**4**	10
Total	13	79	4	96

Table 5.16 Extent of fissure involvement and bucco-lingual width of glass ionomer cement restoration placed in first and second permanent molar teeth.

	Width of glass ionomer			Extent of fissure		
	<1 mm	1 - 3 mm	> 3 mm	< 1/3	1/3 - 2/3	> 2/3
Retained	7 (54%)	23 (29%)	0 (0%)	11 (44%)	19 (31%)	0 (0%)
Lost	6(46%)	56(71%)	4(100)	14 (56%)	42 (69%)	10 (100)
Total	13	79	4	25	61	10

Statistical comparisons:

Sealant retention by width *Chi* $^2 = 5.07$ *DF = 2* *P > 0.05*

Sealant retention by extent *Chi* $^2 = 6.44$ *DF = 2* *P < 0.05 **

Table 5.17 Retention of fissure sealant related to bucco-lingual width and extent of fissure involvement of the glass ionomer cement restorations.

In Table 5.18 marginal integrity and discolouration are shown. Twelve months after placement, 93 (95%) of the glass ionomer restorations showed no visual evidence of crevice formation at the margins and in only 5 restorations was a minimal crevice present (not extending into dentine). Marginal staining was present around 11 glass ionomer restorations: 9 restorations had stain extending round less than a third of the periphery and in a further 2, staining was more extensive and involved between a third and two thirds of the margin.

Table 5.19 summarises the treatment considered necessary after one year. Addition of either glass ionomer cement or sealant were considered necessary if there were signs of demineralisation in the exposed fissure or if there were more than two carious lesions elsewhere in the dentition. Sixty two percent of the sealant restorations required such treatment. Cavitated carious lesions had developed in 7 of the teeth from which sealant had been lost from the occlusal or buccal fissures: a caries prevalence of 7.1 % of the fissures in the permanent teeth at risk. In these patients, the mean number of carious tooth surfaces (in relation to their total number of permanent tooth surfaces) was 3.0 (SD 0.8), compared with a ratio of 1.6 surfaces (SD 1.8) for the 79 patients without active fissure lesions. Similarly, the mean number of filled and carious surfaces in the seven patients with active fissure lesions was greater at 9.1 (SD 4.6) than in those without active fissure lesions (5.9 SD 4.3).

F: Performance after Two years

After two years 59.6% (87 restorations) of the glass ionomer cement fissure sealant restorations were successfully reviewed.

In Table 5.20, the condition of the fissure sealant after 24 months is shown. No difference in sealant retention could be demonstrated between the results after two years compared to those obtained after 12 months ($P > 0.05$) or following six months clinical service ($P > 0.05$).

Marginal Integrity

No visible evidence of crevice	92 (94%)
Visible crevice	
(dentine not exposed at base)	5 (9.4%)
No data	1 (0.9%)
	n = 98

Marginal Discolouration

No discolouration between tooth and restoration	86 (88%)
Discolouration around < 1/3 of margin	9 (9.4%)
Discolouration of margin extending around	
1/3 to 2/3 of restoration	2 (1.7%)
No data	1 (0.9%)
	n = 98

Table 5.18 Marginal integrity and marginal discolouration one year after placement.

Restoration satisfactory	38%
Addition of fissure sealant	60%
Addition of glass ionomer cement and sealant	2%

Table 5.19 Treatment requirements for the glass ionomer sealant restorations after 1 year.

Fissure sealant retention	Percentage of sealant retention
Completely retained	12 (13.8%)
Partially retained	69 (79.3%)
Completely missing	6 (6.9%)
Total	87 (100%)

Statistical comparisons.

Differences between the sealant retention in composite and glass ionomer sealant restorations after 2 years.

$Chi^2=0.735$ $DF=1$ $P>0.05$

Differences between sealant retention after 12 months and after 24 months

$Chi^2=0.868$ $DF=2$ $P>0.05$

Differences between sealant retention after 6 months and after 24 months

$Chi^2=1.840$ $DF=2$ $P>0.05$

Table 5.20 Fissure sealant retention to glass ionomer sealant restorations after two-years.

The majority of the sealant restorations had lost some fissure sealant (79.3%) while only 6.9% of the restorations had lost all sealant covering. When the number of restorations reviewed after 24 months was restricted to those that were seen also after 12 months, a direct comparison of the restorations is possible (Table 5.21). No difference could be shown statistically by restricting the number of restorations reviewed ($P > 0.05$). Overall fissure sealant retention was not statistically different from that observed after 6 months or after one year. When fissure sealant retention is compared for the glass ionomer sealant restorations and for the composite sealant restorations (see Chapter 4), no statistical difference could be demonstrated ($P > 0.05$).

When fissure sealant retention is considered by tooth and restoration surface, no significant difference could be demonstrated among the various surfaces (Table 5.22). Differences in the missing areas of fissure sealant were not significantly dissimilar from that observed after 12 months ($P > 0.05$). The glass ionomer sealant restorations did not perform differently from composite sealant restorations or from the therapeutic fissure sealants ($P > 0.05$).

It was conservatively estimated that 36.7% of the restorations would survive at least another two years before further treatment was required. The tabulated results are shown in Table 5.23. No difference could be demonstrated in the predicted life expectancy between the glass ionomer sealant restorations and composite sealant restorations ($P > 0.05$). Similarly, no difference could be shown between the glass ionomer cement restorations and resin fissure sealants placed as a therapeutic measure in the management of fissure caries ($P > 0.05$).

In Table 5.24, the factors associated with the performance of the glass ionomer cement restorations are shown. No differences in performance could be shown between these results and that for the composite restorations (see Chapter 4) with regard to sealant retention to the restoration surface, marginal integrity of the filling to tooth interface, marginal discolouration around the periphery of the glass ionomer cement and surface wear of the filling material ($P > 0.05$).

Fissure sealant retention.	**% sealant retention**
Completely retained	12 (14.6%)
Partially retained	64 (78.0%)
Completely missing	6 (7.4%)
Totals	82 (100%)

Statistical comparisons.

Differences between the sealant retention in the restricted and unrestricted groups of glass ionomer sealant restoration:

$Chi^2=0.04$ $DF=1$ $P>0.05$

Table 5.21 Sealant retention to glass ionomer sealant restorations reviewed after one and two years.

Surface areas where sealant was retained or lost

	Restoration	Occlusal	Buccal	Palatal
Retained	31 (35.6%)	40 (46.0%)	11 (28.9%)	22 (46.8%)
Lost	56 (64.4%)	47 (54.0%)	27 (71.1%)	25 (53.2%)
	n=87	n=87	n=38	n=47

Statistical comparisons.

Differences between sealant retention and loss by surface for all glass ionomer sealant restorations after 24 months.

Restn v Occl. $Chi^2 = 1.93$ $DF=1$ $P > 0.05$

Bucc v Occl $Chi^2 = 3.17$ $DF=1$ $P > 0.05$

Pal v Occl $Chi^2 = 0.08$ $DF=1$ $P > 0.05$

Bucc v Pal $Chi^2 = 2.82$ $DF=1$ $P > 0.05$

*Differences between the areas of sealant loss after **12** and **24** months.*

$Chi^2 = 4.76$ $DF=7$ $P > 0.05$

*Differences between the areas of sealant loss between **composite** and **glass ionomer** sealant restorations (Type 2 v Type 3).*

$Chi^2 = 5.82$ $DF=7$ $P > 0.05$

*Differences between the areas of sealant loss between **glass ionomer sealant restorations** and **therapeutic fissure sealants** (Type 3 v Type 1) .*

$Chi^2 = 5.29$ $DF=5$ $P > 0.05$

Table 5.22 Areas of completely and partially lost and completely retained fissure sealant.

Life expectancy	Type 3 Restoration
immediate replacement	11 (12.6%)
1 - 2 years	45 (51.7%)
more than 2 years	31 (36.7%)

n = 87

Statistical comparisons.

life expectancy between ***glass ionomer*** *sealant restorations (type 3) and* ***composite*** *restorations (type 2 and type 4).*

$Chi^2 = 4.33$ DF=2 $P > 0.05$

Life expectancy between ***glass ionomer*** *sealant restorations (type 3) and* ***therapeutic*** *fissure sealants (type 1).*

$Chi^2 = 2.12$ DF=2 $P > 0.05$

Table 5.23 Prediction of the estimated future life of the glass ionomer sealant restorations after 24 months.

	Type 3
Presence of restoration:	
covered with sealant	49 (56.3%)
no sealant covering	37 (42.5%)
restoration missing	1 (1.1%)
Marginal integrity:	
no visible crevice	84 (96.5%)
crevice-no dent. exposed	1 (1.1%)
dent. exposed - restn present	1 (1.1%)
dent. exposed - restn absent	1 (1.1%)
Marginal discolouration:	
no discolouration	70 (80.4%)
around < 1/3 margin	13 (14.9%)
between 1/3 and 2/3	3 (3.4%)
around > 2/3 margin	1 (1.1%)
Surface wear:	
absent	83 (95.4%)
present	4 (4.5%)

Statistical comparisons *between* ***glass ionomer*** *sealant restorations and* ***composite*** *sealant restorations.*

Sealant over restoration $Chi^2 = 1.92$ $DF=2$ $P > 0.05$

Marginal integrity $Chi^2 = 3.71$ $DF=3$ $P > 0.05$

Marginal discolouration $Chi^2 = 2.99$ $DF=3$ $P > 0.05$

Occlusal wear $Chi^2 = 0.01$ $DF=1$ $P > 0.05$

Table 5.24 Performance of the glass ionomer sealant restorations after 24 months.

After 2 years, only 13.8% of the glass ionomer sealant restoration had intact fissure sealant but the two external assessors considered that 38.9% of the restorations required no further treatment at the present time. Eleven of the restorations reviewed (12.6%) were considered to need replacement and were therefore eliminated from the trial. The presence of cavitated carious lesions was the principal reason for restoration replacement (81.8%).

The simple addition of further fissure sealant to previously sealed surfaces was found necessary in 48.2% of restorations. Treatment requirements for the glass ionomer sealant restorations shown in Table 5.25 were found not to be statistically different from that of the composite sealant restorations ($P > 0.05$).

	Type 3
No treatment required Addition of fissure sealant New restoration required	34 (38.9%) 42 (48.2%) 11 (12.6%) n = 87
Reason for new restoration Secondary caries Primary class 1. Primary class 11. Restoration missing. Restn. wear exposing dentine at base.	 1 (9.1%) 3 (27.3%) 5 (45.5%) 1 (9.1%) 1 (9.1%) n = 11

Statistical comparisons:

*between **glass ionomer** sealant restorations and **composite** sealant restorations.*

$Chi^2 = 3.65$ DF = 3 $P > 0.05$

Table 5.25 Treatment requirements after 24 months.

5.11.4. DISCUSSION.

A: Use of glass ionomer cement fissure sealant restorations.

General dental practitioners responding to a postal questionnaire (Paterson *et al* 1990) confirmed the general acceptance of the sealant restoration technique within general dental services, but also showed the use of glass ionomer sealant restorations was the most popular: 85% of the respondents had placed sealant restorations using these materials. Returns to the Scottish Dental Practice Board during the six months period from October 1988 to March 1989 showed sealant restorations placed using glass ionomer and fissure sealant to account for 58.7% of all restoration types involving the enamel biopsy or investigative cavity technique. In the current field trial involving Community Dental Services, 37% of similar cavity types were restored using these materials. Although it would appear simpler to achieve bonding between composite resin and fissure sealant than between glass ionomer and sealant, the high reported use of the latter materials in the sealant restoration technique may reflect the potential these materials have in inhibiting caries due to fluoride release (Swartz *et al* 1984) or to descriptions of the use of this combination of materials in recent publications just prior to this study commencing (Burke 1989).

Teeth restored using these materials reflect the general trend of restoration placement in children (Stamm 1984). The mean age of patients in whom glass ionomer sealant restorations were placed was higher than that of those receiving therapeutic fissure sealants in first and second permanent molar teeth. It would appear that therapeutic fissure sealants are generally placed within thirty months of tooth eruption, while lesions do not reach dentine and require investigative intervention until another eighteen months have elapsed. Interestingly, the age of patients did not differ from that of children receiving composite and fissure sealant or laminate sealant restorations.

B: Materials and techniques employed.

By definition, glass ionomer sealant restorations extend into dentine but cavity extent is limited and the margins are therefore not in occlusal contact (Garcia-Godoy 1986 and Paterson *et al* 1991). It was surprising, therefore, to note the low reported use of local anaesthetic during the placement of these restorations. This may reflect either that the operators (or their patients) did not like local anaesthetic and found this stage of operative treatment traumatic or that the cavities did not extend fully into dentine. Cross referencing the data for this restoration type with that reported on the extent and depth of cavity preparation, showed that all cavity preparations had been reported to involve dentine at the cavity base.

Paterson *et al* (1991) recommended the use of the smallest round, diamond coated bur for cavity preparation. From the data supplied on the registration cards, it would appear that round diamond coated burs are routinely being used, but there was a wide variation in the size of bur: 29.4% did not respond to this question while 49.2% used a bur of greater than an ISO 012 (> 1.2mm in diameter). The failure to respond to this question was higher than for all other questions. The recommended size for the enamel biopsy technique is an ISO 008 (0.8mm in diameter) which was used during the investigation of only 2.0% of cavities.

In Table 5.6, the reported use of glass ionomer cements is shown. One manufacturer's products (De Trey/Dentsply) were used for the restoration of 144 teeth and was employed by all of the participating operators. Only 3.3% of the restorations were placed using a glass ionomer cement with radio-opaque properties. This may result in future diagnostic problems regarding the incorrect diagnosis of caries lesions below what would appear to be a fissure sealed surface. The consequences of this practice could be the unnecessary investigation and filling of satisfactorily restored teeth.

Almost a third of the glass ionomer fillings were etched before the sealant was applied to the filling surface and the adjacent enamel fissures. Etching of glass ionomer before application of composite resin will be discussed in Chapter 6. As the material is adversely affected by etching, Paterson *et al* (1991) advocated the use of an intermediate enamel/dentine bonding resin to improve surface wetting of the cement surface and allow resin penetration within the cement mass. The etching time of the cement was likely to be the same as that employed for enamel preparation. Over 80% of the restorations would therefore be etched for at least 30 seconds: a treatment regime that can result in marked deterioration of the cement (Taggart & Pearson 1988).

One hundred and forty three restorations were sealed using material from one manufacturer (Johnson & Johnson, now De Trey/Dentsply). The high reported use of an autopolymerising resin was surprising, but most probably reflects the non availability of curing lights in some of the surgeries used by the Community Clinical Dental Officers. This may also be reflected in the high use of glass ionomer materials for the restoration of minimally carious teeth. The case for using opaque fissure sealants was discussed by Simonsen (1988) and Rock *et al* (1989) who advocated their use as they were both easier to place with the patient supine (due to their greater viscosity) and easier to check at subsequent recall visits. All pit and fissure sealants used in the current study were unfilled, despite literature reports favouring filled materials (Strang *et al* 1989). As sealant restorations are more likely to come into occlusion and therefore be subjected to wear, use of filled fissure sealants would seem more appropriate. It could also be argued that unfilled resins would wear quickly and be less likely to interfere with occlusal function for any prolonged period. Rock *et al* (1990) reported retention of a filled sealant material was poorer than that of unfilled materials. Almost half of the light cured sealants were polymerised for more than one minute, with 72% being cured for more than 30 seconds. Problems may occur if light cured resins are not polymerised for a sufficient length of time (Houpt *et al* 1986) but over exposure to light will not have deleterious effects on the sealant.

Operator control of gel etchants and the ability to easily see the materials has undoubtedly been responsible for the preference of these materials. Liquid etchant is supplied by the manufacturer of the most commonly used materials but has not been universally employed as an enamel or glass ionomer etchant. Rock *et al* (1990) investigated the effect of the etchant material on fissure sealant retention and reported no difference between gel and liquid materials. When Garcia-Godoy & Gwinnett (1987) investigated the effect of solution and gels of two viscosities, they reported no differences in etching ability of these etchant materials on the occlusal enamel of the cuspal slopes and confirmed the poor penetration of the materials into the depth of occlusal fissures. The majority of operators were still using etch times in excess of 30 seconds (with 10.4% etching for greater than 45 seconds) despite recent literature reports on effective fissure sealant retention and bond strength to enamel when reduced etch times are used (Eidelman *et al* 1988 and Tandon *et al* 1989).

C: Performance of glass Ionomer cement fissure sealant restorations after six Months.

The ability of the Community Dental Services to recall almost 85% of patients is heartening, as most authorities were actively encouraging their staff to return patients to the General Dental Services following the guidelines of Circular HC(89)2 (Department of Health 1989). Zoitopoulos & Jenner (1991) described the loss of 16.5% of previously regular attenders in the Halton Health Authority area by this practice.

After six months only 21% of the sealants were intact. The retention rate is significantly lower than that reported in the same study when therapeutic fissure sealants were applied (see Chapter 3). This may reflect the longer time required and consequently poorer levels of cooperation achieved for the insertion of a glass ionomer sealant restoration. Unfortunately, no information was available on the areas of lost fissure sealant after the initial six months review. Raadal (1978b) concluded that the presence of a composite restoration did not adversely affect the overall retention rate of sealant when compared with fissure sealants placed as a preventive measure.

Following the loss of sealant, six glass ionomer restorations showed surface wear clinically and twelve fillings had marginal stain. Sealant loss, therefore, had contributed to deterioration in 14.5% of the sealant restorations reviewed. Loss of sealant had also allowed four cavitated lesions to develop in previously sealed surfaces while leakage around glass ionomer cement restoration had resulted in seven secondary caries lesions, despite the reported leaching of fluoride which may have a caries inhibitory affect (Swartz *et al* 1984). The reluctance of Community Dental Officers to subject patients to radiographic assessment (see Chapter 1) is reflected in high incidence of clinically detected caries on approximal surface seen only six months after restoring a carious lesion on a pit and fissure surface of the same tooth.

After a short period of clinical performance, it was still considered that glass ionomer sealant restorations required some minimal maintenance to allow them to remain in good clinical condition. Fortunately, maintenance is restricted to replacing minor amounts of lost sealant. Cost implications of this are minor while still maintaining the strength and integrity of the tooth.

D: Performance of glass ionomer cement fissure sealant restorations after one year.

The use of local anaesthetic has been associated with greater success in the trial comparing sealant restorations with amalgam fillings in first molars described by Walls *et al* (1985). There was no correlation in the current study between the administration of local anaesthetic and the retention of fissure sealant.

The lack of difference in fissure sealant retention when gel and liquid etchants were used confirms the observations of Rock *et al* (1990) who noted almost identical results with the two etching materials. Similarly, Barkmeier *et al* (1985) and Beech & Jalaly (1980) observed that little difference in fissure sealant retention rates was obtained by increasing etching times above 30 seconds.

When the missing areas of sealant are analysed, it is apparent that sealant has been lost from over almost 70% of the glass ionomer cement surfaces. There is considerable debate about the most appropriate method of preparing glass ionomer cement surfaces to receive either composite resin or fissure sealant. Paterson *et al* (1991) suggested that etching the surface should be avoided and the surface should be treated with a bonding agent such as Scotchbond Dual Cure (3M) which is a phosphorylated ester of bis-GMA. This enamel dentine bonding resin may bond ionically to the set surface of the cement or may improve the surface wetting ability before the application of sealant. This technique has been shown *in vitro* to increase the shear bond strength between these materials (Gray 1994). Taggart & Pearson (1988) described a deterioration in the mechanical properties following simple acid etching of glass ionomer cement surfaces to improve the retention of composite resins.

In slightly more than a third of the restorations, the glass ionomer cement surface was etched in an attempt to improve the retention of the overlying fissure sealant. When the results in Table 5.15 and Figure 5.5 were subjected to statistical analysis, it was observed that the etching of the restoration surface for 30 seconds or longer did not significantly improve the retention. This analysis of data may indicate that there are other factors involved, such as inadequate isolation or insufficient irrigation of the glass ionomer surface following etching. While the complete retention of the sealant resin over the entire surface of the restoration may not influence its clinical durability, the presence of resins at the margins should reduce leakage.

There would appear to be a much greater problem in achieving the retention of sealant in the buccal fissures of lower molars than any other part of the tooth. This is usually considered to be the most difficult part of the tooth to keep dry after etching the enamel. It may be that undetected salivary contamination has occurred more frequently in this fissure. The buccal cusp of the lower molar is frequently a working cusp in lateral movements of the mandible and it may be that the buccal fissure is subjected to greater mechanical stress during mastication than the palatal fissure of the upper molar.

There were significant differences in sealant retention over the glass ionomer cement surface dependant on its extent along the involved fissure: the greater the extent of the restoration, the poorer was the retention. This could be due to the reduced area of enamel remaining on the cusp slopes surrounding the restoration which could offer micromechanical retention for the fissure sealant. Differences in the buccolingual width of the restoration did not significantly influence the retention of the fissure sealant.

The indications for the use of glass ionomer cement in the restoration of the minimal occlusal cavity were described by Paterson *et al* (1991), who recommended its use in cavities of minimal width where the margins were not in occlusal contact. This was suggested to avoid wear on the restoration surface. The descriptive statistics show that this type of sealant restoration is being used to restore larger cavity types than had been recommended. It may be that the release of fluoride from glass ionomer cement (Causton 1981) and its reported anti caries properties make this a popular choice of material in the Community Dental Service, since cavities in deciduous teeth are frequently restored with glass ionomer cement.

The detection of cavitated lesions in 7.1% of previously sealed surfaces is considerably higher than the figures reported by Mitchell and Murray (1987) who reviewed 3017 fissure sealants placed in Newcastle Dental Hospital, where lesions were observed in 3.1% of previously sealed surfaces. The presence of decalcification of fissures, opacities around the fissures and frank cavitation were scored as caries lesions. This scoring system will be more sensitive than that used by Mitchell and Murray (1987): the latter authors did not specify the criteria used to determine fissure caries but corrected their results using an actuarial life table to take account of fissure sealants lost to recall. This gave a figure of 4.9% overall and 5.5% for the molar teeth. Fluoridation of the water supply has not occurred in the current trial area in the West of Scotland and this could account for the differences observed in caries prevalence.

The necessity for the replacement of missing areas of fissure sealant is a difficult clinical judgement to make. Simonsen (1980) in his follow up reports on Preventive Resin Restorations commented that success, in his view, was the prevention of further primary or secondary caries. He also observed that the fissure sealant was incomplete in a number of his restorations.

In the context of the current large field trial, it seemed reasonable to attempt to define criteria to allow rapid judgements to be made. The essential feature must be to make a judgement on the likelihood of further caries developing if the sealant is left incomplete. It was on this basis that the sealant was considered to require replacement if the missing zone involved a stained or decalcified fissure or if there were more that two other carious surfaces present in the mouth. In practice, it appeared that the assessors were more demanding in their requirement for the placement of more fissure sealant than the CDO's. Since the restorations were present on patients who were subject to routine recall and who were to be seen again by the assessors after two years, no attempt was made to convince the CDO that modification was necessary.

Patients in the current trial who developed cavitated lesions in previously sealed surfaces had a higher proportion of carious surfaces (expressed as a ratio to the total available surfaces) than in those patients where cavitation did not follow the loss of the sealant. The number of previously filled surfaces was also higher in this group. This would suggest that the decision was correct to replace lost fissure sealant when there were two or more other carious lesions present in the dentition.

E: Performance of glass ionomer cement fissure sealant restorations after two years

The results after 2 years of glass ionomer cement sealant restorations placed in the conditions of a busy practice in the Community Dental Services show this restorative technique to perform well, with only 12.6% of the sample placed having totally failed. Due to cavitated fissure caries 27.3% of the failures required replacement and, as a result of approximal caries, 45.5% of restorations required replacement. Where cavitated fissure lesions developed, the technique may be criticised as the placement of fissure sealant resin is performed as a preventive measure in place of extending the cavity outline into all potential caries risk areas. Where sealant has been lost, the physical barrier which prevents oral bacteria and their nutrients accumulating in the fissures are also lost and the acidic conditions considered necessary for caries initiation may again prevail. Gwinnett & Matsui (1967) reported the presence of resin in the pores created by etching of enamel surfaces and postulated that this would encapsulate the crystals of hydroxyapatite and prevent their dissolution in acidic conditions. The continued protection of enamel following loss of sealant was reported by Hinding (1974), but early loss of sealant, due to improper fissure sealing technique, is unlikely to allow resin penetration into the micropores of etched enamel (Going 1984). In such circumstances, the fissures remain exposed to the oral environment as if no treatment had been attempted to these vulnerable areas.

Gwinnett (1973) also showed that sealant does not always penetrate the depth of fissures due to the entrapment of air, organic debris or prophylactic pastes in the depth of fissures. Gwinnett also postulated that resins did not penetrate the micropores of etched enamel on the side walls of the fissures, as the acid solutions could not adequately penetrate. However, Brown *et al* (1988) reported that gel and liquid etchants both penetrated fissures equally well.

It is likely that the early loss of sealant from pit and fissures surfaces of the teeth treated in this field trail represents an error in etching protocol which will not confer cariostasis to the tooth.

Despite the use of glass ionomer cement restorations in cavity sizes that were considered to be larger than that described for the technique, surface wear of the restorations did not appear to be a problem even after two years. The restorative part of the sealant restorations performed well with few problems: the performance of the fissure sealant was more problematic requiring the need for replacement fissure sealant at periodic intervals.

Loss of sealant from the glass ionomer cement sealant restorations occurred quickly following placement, but after 12 and 24 months was not significantly different from that observed after 6 months. Over a two year observation period, the performance of the glass ionomer cement and the fissure sealant was not significantly different from that noted in the small intra-enamel composite sealant restorations or in the larger laminate restorations.

5.12 CONCLUSIONS.

1. Glass ionomer cement fissure sealant restorations were the second most popular restorations in the field trial after laminate restorations.

2. These restorations were placed predominantly in first permanent molar teeth and seldom used in premolar teeth.

3. Restorations were placed 3-4 years after tooth eruption.

4. Just over 50% of the restorations were placed under local anaesthetic.

5. Over 50% of the enamel biopsies preceding these restorations were performed with a bur larger than 1.2mm in diameter; 2% were performed with an 0.8mm diameter bur.

6. The most common method of isolation used was cotton wool rolls plus an aspirator.

7. 96% of the restorations were placed with a single material. Only 3.3% were placed with a radiopaque glass ionomer cement.

8. Most operators preferred a self cured fissure sealant for these restorations.

9. The complete retention rates for fissure sealant after 6, 12 and 24 months were 21.3%, 12.2% and 13.2%. These differences were not statistically significant.

10. The most frequent site of sealant loss was from mandibular molar teeth followed by the surfaces of the glass ionomer cement restorations.

11. Fissure sealant was lost significantly more frequently from the surface of the glass ionomer cement restorations than from the adjacent occlusal fissures.

12. No significant difference was found in sealant retention to maxillary or mandibular molar teeth or in the right and left sides of the dentition.

13. No significant difference was observed in the retention of self and light cured sealants.

14. Etching of the glass ionomer surface did not improve fissure sealant retention.

15. The duration of acid etching did not influence the retention of fissure sealant.

16. The use of an aspirator in addition to cotton wool rolls significantly improved fissure sealant retention in the problematic buccal fissure.

17. The most frequent cause of elimination of teeth from the field trial was the development of approximal caries.

18. After two years 4.5% of the glass ionomer cement restorations showed surface wear and 19.4% marginal discolouration.

19. The overall performance of the glass ionomer/fissure sealant restorations was not significantly different from the composite resin/ fissure sealant restorations.

20. It was estimated that 36.7% of the restorations reviewed after two years would survive for at least another two years; a further 51.7% had an estimated life of 1-2 years.

21. After 2 years, 87.1% of the restorations required either no treatment (38.9%) or the simple addition of further fissure sealant (48.2%).

Chapter
6

In vitro assessment of factors influencing the shear bond strengths of different fissure sealants to composite resins and various forms of glass ionomer (polyalkenoate) cements.

6.1 INTRODUCTION.

6.1.1 Fissure sealant retention to restorative material surfaces used in the sealant restoration technique

The retention of fissure sealant in carious teeth managed by placement of a "sealant restoration" is usually excellent and the presence of the restoration has been reported not to reduce the retention of fissure sealant (Raadal 1978b). Houpt *et al* (1984) found 83% complete retention of fissure sealant after three years in a two centre trial where 332 composite fissure sealant (P.R.R.) had been placed. Simonsen and Stallard (1977) reported 100% sealant retention after one year and 97-100% fissure sealant retention three years post placement (Simonsen 1980). Further application of sealant was required to 28% of the sealant restorations reviewed by Walls *et al* (1988) after two years and, in the same study, further periodic additions were required on up to four occasions over the five year assessment period (Welbury *et al* 1990).

In the current field trial, results have shown that problems are being experienced in the retention of fissure sealant to the surface of both composite resin and glass ionomer cement fillings placed during the provision of sealant restorations in the Community Dental Services. Loss of sealant from the surface of composite restorations is significantly greater than that from the adjacent occlusal pits and fissures when the resin base systems of the composite and sealant are mismatched (see Chapter 4). Similarly, sealant loss from the surface of glass ionomer cement restorations - placed as part of sealant restorations used in the management of small fissure lesions - is significantly greater than from the adjacent fissures of occlusal surfaces of permanent molar teeth (see Chapter 5).

Investigation of the magnitude of the bond of fissure sealant resin to the surface of composite resin or glass ionomer cement filling materials has not previously been reported.

6.1.2 Resin to Resin Bond Strength Values.

Due to the improved formulation of composite materials, they are now increasingly used in the restoration of posterior teeth as well as anterior restoratives. The bond strength between increments of composite materials has been the subject of investigation. Problems with wear and discolouration are inherent with this polymerisable material. There has also been some debate on the need for complete replacement or repair of deficient areas or surfaces.

In vitro work has shown that the bond strength of a repaired composite is reduced compared to complete and homogeneous control samples (Forsten & Valraho 1971, Reisbick & Brodsky 1971, Causton 1975, Boyer *et al* 1978, Lloyd *et al* 1980, Chan & Boyer 1983, Miranda *et al* 1984, Azarbal *et al* 1986, Soderholm 1986, Saunders 1990, Soderholm & Roberts 1991 and Pucket *et al* 1991). Soderholm (1986) reported the flexural strength of repaired composite ranged from 20 to 85% of the flexural strength of unrepaired samples. The variation in results has been explained as arising from different experimental protocols, involving alternative surface preparation and treatment regimens. In addition, the magnitude of the bond has been measured using flexural, shear and tensile methods.

Initially, work concentrated on the use of **anterior composite resins** which yielded bond strengths varying from 20 - 85% of the unrepaired control samples of composite. Most operators considered the repairs to be clinically adequate as the bond strengths achieved - greater than 18MPa - were similar to those of composite to etched enamel surfaces.

Posterior composite resins are more heavily filled and yield lower bond strengths following repair procedures (Lloyd & Dhuru 1985). They considered, however, that this could be overcome by using a layer of unfilled resin between the original mature composite and newer additions. This was found to be true even when the surface was contaminated by saliva. The ground surface of seven day old posterior composite samples was observed to provide a poor surface for bonding new additions (Eli *et al* 1988). In 1989, Crumpler *et al* reported that optimal bond strength could be achieved by reducing the surface of mature composite using a diamond bur, cleaning with an etching gel and applying an unfilled bonding resin to increase the wettability of the matured surface.

Soderholm & Roberts (1991) offered the following possible solutions in explanation for the reduced bond strength following repair:

i/ incomplete bond formation between the cut composite surface and the new layer.

ii/ the cut surface contains a significant amount of filler which is devoid of silane coating and, therefore, would not support bonding with composite resin.

iii/ the cut surface contains matrix lacking in reactive sites.

In 1986, Chalkey & Chan reported the occurrence of increased microleakage at the site of repairs completed using anterior composite resin. Microleakage allows the bond to deteriorate and this may ultimately lead to the failure of the restoration. He also reported that when the composite resin used to repair an existing matured material is based on a different chemical formulation, the amount of microleakage was increased. Repair of posterior composite resins, based on a bisGMA formulation, using a urethane based material of similar filler loading produces a bond of a significantly lower magnitude (Puckett *et al* 1991).

Addition of composite resin or repairs to composite fillings should be able to withstand the forces exerted during mastication. These forces are of an impact nature but with the addition of a cyclic component. Johnson (1972) reported the effect of loading on the teeth was a function of volume under stress. When a structure is subjected to repeated stress cycles, it may fail at stress levels below its tensile strength by a process of fatigue (Ashby and Jones 1980).

Fatigue life is defined as the number of stress cycles that a material can withstand before failing. At high stress values, failure may occur after a low number of cycles but conversely, when low stress values are applied, failure may occur only after prolonged stress cycling (Saunders 1990). Below a certain value, known as the fatigue limit, materials can be subjected to a very high number of cycles without clinical failure.

6.1.3 Resin to glass ionomer cement bonding.

A: Glass ionomer cement to composite resin bonding.

There have been no reports in the literature of the bond strength of glass ionomer cements to fissure sealant resins. The bonding of composite resin to the etched surface of glass ionomer cements was described by McLean and Wilson (1977b). This method was described as the laminate or sandwich technique. In 1986, Garcia-Godoy described a technique for the restoration of minimal occlusal cavities which did not involve a load bearing area and whose pulpal floors extended just into dentine. The adjacent enamel and the surface of the glass ionomer cement restoration were etched and covered with fissure sealant. In a subsequent report, Garcia-Godoy reported reduced microleakage for these restorations compared to minimal composite and fissure sealant restorations. Paterson *et al* (1991) suggested that to avoid the danger of mistaken diagnosis of occlusal caries on radiographs, a radiopaque glass ionomer cement should be used for the sealant restoration technique.

Although glass ionomer cement was originally designed as a restorative material for use in class V abrasion cavities, it has many of the ideal properties of a lining cement. It has the advantage of fluoride release (Meryon & Smith 1984) and being a dynamic material with ionic exchange at the tooth restoration interface, it can bond with enamel and dentine (McLean 1988).

When used as a lining cement in the laminate or sandwich technique, McCullock & Smith (1986) reported that teeth weakened by caries and cavity preparation could be strengthened. The opal glass based lining cements are radio-opaque and have an increased speed of set.

During the 1980's there was concern over the possibility of hydrolysis of phosphonated dentine bonding resins (Mount 1989) McLean (1977b) described the use of glass ionomer cements as a lining to replace lost dentine i.e. a structural lining. Both lining and exposed enamel margins could be etched using buffered 37% phosphoric acid to achieve micromechanical retention for composite resins. The laminate restoration was reported to have superior retention with less microleakage and less secondary caries lesions (Garcia Godoy 1986).

B: Etching of glass ionomer cement surfaces.

Etching of glass ionomer cement has been found to achieve a mechanical union between the cement and composite resins. In 1987, Causton *et al* reported the superiority of phosphoric acid etch over citric acid conditioners. McLean *et al* (1985) observed that acid etching glass ionomer cements removed 0.43ug/mm^2 /minute. Analysis showed that the lost ions consisted of calcium, aluminium and silicon.

In 1988, McLean addressed the need for etching of the glass ionomer cement prior to the application of the composite resin and concluded that the resultant bond strength was inferior if the etch regime were omitted. In his view, only thin linings of less than 0.5mm should be left unetched. Welbury (1988), however, reported that the bond strength of unetched specimens was insignificantly reduced, but the dependability of the bond was better if etching were performed. Garcia-Godoy (1986) found differences in the surface of unetched specimens of glass ionomer cement - this led him to conclude some cements required surface preparation before bonding an overlying layer of composite resin.

C: Optimal etching time for glass ionomer cement surfaces.

The time for which the surface of glass ionomer cement is subjected to acid etching has been investigated by many workers. In 1988, McLean reported etching to remove matrix from around the glass particles, leaving them proud of the surface. This produced an surface contour suitable for micromechanical retention. He recommended a short etch period of 15 - 30 seconds. This confirmed the work by

Causton *et al* (1987) who had suggested no gain was achieved by etching for longer than 30 seconds.

When Taggart & Pearson (1988) investigated the effects of etch time on the anhydrous glass ionomer ChemFil (DeTrey/Dentsply), they used scanning electron micrographs (S.E.M.) from an amine replica of the cement surface to help overcome the problems of cracking and crazing during the processing of the specimens. They reported that glass particles on the surface of the cement were tenuously attached to the underlying matrix, even after etch times as short as 15 seconds. Etch regimes of greater than 30 seconds produced alterations of the cement surface up to a depth of 300um. This made thin linings of less than 0.5mm unsuitable for etching.

D: Optimum time after mixing glass ionomer cement for etching.

The time interval between mixing the glass ionomer cement and etching its surface was investigated by Causton *et al* (1987) and Welbury *et al* (1988). Causton *et al* investigated the effects of etching a restorative and a cermet cement at varying time intervals after mixing , but before bonding a heavily filled posterior composite resin to its surface. They reported that the appearance on S.E.M. did not relate well to the bond strength of the union. Cermet cements produced lower bond strengths than restorative cements and failed adhesively during laboratory testing of bond strength. They concluded that there was no difference in the bond strengths achieved by restorative cements when etched at any time interval after 5 minutes, while the cermets should be left for as long a period as possible before etching. These recommendations were based on the findings of specimens which were stored for 7 days before etching, and found to achieved 68% better bond strength than those specimens that were etched after 10 minutes. Welbury *et al* (1988) confirmed these findings and reported that premature etching significantly reduced the bond strength. The use of restorative cements achieved improve bond strengths compared to cements formulated specifically for lining (Welbury *et al* 1988 and Hinoura *et al* 1987).

E: Use of an intermediate resin.

A significant increase in bond strength was achieved if an intermediate resin were applied to the glass ionomer cement surface. Its use with lining or cermet glass ionomer cements was reported to be more important in achieving improved bond strengths in laboratory testing (Causton *et al* 1987), particularly where the material is being etched at an earlier stage of maturation. When an intermediate resin is used, bond strengths are improved and failure occurs within the brittle and weak glass ionomer cement.

Hand mixing of glass ionomer cements would appear to produce a more porous cement with voids of up to 50 micrometres. (McLean *et al* 1985, Causton*et al* 1987 & Mount 1989). This may help improve bond strength compared to materials which are mechanically mixed and freer from voids. Improved wetting of the cement surface by the resin appears to strengthen its outer surface, to the extent that failure then ultimately takes place within the unstrengthened body of glass ionomer cement.

Poor adaptation of heavily filled composite resin to glass ionomer cement has been reported (Causton *et al* 1987 & Mount 1989). Etched cement surfaces have a high surface energy which allows good wetting by low viscosity resins which have a low surface energy.

The bond strength was further improved if the intermediate resin were light cured before application of the composite (Hansen 1984). Intermediate resins which have a volatile vehicle (eg. Scotchbond Dual Cure, 3M) should be carefully air dried to prevent the formation of an incomplete bond surfaces similar to that described by Prevost*et al* (1982) between dentine and composite.

F: Polymerisation shrinkage of composite resins.

The volumetric change which occurs in composite resins during polymerisation may stress the union between the two materials. Jensen & Chan (1985) reported that lightly filled resins shrank more on setting than heavily filled composites designed for use in restoration of posterior teeth. Mount (1989), however, reported a problem in adapting heavily filled composite resins to glass ionomer surfaces without incorporating voids.

6.1.4 AIMS of study.

In this section of the study, the bond strength of fissure sealant to both composite resin and glass ionomer cement filling surfaces was evaluated.

In addition it seemed prudent to identify:

i) Optimal surface treatment of restorative materials.

ii) Influence of the polymerising resin type in the fissure sealant.

iii) Influence of the filler loading in the fissure sealant.

iv) The effect of mismatching the resin bases in the composite resin and the fissure sealant.

v) The effect of the glass ionomer cement type i.e. restorative or lining.

The effect of the above variables were investigated in a series of *in vitro* studies, in order to determine how the greatest shear bond strength values of fissure sealant to restorative materials could be achieved.

6.2 MATERIALS AND METHODS.

6.2.1 Bonding of fissure sealants to composite resins.

The materials used in this study were the composite resins P50 (3M, Batch Number GH-6200-1287-8), Tetric (Ivoclar/Vivadent, Batch Number 460275) and Heliomolar (Ivoclar/Vivadent, Batch Number 460243) which are marketed as suitable for the restoration of posterior teeth. P50 and Tetric have a hybrid structure while Heliomolar is a microfilled filling material. Only P50 composite resin has a bisGMA resin base while the other materials are formulated on a urethane dimethacrylate structure. Three visible light cured pit and fissure sealant resins were used as additions to the surface of the filling material: Delton (DeTrey/Dentsply, formerly Johnson & Johnson, Batch Number 2C6306), Helioseal (Vivadent, Batch Number 340251) and Estiseal (Kulzer, Batch Number ChB. 219). All fissure sealant materials have a radiolucent bisGMA resin base. Delton and Helioseal are unfilled materials while Estiseal contains a filler loading of 27% silica.

Composite resin specimens were prepared in a stainless steel mould which had a countersunk head measuring 10mm. by 3mm. in depth (see Figure 6.1). The composite resin filling material was placed into the mould using a teflon coated thermoplastic instrument (Hawes Neos) and the surface finished parallel to that of the upper surface of the mould, in line with the shearing force. It was polymerised for three minutes using visible blue light of 470nm. before further surface preparation. Ten specimens of each composite resin were prepared for every surface treatment regimen.

Surface preparation regimens were assessed in combination with the light cured fissure sealants. These were as follows:

1) The composite was left as polymerised i.e. no preparation.
2) The set surface was prepared using a rotating disc (Softlex Coarse, 3M)
3) The set surface was prepared using a rotating disc and a halophosphorus ester of bisGMA resin applied (Scotchbond Dual Cure, 3M).
4) The set surface was prepared using a rotating disc and a silane coupling agent (Scotchprime 3M) applied before a layer of bonding resin.

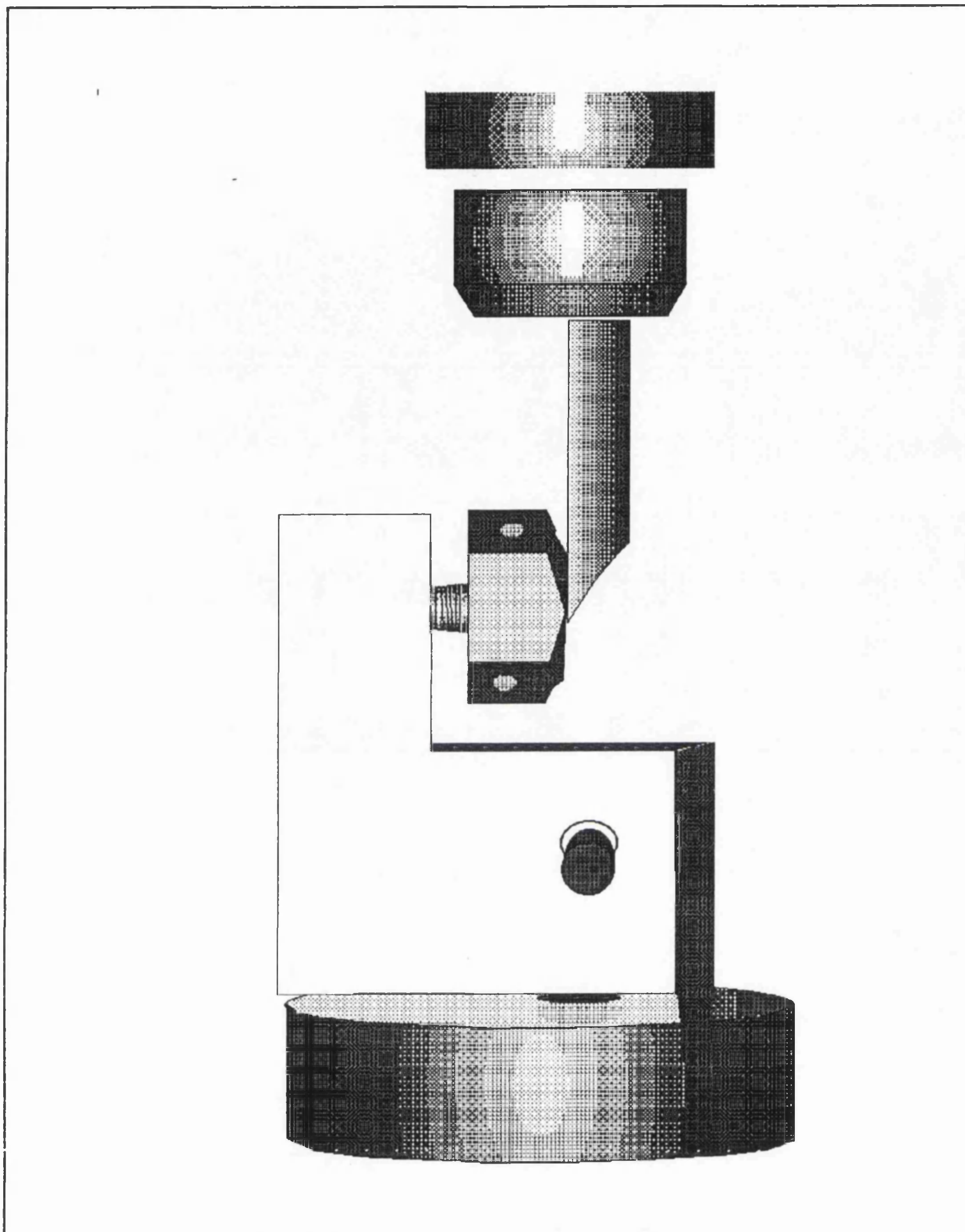


Figure 6.1 **Profile view of the test appratus. The bolt containing the glass ionomer cement sample is rigidly held in the base, while the shear plate accurately fits around the stainless steel washer containing the sample of fissure sealant.**

A stainless steel washer with an internal diameter 5 mm. and a depth of 1.0mm was centred over the composite resin surface using a poly-vinyl siloxane putty jig (see Figure 6.2). Fissure sealant was applied and polymerised for 60 seconds with a visible blue light source of 470nm. The samples were stored in tap water for a period of 7 days before being subjected to thermocycling at 5, 20, 37, and 55 degrees Centigrade for 5 hours, with a dwell time of 10 seconds for each temperature.

The bond strength was measured under shear loading on a Nene Universal Testing Machine with a cross head speed of 0.01 cm per minute. A shaped rod was used to apply the shearing force to the stainless steel washer which contained the fissure sealant (see Figure 6.3). The mode of failure for each specimen was noted and mean shear bond strength values and standard deviations were calculated for each of the surface treatment regimens.

6.2.2 Bonding of fissure sealants to anhydrous glass ionomer restorative cements.

The materials used in this study were the anhydrous glass ionomer (polyalkenoate) cement ChemFil ll (De Trey/Dentsply Batch No 920504) and the light cured and chemically cured fissure sealant Delton (formerly Johnson and Johnson now De Trey/Dentsply, Batch Numbers: Light Cured 972001 and Self Cured 972101) . Specimens were prepared in the stainless steel moulds described in section 6.2.1. The glass ionomer cement was mixed with distilled water according to the manufacturers' instructions and placed into the mould using a stainless steel spatula. The surface was finished parallel to the surface of the mould, in line with the shearing force. It was left to set for four minutes before further surface preparation. Ten specimens were prepared for each surface treatment: two groups of specimens were allowed to set under a cellulose acetate matrix strip to impart a smooth surface finish.

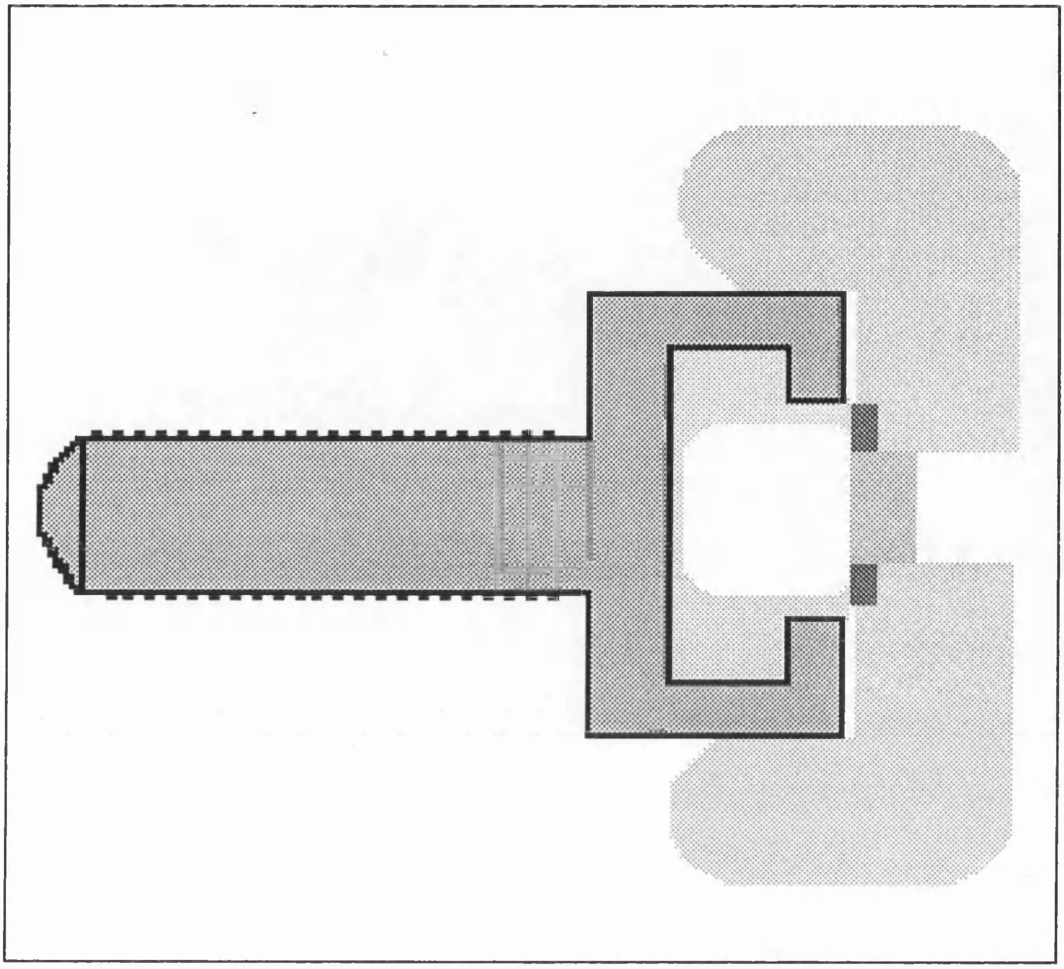


Figure 6.2 **Transverse section through the bolt with countersunk head containing the sample of restorative maerial. A putty mould was used to centrally locate the washer, containing the fissure sealant, on to the surface of the restorative material.**
A central channel through the putty allowed access of the visible blue light to fissure sealant surface.

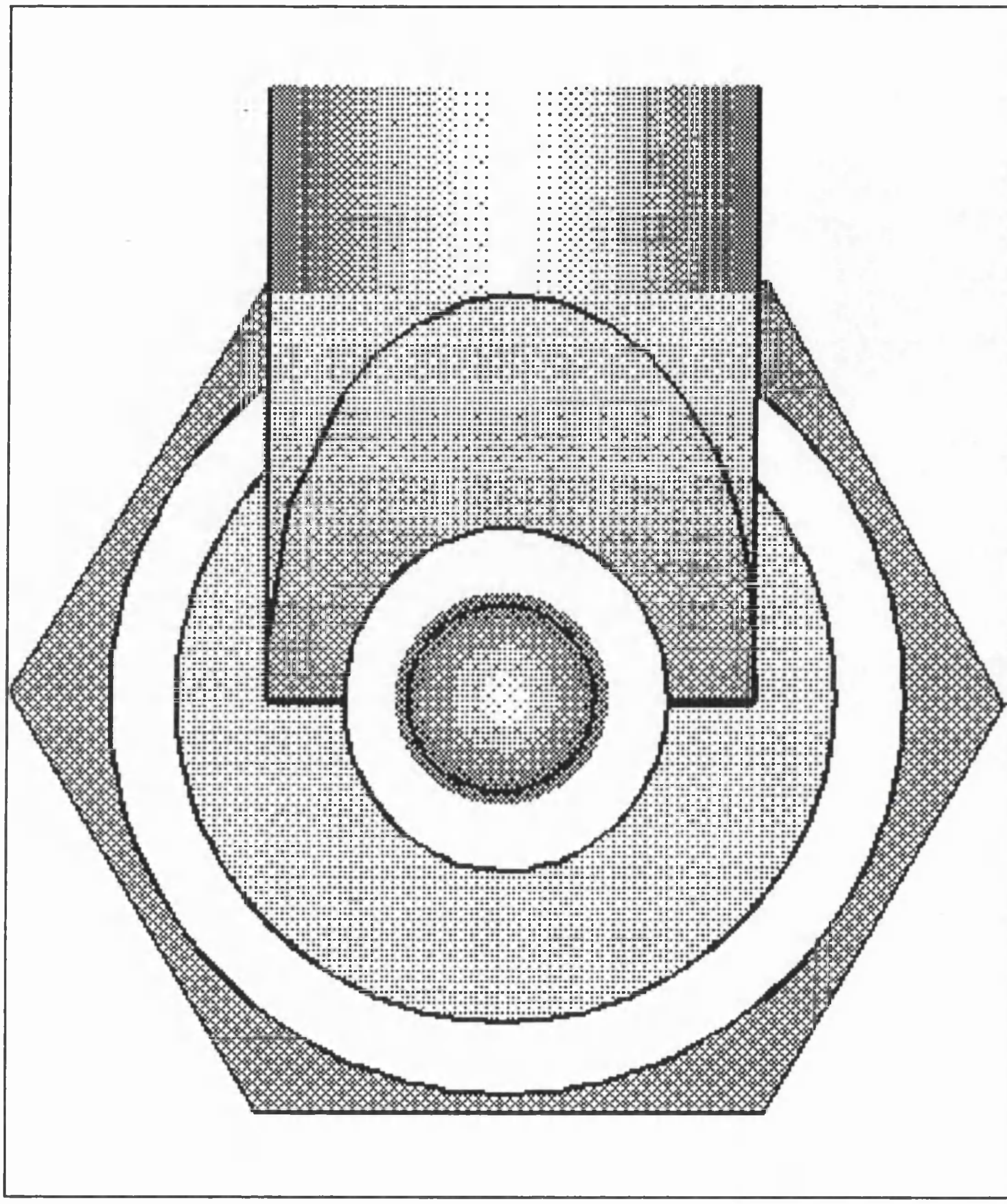


Figure 6.3 **The shearing plate fits accurately around the stainless steel washer. Unwanted lateral movements are not permitted with this apparatus.**

Eight different surface preparation regimens were assessed in combination with both light cured and self cured Delton. These were as follows:

1) The cement was left as set i.e. no preparation.
2) Scotchbond Dual Cure (3M Health Care Batch No 92 F1 2A) was applied to the set surface and cured for 20 seconds using a 470nm light source.
3) The surface was etched for 10 seconds with 37% buffered ortho-phosphoric acid. It was then washed and dried for 30 seconds before the application of the sealant.
4) The surface was etched for 30 seconds, washed and dried for 30 seconds.
5) The surface was etched for 10 seconds, washed and dried before the application of Scotchbond Dual Cure.
6) The cement was allowed to set under a celluloid matrix strip.
7) The cement was allowed to set under a matrix strip before Scotchbond Dual Cure was applied.
8) The set cement surface was subjected to a 30 second wash and dry sequence using the triple dental syringe.

The stainless steel washer of internal diameter 5 mm was centred over the glass ionomer cement surface and the fissure sealant was applied. It was either allowed to cure chemically or was subjected to 60 second exposure of visible blue light of 470nm. Exposed glass ionomer cement was coated with copal ether varnish before the samples were stored in tap water for a period of 7 days. They were then subjected to the same thermocycling regimen described in 6.2.1.

Shear Bond Strength testing was carried out in a similar manner to that already described for composite resin and fissure sealant.

6.2.3 Bonding of filled and unfilled fissure sealant to encapsulated and anhydrous glass ionomer cements.

In a further study, the bond strengths achieved with encapsulated, mechanically mixed varieties of two glass ionomer cements were compared with the anhydrous, hand mixed material ChemFill II. The glass ionomer (polyalkenoate) cements used in this study were the proprietary cement ChemFil 11 (De Trey/Dentsply Batch Number 920504) and the encapsulated versions of ChemFil (DeTrey/Dentsply, Batch No Ch.-B. 900913) and Baseline (DeTrey/Dentsply, Batch No Ch.-B. 900409). The results with light and chemically curing unfilled fissure sealant, Delton (formerly Johnson and Johnson, now De Trey/Dentsply Batch Numbers: Light Cured 972001 and Self Cured 972101) were compared with the filled fissure sealants Fluroshield (Caulk/Dentsply, Batch Number 012991) and Estiseal (Kulzer, Batch Number Ch.B. 219) .

Specimen preparation, storage and shear bond strength measurements were performed in a similar manner to that described in 6.2.2. Ten samples were prepared for each treatment regime.

Four surface preparation regimens were assessed in combination with both light and self cured Delton. These were as follows:

1) The cement was left as set i.e. no preparation was carried out.
2) Scotchbond Dual Cure (3M Batch Number 92 F1 2A) was applied to the set surface and cured for 20 seconds using 470nm light source.
3) The surface was etched for 30 seconds with 37% buffered orthophosphoric acid gel. It was then washed and dried for 30 seconds before the application of the sealant.
4) The surface was etched for 10 seconds, washed and dried before the application of Scotchbond Dual Cure.

6.2.4 Statistical analysis of data.

For all *in vitro* tests statistical analysis was performed on a microcomputer using the statistics programme C-Stat (Oxtech Ltd 1991). Two way analysis of variance (ANOVA) was used to assess the effect of surface treatment of the composite resin or glass ionomer cements and the different fissure sealant materials. Surface treatments of the restorative materials were compared separately for each of the fissure sealants using the two sample t-test with Bonferroni's correction for multiple comparison (Altman 1991).

6.3 RESULTS.

6.3.1 Bonding of Fissure sealants to Composite Resin Surfaces.

A: The bond strength of filled and unfilled fissure sealants to the surface of composite resins.

The mean shear bond strengths of two unfilled fissure sealants (Delton and Helioseal) and a filled sealant resin (Estiseal) to the untreated surface of the hybrid composite P50 are shown in Table 6.1 No differences in the mean shear bond strengths were demonstrated among the fissure sealants. The estimated difference in the means between Delton and Helioseal was 0.79 with a confidence interval of -5.0 to 6.6, while that for Delton to Estiseal was 3.72 with a 95% confidence interval of -1.2 to 8.6. All tested samples failed adhesively between the fissure sealant and the composite resin, irrespective of the surface treatment regimen used.

B: The optimal surface treatment of the composite restoration

The effect of surface treatment of the composite surface, before the application of filled and unfilled fissure sealants, is shown in Table 6.2. A two way analysis of variance was performed using the type of fissure sealant and the surface treatment regimen to the composite resin as factors. The interactions between the type of fissure sealant and the surface regimens was highly significant ($F=5.32$ $P<0.001$) . Therefore, no simple overall comparison of fissure sealants or surface treatments is possible. Separate comparisons of the fissure sealants must be made for each surface treatment and separate comparisons of the surface treatment must be made for each fissure sealant. This results in a large number of comparisons being made. Bonferroni's method (Altman 1991) was applied to give a set of confidence intervals with an overall confidence of 0.95.

light cured fissure sealants

	Delton Mean (S.D.)	Helioseal Mean (S.D.)	Estiseal Mean (S.D.)
As set	15.69 (5.13)	14.90 (5.60)	11.97 (2.25)

Statistical Comparisons

Delton versus Helioseal

T-test P=0.76

Corrected t-test confidence interval (-5.0, 6.6)

NOT SIGNIFICANT

Delton versus Estiseal

T-test P=0.11

corrected t-test confidence interval (-1.2, 8.6)

NOT SIGNIFICANT

Table 6.1 Comparison of mean shear bond strengths between P50 composite resin and filled and unfilled fissure sealants.

Light cured fissure sealants

Surface treatment to P50 composite resin	Delton mean (st. dev.)	Estiseal mean (st.dev.)
As set	15.69 (5.13)	11.97 (2.25)
Ground surface	14.64 (5.50)	17.49 (4.02)
Ground + bonding resin	15.48 (4.25)	11.62 (3.58)
Ground + silane + bond	20.49 (4.38)	12.28 (2.76)

Statistical Comparisons:

Surface treatments.

Values connected by vertical line are not significantly different (P>0.05).

Interaction between type of fissure sealant and surface treatment

ANOVA F = 5.32 P < 0.001

SIGNIFICANT

Differences between fissure sealants.

Only significant difference between Delton and Estiseal occurred when the surface was ground, silane applied and a bonding resin (P<0.05).

Table 6.2 The effect of surface treatment on mean shear bond strengths achieved to P50 using Delton and Estiseal.

C: Differences in mean shear bond strength between the fissure sealant resins.

No differences in mean shear bond strengths between the filled fissure sealant Estiseal and the unfilled material Delton could be determined at the 5% level of significance for three of the surface treatment regimens (Table 6.2).

When the surface of the composite resin was ground using a disc and a layer of silane coupling agent applied before the polar bonding resin Scotchbond, the mean shear bond strength of the unfilled fissure sealant Delton was significantly higher than that for the filled sealant Estiseal. The estimated mean difference was 8.21 with a 95% confidence interval of 3.7 to 12.8.

D: Differences in mean shear bond strength of fissure sealant to Composite resins observed with various surface treatment regimens.

The mean shear bond strength values of unfilled and filled sealants are shown in Table 6.2. Values connected by a vertical line are not statistically different.

When unfilled fissure sealant was used, the application of silane and bonding resin to the ground surface resulted in a higher mean shear bond strength than the other treatment regimens - this difference was statistically significant. The highest mean shear bond strength achieved with the filled fissure sealant was to the ground surface of the composite. This surface treatment regimen produced a shear bond strength significantly higher than that achieved with all other treatments.

E: Differences in mean shear bond strengths between urethane/ bisGMA based composite resins and an unfilled fissure sealant.

In Table 6.3, no statistical difference could be shown in the mean shear bond strength of a urethane dimethacrylate based microfilled composite resin (Heliomolar) and a hybrid material (Tetric) formulated from a similar resin base.

Statistical analysis of the mean shear bond strengths achieved using a bisGMA based composite (P50) and those formulated with the urethane resin, demonstrated significant differences at the 1% level of significance.
The estimated difference in the means between P50 and Heliomolar was 6.45 with a confidence interval of 1.6 to 11.3, while that for P50 to Tetric was 6.58 with a 99% confidence interval of 1.6 to 11.6.

Composite resin surface treatment (as set)	**Delton L/C** mean (st.dev.)
Heliomolar	9.24 (1.89)
Tetric	9.11 (3.22)
P50	15.69 (5.13)

Statistical Comparisons:

Heliomolar versus Tetric.

T-test P=0.92
confidence interval (-2.6, 2.8)
NOT SIGNIFICANT

P50 versus urethanes.

T-test P=0.01
P50 versus heliomolar: confidence interval (1.6, 11.3)
P50 versus tetric: confidence interval (1.6, 11.6)
SIGNIFICANT AT 1% LEVEL

Table 6.3 The effect of the resin chemistry on the shear bond strength between composite and fissure sealant.

6.3.2 Results of bond strength measurements of light and self cured fissure sealants to the surface of anhydrous glass ionomer cement.

A: Effect of surface treatment and the curing type of the fissure sealant.

Two way analysis of variance on the effect of the surface treatment of the glass ionomer cement and the curing type of the fissure sealant showed highly significant interaction ($F = 3.48$ $P < 0.01$). No simple comparison of the surface treatment with self cured versus light cured Delton is possible. Separate comparisons must be made for each combination of surface treatment and self/light cured sealant. This results in a large number of comparisons which were made using two sample t-test corrected for multiple comparison using Bonferroni's method. This gives an overall p-value for the set of comparisons of 0.05.

The shear bond strength values for the two versions of fissure sealant to the glass ionomer cement surface are given in Table 6.4. Where the shear bond strength was found to be less than 4.0 MPa, failure occurred adhesively. Shear failure at higher values occurred cohesively within the glass ionomer cement.

B: Differences in bond strength between light cured and self cured fissure sealant.

When the measured bond strength for the two types of sealant was compared for each surface treatment, there was a trend for the light cured fissure sealant to bond more strongly to surfaces which had been coated with an ionic bonding resin (i.e. Scotchbond Dual Cure) but this was not statistically significant ($P > 0.05$). Similarly, there would appear to be improved retention of the self cured sealant to cement surfaces where no bonding resin had been applied but again this fell below the level of statistical significance ($P > 0.05$).

Surface Treatment	Regimen Number	Self Cured FS Shear Bond Str		Light Cured FS Shear Bond Str		Mode of Failure
10s etch Scotchbond	5	6.3 SD 2.0	1	8.5 SD 2.0	3	Cohesive
Scotchbond	2	7.4 SD 2.0		6.6 SD 1.6		Cohesive
Matrix/ Scotchbond	7	3.4 SD 1.5		5.0 SD 1.0	4	Adhes(s/c) Cohes(l/c)
30s etch	4	3.8 SD 1.4		3.4 SD 1.2		Adhesive
No treatment	1	3.3 SD 2.3	2	2.5 SD 0.4	5	Adhesive
10s etch	3	3.1 SD 1.2		1.8 SD 0.6		Adhesive
30s wash and dry	8	2.2 SD 1.3		1.5 SD 0.7		Adhesive
Set under matrix	6	0.0		0.0		Adhesive

__Statistical comparisons__

__No__ significant differences between any of the items __within__ groups 1,2,3,4,5.
Significant differences when:

Group 1 values compared with group 2 values (P<0.05) *
Group 3 values compared with group 5 values (P<0.05) *
Group 4 values compared with group 5 values (P<0.05) *

Regimen 7 values compared with regimen 6 values (P<0.001) ***

Table 6.4 Comparison of shear bond strength values obtained with different surface treatment regimes and light and self cured fissure sealants.

C: Differences in bond strength obtained with different surface treatment regimens.

When self curing sealant was employed, there was no statistically significant difference between glass ionomer samples to which bonding resin was applied whether or not the surfaces were etched prior to application of the bonding resin. This group of samples, however, displayed significantly higher mean shear bond strengths than all the other surface treatment regimens.

Similar findings were noted with the light cured sealant. The bond strength achieved following the application of the bonding resin to the smooth surface (imparted by setting the glass ionomer cement under a matrix strip) was not significantly different from that obtained by applying the bonding resin to the untreated glass ionomer cement surface.

Application of sealant to cement surfaces placed with a spatula may have allowed a degree of mechanical union but failure still occurred adhesively between the cement and the fissure sealant. In addition, acid etching the surface for 10 or 30 seconds did not significantly improve the retentive bond between the fissure sealant and the cement.

Scotchbond Dual Cure significantly improved bond strengths compared to etched cement surfaces. A short etch before applying Scotchbond Dual Cure produced bond strengths that were not significantly higher than those obtained with the omission of the short etch regimen.

The application of Scotchbond Dual Cure to the smooth cement surface (obtained by allowing the cement to set against a matrix strip) significantly improved the retention for both types of sealant ($P<0.001$) when compared with the untreated smooth surface.

6.3.3 Bond strength values observed of fissure sealants to encapsulated glass ionomer cements.

A. Comparison of values for shear bond strength of fissure sealant to 3 glass ionomer cements.

The shear bond strength values for light and self cured Delton to the three glass ionomer (polyalkenoate) cements (ChemFil 11, encapsulated ChemFil and encapsulated Baseline) are given in Tables 6.5 to 6.7. Where the shear bond strength was less than 4MPa, failure occurred adhesively at the interface between the cement and the fissure sealant. Shear failures at higher values occurred cohesively within the glass ionomer (polyalkenoate) cement.

An analysis of variance was performed using the type of glass ionomer (polyalkenoate) cement, surface treatment regimen and curing type of Delton fissure sealant as factors. The interactions between the cement types and self/light Delton and also between the surface treatment and the two polymerising versions of fissure sealant were both highly significant. The 3-way interaction was also significant at 1% level of significance. Therefore, no simple overall comparison of cements, surface treatments or self versus light cured Delton is possible. Separate comparisons for each cement must be made for each combination of surface treatment and self/light cured fissure sealant. This results in a large number of comparisons being made. Bonferroni's method (Altman 1991) was applied to the multiple comparisons to give an overall p-value for the set of comparisons of 0.05.

B. Differences among the glass ionomer (polyalkenoate) cements.

When the results were analysed for the each of the glass ionomer (polyalkenoate) cements, the multiple comparisons showed there to be no significant differences among the results for the three cements (see tables 6.5 to 6.7). There was one exception, however, the application of light cured Delton to the surface of encapsulated ChemFil treated with Scotchbond Dual Cure (Table 6.6) showed a shear bond strength that was significantly higher than that achieved with anhydrous ChemFil 11 (Table 6.5) but not different from that achieved with encapsulated Baseline (Table 6.7).

ChemFil 11 P/L	**Delton S/C** Mean (SD)	**Delton L/C** Mean (SD)
As set	3.3 (2.3)	2.5 (0.4)
30s A/etch	3.8 (1.4)	3.4 (1.2)
Sc.Bond	7.4 (2.0)	6.6 (1.6)
10s a/e + Sc.B	6.7 (2.2)	8.5 (2.0)

Values connected by a vertical line are not significantly different (P > 0.05).

Table 6.5 Shear bond strengths (MPa) of fissure sealant to glass ionomer cement surface with different surface treatment regimens (SD = standard deviations).

ChemFil Capsules	Delton S/C mean (SD)	Delton L/C Mean (SD)
As set	3.1 (1.5)	2.8 (0.8)
30s A/etch	6.0 (1.4)	3.5 (0.9)
Sc.Bond	7.0 (1.8)	10.5 (3.5)
10s a/e + Sc.B	7.3 (2.5)	7.0 (1.9)

Values connected by a vertical line are not significantly different ($P > 0.05$).

Table 6.6 Shear Bond Strength Values Obtained between Encapsulated Glass Ionomer Cement (Chemfil II) and Fissure Sealant Using Different Surface Treatment Regimens.

Baseline Capsules	Delton S/C Mean (SD)	Delton L/C Mean (SD)
As set	1.2 (0.6)	0.8 (0.3)
30s A/etch	4.3 (0.8)	2.3 (1.1)
Sc.Bond	7.1 (1.3)	9.1 (2.3)
10s a/e + Sc.B	8.5 (2.6)	7.3 (1.7)

Values connected by a vertical line
are not significantly different (P > 0.05).

Table 6.7 **Shear bond strength values obtained between encapsulated glass ionomer cement (Baseline) and fissure sealant using different surface treatment regimens.**

C. Differences among the surface treatment regimes.

When the surface treatment regimes were considered, the mean shear bond strength for those cements which were not subjected to a surface treatment were always lowest. With one exception, the mean shear bond strength of cement surfaces which were etched for 30 seconds were not significantly greater than those which had not been prepared - when the surface of encapsulated ChemFil was left untreated the bond strength with self cured Delton was significantly lower than that achieved after a 30 second etch.

The mean shear bond strength of Delton fissure sealant to untreated glass ionomer (polyalkenoate) cement surfaces was always significantly lower than to those surfaces where a bonding resin had been applied ($P<0.05$).

The strength of the union between **light cured** Delton and etched glass ionomer (polyalkenoate) cements was significantly lower than that achieved when a bonding resin was applied to the cement surfaces prior to the application of the fissure sealant. Similarly, when **self cured** Delton was applied to the surface of anhydrous ChemFil 11, the mean shear bond strength of the Scotchbond Dual Cure treated surface was significantly greater. No improvement was shown between the surfaces coated in ionic bonding resin and those which had been etched for 30 seconds when encapsulated glass ionomer (polyalkenoate) cements were employed (i.e. ChemFil and Baseline Capsules).

No significant improvement in mean shear bond strength could be demonstrated by including a short 10 second etch of the cement surface before applying the bonding resin ($P>0.05$).

D. Differences between light and self cured Delton.

Where the surfaces of the glass ionomer (polyalkenoate) cements were etched or left untreated, the mean shear bond strength values were always greater when self cured Delton fissure sealant was used. When the measured bond strength for the two types of sealant was compared for each surface treatment, there was a trend for light cured Delton to bond more strongly to surfaces coated with the ionic bonding resin (Scotchbond Dual Cure). This was only significant when encapsulated restorative glass ionomer cement (ChemFil II) was used (Table 6.6).

E. The effect of applying bonding resin to the unset glass ionomer cement surface.

In Table 6.8, the effect of applying Scotchbond Dual Cure to the unset glass ionomer (polyalkenoate) cement surface was investigated. No difference was shown between the mean shear bond strength when the bonding resin was applied, either before or after the initial setting of the encapsulated Baseline ($P=0.9$). A 95% confidence interval for the difference between the mean shear bond strengths is from -2.0 to +2.2 .

F. The effect of the use of filled fissure sealant on the mean shear bond strength values.

The effect of filled fissure sealants was considered in Table 6.9. For each of the fissure sealant materials, the mean shear bond strength obtained to the untreated Baseline surface was significantly lower than that achieved to cement surfaces coated with Scotchbond Dual Cure ($P<0.001$). The filled fissure sealants Estiseal and Fluroshield, showed significantly greater mean shear bond strengths to the untreated surface of encapsulated Baseline than those obtained using light cured Delton ($P<0.05$).

After the application of the bonding resin Scotchbond Dual Cure (3M), Fluroshield showed a significantly higher mean shear bond strength value than those obtained with either Estiseal or light cured Delton ($P<0.01$).

Delton L/C

	Baseline (unset) Mean (SD)	**Baseline (set)** mean (SD)
Scotchbond Dual Cure	9.0 (2.0)	9.1 (2.3)

<u>*Statistical comparison:*</u>

Confidence interval for difference between test samples (-2.04 to 2.19) showed no significant difference.

Table 6.8 Comparison between mean shear bond strength values obtained when fissure sealant applied to the Scotchbond treated surface of set and unset Baseline.

Baseline Capsules	**Estiseal** Mean (SD)	**Fluroshield** Mean (SD)	**Delton L/C** Mean (SD)
As set	3.5 (1.2)	3.2 (1.2)	0.8 (0.3)
Sc.Bond	8.7 (1.6)	13.3 (3.3)	9.1 (2.3)

Values measured in MegaPascals (MPa).

Statistical comparison:
as set: Fluroshield Estiseal Delton (L/C)

Sc.B: Fluroshield Delton(L/C) Estiseal

No significant differences were found with the materials underlined (P > 0.05).

Table 6.9 Mean shear bond strength values achieved between untreated and scotchbond coated baseline encapsulated glass ionomer cement and three different fissure sealants.

6.4 DISCUSSION.

6.4.1 Laboratory considerations.

Although detailed experimental protocols were adhered to, the standard deviations of the mean shear bond strengths observed were relatively large. The standard deviation of the mean for Estiseal to the surface of P50 composite resin was found to be 18.8%, and that of Helioseal to the same composite filling material was 37.6%. Similar findings have been reported by Crumpler *et al* (1989) who reported standard deviations ranging from 13.7 to 33.3% of the mean value. They concluded that this made some of the individual surface treatment regimens difficult to evaluate. The large spread of individual shear bond strengths could have arisen due to imperfect alignment of the fissure sealant bonded to composite resin samples with the shear plate of the testing apparatus. Composite surface preparation using discs may also provide an imperfectly flat surface which could produce unavoidable complex stresses during the shear testing.

With a sample size of 10 specimens for each surface treatment, only large differences in shear bond strength could be detected. Results which were not of statistical significance may reflect, therefore, inconclusive comparisons.

The use of discs during the surface preparation of the laboratory samples will not accurately simulate the *in vivo* manipulation of composite fillings prior to the application of a fissure sealant resin as part of a sealant restoration technique. It would be more usual to prepare the small surface areas of composite fillings using a bur or stone. Crumpler et *al* (1989) reported a lower shear bond strength for composite surfaces prepared using polishing discs, but this was not statistically different from those prepared using diamond or tungsten carbide burs.

The effect of water storage on the bond strength of repaired composite samples has been studied by a number of workers with different results. Chan *et al* (1985) reported no change in the bond strength of composite samples bonded to dentine using Scotchbond after one year, following either thermocycling or storage in water. Söderholm (1986) and Söderholm and Roberts (1991) found storage of P30 composite samples in water decreased the bond strength of repairs. He attributed this to hydrolytic degradation which occurred with time, resulting in failures of the filler-matrix bond.

Eliades *et al* (1985) measured the bond strength of several bonding agents used to bond composite to dentine and concluded that thermocyling reduced the bond strength values obtained. Crim *et al* (1985) reported no significant difference in the microleakage of samples of Concise composite fillings placed in extracted teeth following four thermocycling regimes. They reported that, as long as a thermocycling regime was used, there was no difference in the degree of microleakage. Brown *et al* (1972) and Lloyd *et al* (1978) speculated that *in-vitro* thermocycling produced similar damage within a few thousand cycles as would appear *in vivo* over several years.

6.4.2 Bonding of Fissure Sealant to Composite Resin.

A. The effect of omitting surface preparation.

In Tables 6.1 and 6.2, the effect of omitting a surface preparation regimen before placement of a covering of filled or unfilled fissure sealants is shown. The mean shear bond strengths of two unfilled bisGMA fissure sealants (Delton and Helioseal) to the unprepared surface of the hybrid composite resin P50 (3M) was found not to differ significantly. When the fissure sealant Estiseal (Kulzer) - which has a filler loading of 27% - was applied to similarly prepared surfaces, the mean shear bond strength was reduced by 23.7%. This difference was not, however, of statistical significance. Puckett *et al* (1991) investigated the bond strength of three hybrid composite resins used to repair composite restorations *in vitro*, and reported tensile bond strengths of 10 to 17 Mpa when no intermediary bonding resin was applied to the unprepared composite resin surface. These values are similar to those obtained in this investigation.

The posterior composite resin samples were not subjected to a surface preparation but allowed to set while exposed to air. Boyer *et al* (1978) discussed the differences in the surface of chemically cured composite (Concise, 3M) when allowed to set against a matrix strip and that obtained by allowing it to polymerise while exposed to air. Johnson (1971) reported that when air was excluded by the smooth matrix, the surface was composed of a layer of resin and was very smooth. In contrast, composite surfaces exposed to air during curing are rougher and have a layer of unset liquid monomer, the polymerisation of which has been inhibited. This may act as a homogenous, intermediate layer of bonding resin which has wetted the composite surface. The effect of this reduces with time due to its gradual polymerisation.

The importance of the quantity of resin at the interface of composite to composite repairs or additions was illustrated by Lloyd and Dhuru (1985) who found high tensile repair strengths of fractured specimens of macrofilled composite resins. They attributed this to the fracture surface of the samples containing a high percentage of resin through the plane of the fracture.

Although immediate repairs of composite samples always have a lower bond strength than the cohesive strength of the materials, Azarbal *et al* (1986) found the repair strength of microfilled composites to be higher than that for other filler types and loading, when these were expressed as a proportion of the cohesive strength of the materials. Lloyd *et al* (1980) confirmed the improved strength of immediate repairs and reported on the affect of salivary contamination of the sample surfaces which reduced its capacity for additional bonding. It is considered that repair during the first 24 hours provides the greatest reactivity on the sample surface.

Free radical initiated polymerisation of added monomer occurs between the substrate and the new resin to produce covalent bonding between the layers (Chan and Boyer 1983). Alternatively, free radicals may initiate graft polymerisation onto substrate polymer chains (Gaylord & Ang 1964).

Causton (1975) reported that the maximum shear stress to which composite bonds could be exposed in the clinical situation to be approximately 9 MPa. It would therefore seem prudent to ensure that composite repairs or additions of fissure sealant to the surface of composite fillings placed as a part of the sealant restoration technique, should have a shear bond strength at least equalling this value.

In the current study, the similarity in the mean shear bond strengths of P50 to the unfilled and filled resins in the fissure sealant could have arisen due to common interface between the sealants and the composite. Adhesive failure was noted to occur in all specimens and could be attributed to the presence of the oxygen inhibition layer acting as an unfilled resin. In this way similar bond strength values could be expected. The difference in the thermal expansion co-efficients between the unfilled resin layer on the surface of the composite samples and that of the filled Estiseal sealant could have stressed the union between these materials, resulting in failure at a lower bond strength than that observed for the unfilled Delton samples.

B. The effect of surface grinding.

In Table 6.2 the effect of surface grinding on the mean shear bond strengths of the composite resin to filled or unfilled pit and fissure sealant are shown. When the unfilled sealant Delton was used, the mean shear bond strength was reduced but this was not statistically significant. The application of the filled sealant resin Estiseal, resulted in a significant increase in the mean shear bond strength.

Polishing or grinding the surface of composite resins has been reported to reduce the bonding ability of further additions or repairs (Boyer *et al* 1976, Davidson *et al* 1981 and Chiba 1983). Other studies have shown the bond strength to be unaffected by this surface treatment (Lloyd *et al* 1980 and Causton 1975).

The ground surface of posterior composite is mainly composed of inorganic filler, (Puckett *et al* 1991) the cut surface of which is poorly wetted by further additions of resin (Vankerckhoven *et al* 1982 and Söderholm & Roberts 1991). Scanning electron micrographs have shown the surface to be covered with a smooth smear layer of resin matrix which is not removed by washing with water or etching with buffered phosphoric acid (Söderholm 1986). It is probable that during the cutting process, the resin matrix in the composite is melted and covers the surface. Further additions to this low strength layer may result in reduced bonding. Using the posterior composite P30, Söderholm & Roberts (1991) reported the mean bond strength of repairs to the cut and etched surface to be unacceptable as only 25% of the cohesive strength of P30 had been achieved. Etching has been shown to remove only the loosest of the smear layer (Söderholm 1986). Crumpler *et al* (1989) reported that washing the ground surface was as effective as etching in achieving a moderate increase in bonding. They suggested that water would rehydrate and roughen the surface by swelling the polymer chains. This could promote better resin penetration. By contrast, Azarbal *et al* (1986) achieved transverse bond strengths to the surface of ground composite resins of 45% for macrofilled materials and 62% when microfilled composite was used.

The heat produced during the polishing procedure has been shown not only to be responsible for smear layer production but may influence polymerisation by reducing the number of chemically reactive groups (Davidson *et al* 1981). This may be responsible for the reported shrinkage away from the composite substrate surface noted by Söderholm & Roberts (1991).

When a diamond wheel was used for surface preparation, Söderholm & Roberts (1991) observed cracking in the resin matrix on S.E.M. They concluded that little chemical bonding could take place on the surface of the resin as the preparation regime produced heat which increased the cross linking and reduced the number of chemically reactive bonds on the surface. This had the effect of reducing diffusion of new resin into the substrate material before light curing took place. By a process of elimination, he inferred that the bonding between the composite additions had occurred by micromechanical means to the cracks in the original resin matrix. Crumpler *et al*

(1989) also suggested that surface roughening allowed mechanical interlocking of the materials but suggested that the increase in surface area was important for chemical bonding.

In the current studies, the observed improvement in bond strength when Estiseal was applied to the surface of ground composite could be explained by two mechanisms. In the first, the filled fissure sealant exhibited less polymerisation shrinkage compared to unfilled materials which placed less strain on the interface. In the second, filled sealants have a higher tensile strength than unfilled varieties and therefore resisted fracture.

C. The effect of bonding resin on the mean shear bond strength of fissure sealant to ground composite resin.

In Table 6.2, the results of the mean shear bond strengths are shown of ground composite surfaces coated with an enamel/dentine bonding resin before the application of the filled and unfilled fissure sealants. The mean shear bond strengths and their distribution are remarkably similar to those of the untreated surface allowed to polymerise while exposed to air. Puckett *et al* (1991) suggested that primary chemical bonding using unfilled enamel bonding resins occurred by the resin reacting with the unsaturated matrix in the substrate composite. They also suggested that additional bonding could occur if the resin could penetrate the composite and entangle around existing polymer chains. Improvements in the bond strength of repairs to mature composite resin have been widely reported following the application of a resin to the ground surface of matured composite (Boyer *et al* 1978, Miranda *et al* 1984 and Azarbal *et al* (1986). Improved bonding by this technique is more marked when microfilled composites are used, as these have a greater resin component (Azarbal *et al* 1986). The reported 24% improvement in bond strength are similar to those reported by Boyer *et al* (1978) and Miranda *et al* (1984). Boyer *et al* (1978) cautioned that thin layers of bonding resin should be used for subsequent additions of composite. When applied as a thick layer, good adaptation of the composite increments was prevented resulting in a deterioration in the repair bond strength.

Söderholm & Roberts (1991) reported improved repair strength of composite following grinding by the application of a polar, enamel/dentine bonding resin which they claimed would penetrate the cracked matrix where it could then form mechanical bonds. This was confirmed by Crumpler *et al* (1989) who suggested the diluting of halo-phosphorus esters of bisGMA found in Scotchbond reduced its viscosity and that by doing so could alter the contact angle with the composite surface resulting in improved wetting. The organic solvent used may also swell polymer chains in the set composite surface allowing improved penetration.

The idea of chemical bonding to the filler component of the substrate composite has also been suggested by Azarbal *et al* (1986) and Söderholm & Roberts (1991). Lloyd and Dhuru (1985) investigated the effect of Scotchbond on salivary contaminated surfaces and found a 14% increase in bond strength compared to no improvement to the control uncontaminated samples.

In this investigation, no improvement could be demonstrated in mean shear bond strength following the application of Scotchbond resin to the ground surfaces of composite samples. This would suggest that no chemical bonding occurs to the filler surface and that the enamel/dentine bonding resin does not penetrate the composite surface significantly better than the pit and fissure sealant.

D. The effect of a silane coupling agent on the shear bond strength of fissure sealant to composite resin.

In the current study, conflicting results were observed when a silane coupling agent was applied to the ground surface. The addition of an intermediate enamel/dentine bonding agent (Scotchbond) to the silanated surface, before the application of the fissure sealants, showed a significant improvement for the unfilled sealant Delton but only a small and insignificant increase in shear bond strength following the application of the filled sealant Estiseal.

Azarbal *et al* (1986) and Saunders (1990) failed to demonstrate improvement in the bonding or transverse strength of silanated repairs using microfilled and hybrid composites resins. Scotchbond has been reported as a more efficient bonding agent than the use of organic coupling agents. Azarbal *et al* (1986) and Crumpler *et al* (1989) found surface treatments with phosphoric acid, hydrofluoric acid and 1.23% APF gel to be equally effective as silane. The former acids were thought to etch the surface of the filler, resulting in mechanical bonds to the roughened surfaces.

In 1986, Söderholm reported that silane in a toluene solvent provided the optimal bonding strength of chemically cured Adaptic composite. He found that the addition of toluene to the priming layer removed the smear layer and formed cracks in the resin matrix of the composite filling material. This improving the bonding by 45-67% compared to cut and washed samples and those prepared by cutting, etching and applying an unfilled bonding agent. If toluene were applied to intact and unprepared surfaces, no cracking developed - this implied that the highly cross-linked matrix could resist solvent attack.

In 1991, Söderholm and Roberts observed that treatment with silane and toluene was not significantly different from a surface treatment of Scotchbond to the surface of P30 samples.

In the current study, the significant improvement in the mean shear bond strength of Delton compared to Estiseal may be explained by the difference in thermal expansion co-efficients which could stress the union between the unfilled polar bonding resin and the filled bisGMA resin of the sealant. Alternatively, poorer surface wetting of the bonding resin could occur when a filled resin is applied. Puckett *et al* (1991) showed that surface wetting is a major factor in controlling the repair bond strength of composite samples *in vitro*. Wetting is controlled by the free surface energy difference between the substrate composite and the viscosity of the applied material.

E. The effect of mismatching the resin bases in the composite and fissure sealant.

In Table 6.3 two composite resins containing urethane bases were compared with one based on a bisGMA formulation . A microfilled, urethane based composite (Heliomolar) and a hybrid containing urethane material (Tetric) were compared and the results contrasted with those obtained using a hybrid bisGMA composite resin (P50). No difference was observed between the two urethane based materials when Delton was applied to the untreated surfaces which had been allowed to cure while exposed to air. It was interesting that the spread of the individual bond strengths was more contained (and therefore had a proportionally smaller standard deviation) with the microfilled material which contained more resin than with the hybrid version. The standard deviations with the microfilled material was 20.4% of the mean compared to 35.3% for the hybrid composite.

When the mean shear bond strengths of these materials were compared with those observed using the bisGMA containing composite P50, they were found to be significantly lower. Puckett *et al* (1991) used the urethane containing resin Occlusin (ICI Ltd) to repair bisGMA composite materials and reported low bond strength values which he attributed to poor surface wetting and the different chemistries of the two resin systems. Saunders (1990) also found Occlusin samples which were bonded with an intermediate resin of Scotchbond Dual Cure, showed the least resistance to impact fatigue stress testing.

The differences in the initiator systems of chemically curing and ultra-violet curing composite resins were cited by Chan & Boyer (1983) as a possible source of poorer bonding between repaired composite samples.

Ward *et al* (1972) also reported Nuva-seal (an ultra-violet activated resin) to bond better to ultra-violet curing restorative resins than did chemically curing resins. This was later indirectly confirmed by Eriksen and Buonocore (1976) who demonstrated less microleakage when the bonding resin and the restorative material contained similar initiator systems.

It would appear, therefore, that the mixing of resin bases in the restorative and fissure sealant resins should be avoided as a poorer shear bond strength occurs which is also reflected in the clinical performance of comparable material combinations. It was not possible to use Occlusin composite resin in the *in vitro* testing as this material was no longer commercially available.

F. Surface wetting and the interface between composite resin and fissure sealant.

Adequate wetting of the surface of the composite resin by the fissure sealant is a major factor in achieving good bond strength between the materials. Wetting is controlled by the free surface energy of the two materials. During the repair of composite resin restorations, Söderholm & Roberts (1991) reported poor adaptation of new composite to etched surfaces when examined using an S.E.M. technique. They postulated that this could be due to insufficient wetting of the surfaces or to polymerisation shrinkage pulling the materials apart during the curing process. This is of clinical significance, as the curing starts at the surface where the light source is applied and pulls away from the area which is cured last. In sealant restorations, this would occur at the interface between the composite and the fissure sealant.

A fissure sealant resin has a different viscosity from that of an enamel/dentine bonding agent based on a similar resin base. It woulde be expected, therefore, that the addition of a more polar bonding resin would wet the surface and be able to penetrate the exposed organic phase of the composite resulting in improved bond strength.

G. Clinical considerations.

Söderholm & Roberts (1991) addressed the problem of degradation of interfacial bond strength between layers of composite resin repairs and reported a reduction *in vitro* when composite repair samples were stored in water over a twelve month period. They questioned the acceptability of the bond strength for adequate clinical performance. As the tensile bond strength of enamel prisms perpendicular to prism direction is only about 10 MPa (Bowen & Rodriguez 1962), it would seem prudent to attempt to achieve interfacial bonding of greater than this value.

When composite resin restorations were repaired, Miranda *et al* (1984) considered the size, extent and location of the repair site important. Saunders (1990) suggested that surface wetting, the amount of chemical activity and the effect of surface treatment before bonding were critical. In an extensive review and investigation of surface preparation and treatments, Crumpler *et al* (1989) advocated mechanical roughening followed by conditioning of the composite surface using either water or phosphoric acid. The application of the enamel dentine bonding resin (Scotchbond) was then shown to produced the optimal repair bond strength. Salako & Cruikshanks-Boyd (1979) warned that the length of visible light curing time is important in obtaining depth of cure and surface microhardness.

From the results of the current study, it would appear important not to mix the resin bases in the composite resin and that in the pit and fissure sealant. When unfilled fissure sealant (Delton) is employed, no advantage is gained by surface preparation of the composite filling or by a conditioning/priming regimen. The mean shear bond strength of Estiseal to the ground surface of hybrid posterior composite (P50) was significantly higher than that to either unprepared surfaces or those coated with bonding resin.

6.4.3 Bonding of Fissure Sealant to Glass Ionomer Cement Surfaces.

A. The effect of etching anhydrous glass ionomer cement.

In Table 6.4, no significant differences were noted between the mean shear bond strengths of specimens which were subjected to 10 and 30 second etching and those which were not etched. Welbury *et al* (1988) reported similar findings but subjected their results to a Weibull analysis which relates the probability of failure to stress and is a measure of the dependability of the bond. They observed that omitting the etch procedure resulted in a bond whose dependability was questionable.

In glass ionomer cement / composite resin restorations, Causton *et al* (1987) and McLean (1988) suggested that no benefit was obtained by etching the surface of glass ionomer cement for longer than 15-30 seconds before the application of a filled composite resin. Longer etch times were found not only to remove matrix from around the glass particles but also to leave the glass only tenuously attached making the bond weaker. Acid penetration of up to 300 microns into the glass ionomer cement has been reported by Taggart & Pearson (1988). Impairment in physical properties of glass ionomer cement following etching with strong acids has also been questioned by Subrata & Davidson (1989)

B. The effect of the application of a bonding agent before fissure sealant is placed.

When glass ionomer cement was allowed to set under a cellulose acetate strip, a smooth surface was imparted which would minimise mechanical interlocking with the bis-GMA pit and fissure sealant. The application of Scotchbond Dual Cure, following either a short etch or to the smooth surface, improved the bond strength significantly ($P < 0.05$) compared to surfaces prepared in an identical fashion but to which the bonding agent had not been applied. Retention would appear to be dependant on either chemical bonding of the Scotchbond Dual Cure to the metallic ions in the glass ionomer cement or to improved surface wetting and penetration of the more polar bonding resin.

In 1987, Causton *et al* reported improved bond strengths when an intermediate resin was applied to the surface of the glass ionomer cement before a filled composite resin. During testing of this bond, a significant improvement in bond strength was shown, with failure occurring cohesively within the brittle and relatively weak cement.

C. The effect of polymerisation shrinkage.

During the placement of laminate composite restorations. Hansen (1984) reported a greater degree of polymerisation shrinkage when composite resins with a low filler loading were used. A similar phenomenon may occur during the provision of glass ionomer cement and fissure sealant restorations: the unfilled fissure sealant (Delton) has a high polymerisation shrinkage and may pull away from the cement surface.

The mode of failure in the laboratory specimens was considered to be important. In the field trial of glass ionomer cement and fissure sealant restorations (see Chapter 5), no evidence of cohesive failure was seen clinically in the cement restorations. Failure was only noted adhesively between cement and sealant. Rather than indicating a rank order of clinical treatment regimens, it was intended to show that by improving the bond strength sufficiently to produce cohesive failure in the specimens, clinical performance could be improved.

If conventional glass ionomer and fissure sealant restorations are being placed, the results in the current study would suggest that the application of a halophosphorus ester of bis-GMA such as Scotchbond Dual Cure will improve the retention of the fissure sealant to the cement surface.

6.4.4. A comparison of shear bond strengths achieved with anhydrous and encapsulated glass ionomer cements.

A. Differences in the glass ionomer cement formulations.

Field trial results on the use of glass ionomer (polyalkenoate) cement and fissure sealant restorations do not show improved retention of the sealant overlying the glass ionomer (polyalkenoate) cement when the latter are etched (see Chapter 5). Tables 6.5 to 6.7 report on the results obtained when the most commonly used fissure sealants (light and self cured Delton) were applied to the surface of glass ionomer (polyalkenoate) cements which had been mixed either by hand or in an encapsulated system.

The field trial data presented in Chapter 5 demonstrates that the use of ChemFil 11 was favoured by the operators in the Community Dental Services: 98% of all polyalkenoate cement restorations placed used this presentation of the material. Encapsulated materials differ from the hand mixed versions in that the polyacid used in the former are of a lower molecular weight and the set cement is weaker than its hand mixed counterpart (Gee & Pearson 1993). The glass ionomer "Baseline" differs from the stronger restorative materials by the incorporation of strontium into the glass to impart radio-opacity. As the filler particle size of this material is smaller, the cement also has a shorter setting time (Mount 1991).

B. The effect of etching encapsulated glass ionomer cements.

There were significant differences in shear bond strength when light and self cured fissure sealants were applied to similarly prepared glass ionomer (polyalkenoate) cement surfaces. Following a 30 second acid etching regime, bond strength was improved particularly for the two encapsulated materials: the improvement, however, was not statistically significant. When light cured Delton was applied to the etched surface of the two encapsulated glass ionomer (polyalkenoate) cements, the improvement in shear bond strength was not of as great a magnitude as that shown for self curing fissure sealants. Penetration of light cured fissure sealants into the pores within the cement may be poorer because of insufficient time elapse before command curing. Alternatively, the encapsulated materials may be less porous. When self cured resin was used, adequate time or better surface wetting may allow improved resin penetration.

An alternative explanation for the lower shear bond strength of light cured fissure sealants could be the greater polymerisation contraction that occurs on curing. The conversion rate of light cured fissure sealants is almost twice that of the self curing materials - this could result in fracture of tenuously attached protruding glass particles from the eroded surface of glass ionomer (polyalkenoate) cements.

C. The use of intermediate bonding resin.

The application of Scotchbond Dual Cure to the set surface of the glass ionomer (polyalkenoate) cement significantly improved the shear bond strength. When light cured Delton was applied to this surface, the shear bond strength was generally higher than that obtained when a self cured sealant was used. This improvement was only significant, however, when applied to the cement surface of encapsulated ChemFil.

Improved retention appears to be dependant on better surface wetting and penetration of the more polar bonding resin into the glass ionomer (polyalkenoate) cement or to chemical bonding of the Scotchbond Dual Cure to the metallic ions on the cement surface. Gray (1994) showed that when surface roughness of the cement was eliminated by allowing the cement to set against a matrix strip, the application of Scotchbond Dual Cure still resulted in a significantly greater mean shear bond strength. This could suggest that either chemical adhesion may be taking place at this interface or improved wetting and penetration of the surface occurs when polar bonding resins are used.

In 1987, Causton *et al* reported improved bond strengths when an intermediate resin was applied to the surface of the glass ionomer (polyalkenoate) cement before a filled composite resin. During testing of this bond, a significant improvement in bond strength was shown with failure occurring cohesively within the brittle and relatively weak cement.

Mount (1989) reported that hand mixed cements contained larger voids of up to 50 microns compared to the mechanically mixed variety. These could be partly instrumental in the improved bond strengths obtained where resin penetration occurs. The more polar ionic bonding resins are more likely to penetrate due to excellent surface wetting properties. Failure would then take place ultimately within the unstrengthened body of the cement mass.

Improved bond strength has been reported when intermediate bonding resins are light cured before application of the composite resin (Hansen 1984). Care must be taken to ensure intermediate resins containing a volatile medium are carefully air dried to avoid an incomplete surface coating (Prevost *et al* 1982).

A short etch regime prior to the application of the bonding resin did not significantly improve the mean shear bond strength. Etching a glass ionomer (polyalkenoate) cement has been described as a means of improving the bond between cement lining and composite resin in the laminate or sandwich technique (McLean & Wilson 1977). Impairment in physical properties of glass ionomer (polyalkenoate) cement following etching with strong acids has been questioned (Substrata & Davidson 1989) and it has been suggested that if lining cements are etched, the etch time should be reduced to no more than 10 seconds to avoid impairing physical properties (Taggart & Pearson 1988).

The time after mixing at which the bonding resin is applied is not critical. Almost identical results can be obtained when Scotchbond Dual Cure is applied to the surface of unset encapsulated Baseline (Table 6.8). As this practice does not adversely affect the union between the two materials, it has much to merit it as prolonged isolation may be difficult without the use of rubber dam.

D. The effect of fissure sealant materials.

Lightly filled composite resins, used in a laminate technique, shrink more than heavily filled composite materials, stressing the union between the glass ionomer cement and the composite (Jensen & Chan 1985). It is likely a similar situation exists in the application of fissure sealant over the surface of the glass ionomer cements.

In Table 6.9, the unfilled fissure sealant Delton was compared with two filled sealants (Estiseal and Fluroshield). Fluroshield contains surface active chemicals (penta - phosphates) to promote better wetting and bonding to etched enamel. The bond strength of Delton to the surface of unprepared glass ionomer (polyalkenoate) cement was significantly lower than that obtained with either of the filled sealants. After the application of a bonding resin to this surface, no statistical difference was observed between Estiseal and Delton. This could be due to the common interface between cement and fissure sealants. Fluroshield has a significantly higher shear bond than the other materials in the group. This may be due to the incorporation of the chemically active PENTA groups in this fissure sealant.

E. Clinical considerations.

The mode of failure in the laboratory specimens was considered important. No evidence of cohesive failure was seen **clinically** in the glass ionomer (polyalkenoate) cement fissure sealant restorations reviewed by Gray & Paterson (1994). Failure was only noted adhesively between cement and sealant.

Rather than showing a rank order of clinical treatment regimes, it was intended to show that by improving the bond strength sufficiently to produce cohesive failure in the *in vitro* specimens, clinical performance could be improved.

6.5 CONCLUSIONS.

1. When unfilled fissure sealant was applied to the surface of the hybrid composite P50, the mean shear bond strength was unaffected by grinding or by the application of an intermediate layer of unfilled resin.

2. Mean shear bond strength values were significantly improved *in vitro* when filled fissure sealants were applied to the surface of mechanically abraded composite resins.

3. When the base resin systems used in composite restoratives and fissure sealants were not of a similar formulation, the mean shear bond strength values were significantly reduced.

4. Significant increases in the shear bond strength were observed *in vitro* when Scotchbond Dual Cure was applied to the surface of the glass ionomer (polyalkenoate) cement before the application of both light cured and self cured types of the fissure sealant Delton.

5. Etching of the glass ionomer (polyalkenoate) cement surface with 37% phosphoric acid did not significantly increase the shear bond strength values.

6. It is considered advisable to apply a bonding resin to the surface of glass ionomer (polyalkenoate) cements which have been allowed to set against a matrix before a fissure sealant is used.

7. No gain in shear bond strength was found by leaving the cement to set before applying the bonding resin.

8. Filled fissure sealants provide a stronger shear bond than unfilled sealants when the surface of the cement is left untreated but following the application of a bonding resin the differences are minimised.

Chapter 7

Clinical trial of sealant restorations placed in a dental hospital environment.

7.1 INTRODUCTION.

7.1.1 Evolution of sealant restoration technique.

A major objective of the dental profession is the prevention of fissure caries but due to problems in diagnosis of the early lesion, the conservative management of carious lesions is of prime importance. Sealant restorations represent an evolutionary process in the use of dental cements and resins in posterior teeth that began with studies of pit and fissure sealants in the 1960's. While fissure sealants are indicated as a preventive measure to minimise caries risk in caries free pits and fissures, the sealant restoration is used in the management of pits and fissures with diagnosed caries.

7.1.2 Field and clinical trials.

A field trial of a restorative technique in General Dental Practice or in the Community Dental Service will show the performance, over a period of time, of that technique under the conditions pertaining in a busy dental practice. By comparison, a carefully controlled clinical trial performed in a dental hospital should show the ultimate performance of a restorative technique under the conditions of ideal clinical practice.

The majority of data relating to the performance of restorative techniques has been drawn from rigidly controlled clinical trials. In these, a limited number of operators placed the restorations using strictly defined protocols. These usually include standardisation of isolation techniques, use of single materials, uniformity in mixing and handling of materials and controlled conditions for etching and curing times (see Simonsen 1981, Raadal *et al* 1991 & Hinding 1974). Effects of operator variability were considered by Rock & Evans (1983) who compared the results from two operators working to the same clinical protocol and found significant differences in fissure sealant retention.

In this chapter of the thesis, the performance of sealant restorations placed under the ideal conditions of hospital dental practice will be described.

7.2 MATERIALS AND METHODS.

7.2.1 Selection of materials and patients.

The restorative materials used in this study were:

four visible light cured hybrid composite resins,

P50 (3M)	*Batch No. 91 D 17 A and 91 10 4A*
Prisma APH (De Trey / Dentsply)	*Batch No. Ch.-B 900405*
Degufill H (Degussa)	*Batch No. Ch.-B 0913113*
Fulfill (De Trey / Dentsply)	*Batch No. Ch.-B 890606*

three glass ionomer cements,

Baseline VLC (Dentsply)	*Batch No. Ch.-B 910814 101371/0*
Ketacbond Capsules (Espe)	*Batch No. Ch.-B/MD T190 004G25*
Baseline Capsules (Dentsply)	*Batch No. Ch.-B 900409 106200/0*

and three visible light cured pit and fissure sealants

Concise White Sealant (3M)	*Batch No. P900207 and P901129*
Estiseal (Kulzer)	*Batch No. Ch.-B 219-045 (13021)*
Fluroshield (Caulk/Dentsply)	*Batch No. 012991*

Patients attending the Conservation Department of Glasgow Dental Hospital and School for routine treatment were assessed for inclusion in the hospital clinical trial. Patients were only admitted to the trial if, on clinical or radiographic examination, they had fissure caries in a previously unrestored permanent posterior tooth. Caries was defined as clinically diagnosed fissure lesions where the diagnosis was performed on the cleaned and dried teeth under good, high intensity illumination. No major cavitation of the enamel was present in the teeth selected for inclusion. Teeth with radiographic evidence of caries in dentine below the occlusal enamel, but which did not extend more than half way through the dentine, were also included. Bitewing radiography was performed using long cone apparatus with Rinn film holders and the radiographs were dried, mounted and viewed at the chairside using diffuse background illumination.

The materials used for the restorations was changed after every forty sealant restorations placed. This allocation was left unbroken despite the distribution of the type of sealant restoration in each of the groups of 40 restorations. All restorations involving the preparation of an investigative cavity were placed after the administration of a local analgesic agent (2% lignocaine with 1:80,000 adrenaline or 3% prilocaine with 0.03 IU Felypressin/ml).

7.2.2 Restorative procedures.

All restorative procedures were performed by one operator (GBG). Before the operative procedure commenced, the tooth was cleaned using a slurry of flour of pumice and a small bristle brush operating at slow speed. An "enamel biopsy" was performed where the operator was suspicious of the presence of caries in dentine due to the presence of enamel opacities, radiographic evidence of dentine caries or the presence of stained and decalcified fissures where there were more than two other active lesions in the dentition. Sufficient tissue was removed to confirm the elimination of caries in enamel or to gain access for removal of dentine caries. This was achieved using a friction grip, ISO 008 diamond coated tapered fissure bur in a red banded, contra-angled handpiece operating at 120,000 rpm. Minimal extension of the cavity outline into sound tooth structure was performed. Dentine caries was removed using a round latch grip steel bur operating at normal speed. No effort was made to extend the cavity along the fissure pattern to achieve "extension for prevention".

After cavity preparation had been completed, the type of sealant restoration and restorative materials were selected according to cavity size and occlusal stops. Isolation was achieved by placing a rubber dam. The technique for placement of the restoration types was as follows:

Type 1. A gel of 37% buffered phosphoric acid (Scotchflow 3M, GT-6110-0291-3) was syringed over all pit and fissure surfaces and extended onto cuspal slopes. This was left undisturbed for 30 seconds before washing for a similar length of time. This was followed by a drying regime using oil free compressed air and the etched enamel surfaces were inspected for frosting. The selected pit and fissure sealant was dispensed into a Dappen's dish and transferred to the tooth surface in increments carried on the point of a Wards amalgam carver. This instrument was dragged along all fissure surfaces of the occlusal and/or buccal/palatal surfaces, dispensing a layer of sealant into the fissures and onto the cuspal slopes. The fissure sealant was polymerised for 60 seconds on each tooth surface using incident light from a Visilux 2 Light (3M). After removal of the rubber dam, the occlusion was checked using articulating paper of 0.04 millimetre thickness (Bausch) and adjusted, where appropriate, using a Shofu Brownie Point and water spray coolant.

Type 2. The cavity in enamel and all adjacent pits and fissures were etched using the technique described above. The appropriate enamel bonding resin, supplied by the manufacturer of the composite resin, was applied sparingly to the cavity walls using an endodontic paper point (Kerr Absorbent Points 062088-0443) and cured for 20 seconds. The hybrid composite resin was transferred to the cavity using a white thermoplast instrument (Hawes Neos Dental) and the surface contours recreated before polymerising. Polymerisation was performed in two distinct stages lasting for a total of two minutes: in the first stage, the tip of the curing light was applied to the buccal and palatal tooth surfaces to allow curing shrinkage to occur towards the light source; and in the second, the light guide was held as close as possible to the occlusal surface of the restoration. The pit and fissure sealant was then applied as described for type 1 restorations and the occlusion checked and adjusted if required.

Type 3. These small cavities which extended just into dentine were restored using glass ionomer cements. The encapsulated materials were mixed for 10 seconds according to the manufacturers' recommendations and injected into the cavity where they were allowed to set for four minutes. The surface of the glass ionomer cement was protected during etching of the surrounding enamel surfaces, by the application of a layer of enamel dentine bonding resin (Scotchbond Dual Cure, 3M), which was carefully applied to only the cement surface using a paper point. This was left for 40 seconds to penetrate pores in the glass ionomer cement surface before curing for 20 seconds.

Light cured glass ionomer cement was mixed according to the manufacturer's instructions and transferred to the cavity on a small flat plastic instrument where it was shaped and polymerised for 60 seconds. Etching of the enamel and application of the fissure sealant was carried out as previously described.

Type 4. In the larger laminate restorations, a lining of glass ionomer cement was inserted to replace the dentine lost through caries removal and cavity preparation. Where the cavity was deep, a sublining of a quick setting calcium hydroxide was applied (Dycal, De Trey/Dentsply). The surface of the glass ionomer cement was protected from the etching gel by the careful application of enamel/dentine bonding resin. Cavity walls and fissure surfaces were then etched and washed as before. A layer of enamel/dentine bonding resin was applied to the walls and floor of the cavity and polymerised before the composite resin restoration was placed and shaped. The fissure sealant was applied to the surface of the composite restoration and adjacent fissures as previously described.

7.2.3 Restoration review.

The restorations were assessed at each of the subsequent review appointments after 6,12 and 24 months. All reviews were performed by the same two assessors (G.B.G and R.C.P.) used in the field trial of sealant restorations placed by the Community Dental Service. The criteria used for assessments were designed for the study by modification of those used in the United States Public Health Service and shown in Chapters 4 and 5. The same criteria were used to determine the need for modifying or replacing the restoration and to assess performance of various aspects of the restorations.

7.2.4 Statistical evaluation.

Results from the review examinations were entered on a data base programme (Survey It! Version 4.0, Conway Information Systems Inc.) and the data was analyzed on micro-computer with the statistical package C-Stat (Oxtech Ltd, 1991) using Chi-square test to show differences between groups. The level of significance was set at 5%.

7.3 RESULTS.

7.3.1 Use of the techniques and materials.

In the hospital clinical trial, 164 teeth were restored with sealant restorations placed by a single operator working to a strict clinical protocol. Fourteen restorations were withdrawn from the trial and lost to all follow-up review examinations: one tooth was prepared as a bridge abutment; one mandibular third molar was extracted following the surgical removal of opposing impacted maxillary third molar; 12 restorations were lost due to patients moving away from Glasgow to secure employment.

The distribution of the remaining 150 teeth restored with sealant restorations is shown graphically in Figure 7.1. Second permanent molar teeth accounted for 49.3% of all restored teeth while the corresponding figures for first and third molars was 24.7% and 18.7% respectively. The graphic also shows the type of sealant restoration used to restore each tooth by quadrant. In Table 7.1 the distribution of the sealant restorations is shown by type. Ninety-two percent of the restorations placed (138 restorations) involved the preparation of an investigative cavity in which the fissure caries was found to be confined to enamel on only 10.9% of occasions (15 restorations). In the majority of the restorations, the caries lesion was found to have established in dentine and spread along the enamel dentine junction to bring the margins of the cavity or the surface of the restoration into occlusal contact. This latter group of cavities were restored using a laminate sealant restoration.

The mean age of patients receiving sealant restorations is shown by type in Table 7.2. There was no correlation between the type of sealant restoration and the age of the patient. Sixty-four percent of the patients treated were male.

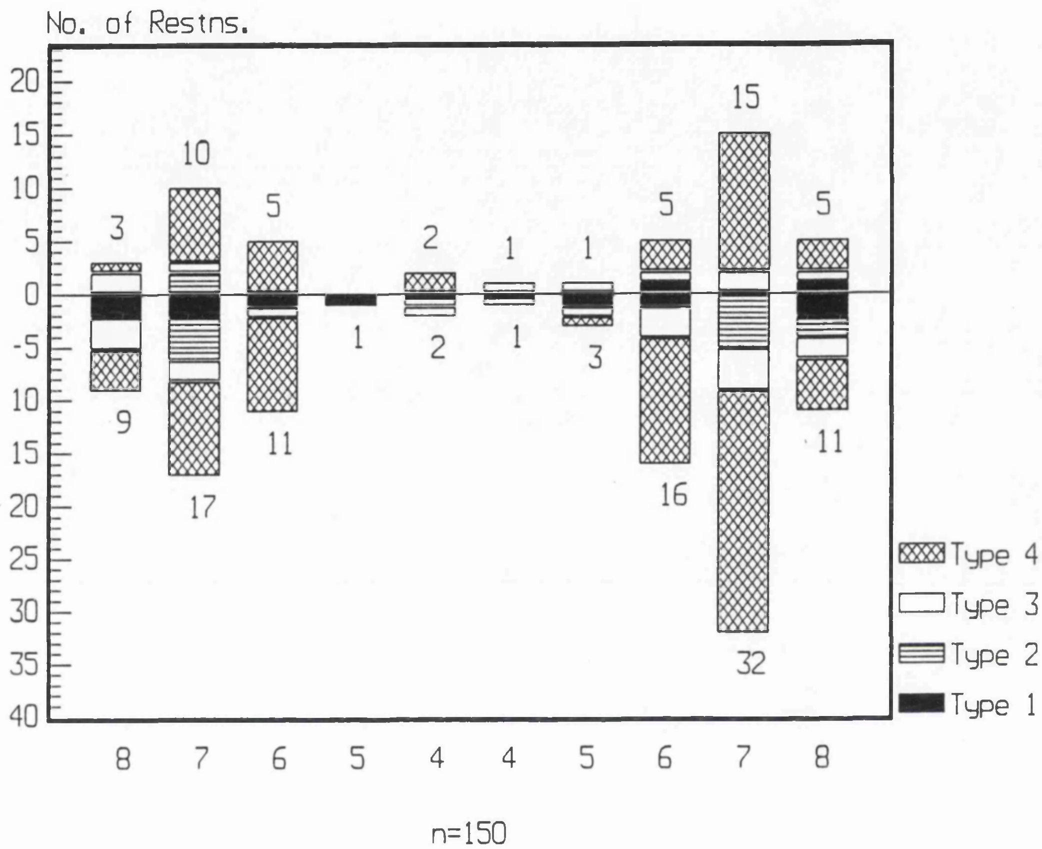


Figure 7.1 **Distribution of sealant restoration types used in the clinical trial among the four quadrants.**

Type 1 F.S. alone	Type 2 Comp + F.S.	Type 3 G.I. + F.S.	type 4 Laminates
12 restns. 8%	15 restns. 10%	26 restns. 17.3%	97 restns. 64.7%

n = 150

Table 7.1 The distribution of the sealant restoration types placed in the hospital clinical trial.

Restoration type	**Mean age (years)**	**Standard deviation (years)**
Type 1	22.80	3.88
Type 2	23.94	5.27
Type 3	25.68	9.30
Type 4	22.28	3.48

Table 7.2 The mean age of patients receiving sealant restorations in the hospital clinical trial of sealant restorations.

One unfilled pit and fissure sealant and two filled sealants were used in the restoration of all teeth in the clinical trial. Opaque fissure sealants were used during the provision of 52% of all sealant restorations.

The combinations of restorative and fissure sealant materials used in each type of sealant restoration are shown in Table 7.3 All composite resins employed were of a hybrid type and presented in compule form while two of the glass ionomer cements were also encapsulated and the remaining material was a light curing glass ionomer formulated as a lining material. All glass ionomer cements were radio-opaque.

7.3.2 Performance of Type 1 sealant restorations.

Twelve teeth were restored using fissure sealant alone in the management of fissure caries. After 6, 12 and 24 months, all restorations were successfully reviewed: a 100% recall rate.

After the first and second review examinations all fissure sealants were scored as completely present but two years after placement the loss of some fissure sealant from an occlusal fissure resulted in the fissure sealant being scored as partly missing.

The retention of fissure sealant at each review examination is shown in Table 7.4 and the treatment requirements in Table 7.5. It was estimated that all restorations would survive a minimum of a further two years.

7.3.3 Performance of Type 2 and Type 4 sealant restorations.

At each of the review examinations, all of the smaller intra-enamel composite and fissure sealant restorations were reviewed while two of the larger laminate restorations were lost from review before the initial six month examination. A further two restorations were lost from recall between one and two years post placement: attempts to recall these patients by letter and telephone failed.

	Concise	Estiseal	Fluoroshield
Type 1 (n=12)			
	2	3	7
(no rest. mat.)			
Type 2 (n=15)			
(Comp+F.S.)			
Fulfill		5	
P 50	4		
Prisma APH			5
Degufill H		1	
Type 3 (n=26)			
(G.I.+F.S.)			
Baseline VLC	9	4	
Ketacbond Capsules		5	
Baseline Capsules		3	5
Type 4 (n=97)			
(Laminate Restn)			
Fulfill		39	
P 50	15		
Prisma APH			31
Degufill H		12	
	n=30	n=72	n=48

Table 7.3 Material combinations used in the restoration of the 150 teeth restored using the sealant restoration technique.

Six months

	Type 1	Type 2	Type 3	Type 4
Compl. present	12 (100%)	15 (100%)	25 (96.2%)	92 (96.8%)
Partly missing	0	0	1 (3.8%)	3 (3.2%)
Compl. missing	0	0	0	0
Recall rate	100%	100%	100%	97.9%

Twelve months

	Type 1	Type 2	Type 3	Type 4
Compl. present	12 (100%)	15 (100%)	20 (76.9%)	72 (75.8%)
Partly missing	0	0	6 (23.1%)	23 (24.2%)
Compl. missing	0	0	0	0
Recall rate	100%	100%	100%	97.9%

Twenty-four months

	Type 1	Type 2	Type 3	Type 4
Compl. present	11 (91.7%)	15 (100%)	18 (69.2%)	62 (66.7%)
Partly missing	1 (8.3%)	0	8 (30.8%)	31 (33.3%)
Compl. missing	0	0	0	0
Recall rate	100%	100%	100%	97.9%

Statistical comparisons.

Differences in sealant retention at the three reviews.

Type 1: $Chi^2=0$ DF=2 P>0.05

Type 2: $Chi^2=0$ DF=2 P>0.05

Type 3: $Chi^2=6.438$ DF=2 P<0.05*

6m v 12m $Chi^2=4.127$ *DF=1* *P<0.05* *

12m v 24m $Chi^2=0.391$ *DF=1* *P>0.05*

Type 4: $Chi^2=28.076$ DF=2 P<0.05*

6m v 12m $Chi^2=17.842$ *DF=1* *P<0.01* **

12m v 24m $Chi^2=1.910$ *DF=1* *P>0.05*

Table 7.4 Fissure sealant retention in all types of sealant restoration after 6, 12 and 24 months.

Six months

	Type 1	Type 2	Type 3	Type 4
No treatment required	12	15	26	94
F.Seal required	0	0	0	1
Rest.mat.+F.S. needed	0	0	0	0

Twelve months

	Type 1	Type 2	Type 3	Type 4
No treatment required	12	15	24	93
F.Seal required	0	0	2	2
Rest.mat.+F.S. needed	0	0	0	0

Twenty-four months

	Type 1	Type 2	Type 3	Type 4
No treatment required	12	15	23	93
F.Seal required	0	0	3	0
Rest.mat.+F.S. needed	0	0	0	0

Table 7.5 Treatment requirements for all types of sealant restorations after 6, 12 and 24 months.

In the smaller type 2 restorations, the area occupied by the composite filling was small. The diagrammatic representations of the area occupied by the restorative material showed them all to occupy less than a third of the fissured surface and the width of all restorations was less than 1mm.

In the larger laminate restorations, the composite resin fillings occupied more than a third of the fissure surface in 91.5% of all restorations with the majority occupying between one and two thirds of the area. The width of the filling was greater than 1mm for 96.8% of all laminate restorations. In Table 7.6 the distribution of the restorations is shown in width and extent within the fissure. As few restorations were placed outwith the median measurements of width and extent, statistical evaluation within the group of laminate restorations is not possible.

Complete fissure sealant retention was maintained over the two year evaluation period for the smaller composite and fissure sealant restorations (Table 7.4). The presence of the small composite resin fillings did not reduce the overall sealant retention. The presence of larger composite fillings in pits and fissures, however, did adversely affect sealant retention: after six months only 3 of restored teeth (3.2%) had partially missing fissure sealant but two years after placement, 33 of the laminate restorations (33.3%) had lost some fissure sealant material.

The areas of retained and missing fissure sealant material after 2 years are shown in Table 7.7. The majority of the missing areas of sealant were from the surface of the composite resin filling. The retention of the fissure sealant to the various enamel surfaces was not problematic and did not differ from those restorations where sealant that was scored as missing after the initial six months review. As all fissure sealant loss after the six month review was from the surface of the composite resin filling, the results indicate a significant loss of fissure sealant from this surface between six and twelve months post placement ($P<0.01$).

Width of restoration across cavity

	up to 1mm	1 to 3mm	more than 3mm
< 1/3	0	8	0
1/3 to 2/3	3	68	4
> 2/3	0	11	1

n=95

Table 7.6 **The distribution of laminate restorations placed in the clinical trial by width and extent of fissure pattern involved.**

Type 2

	Restoration	Occlusal	Buccal	Palatal
Retained	15 (100%)	15 (100%)	2 (100%)	13 (100%)
Lost	0	0	0	0

Type 3

	Restoration			Occl.	Buccal	Palatal
	L/C	Encap	Total			
Retained	8 (61.5%)	11 (84.6%)	19 (73.1%)	26 (100%)	14 (93.3%)	7 (100%
Lost	5 (38.5%)	2 (15.4%)	7 26.9%)	0	1 (6.7%)	0

Type 4

	Restoration	Occlusal	Buccal	Palatal
Retained	65 (69.9%)	91 (97.8%)	58 (98.3%)	31 (100%)
Lost	28 (30.1%)	2 (2.2%)	1 (1.7%)	0

Statistical comparisons:

type 2 v type 4 (restoration surfaces)	*Chi^2=6.097*	*DF=1*	*P<0.05**
type 2 v type 3 (restoration surfaces)	*Chi^2=4.870*	*DF=1*	*P<0.05**
type 2 v type 3 (VLC)	*Chi^2=7.023*	*DF=1*	*P<0.01***
type 2 v type 3 (encapsulated)	*Chi^2=2.485*	*DF=1*	*P>0.05*
type 3 v type 4 (restoration surfaces)	*Chi^2=0.990*	*DF=1*	*P>0.05*
encap v VLC GI (restoration surfaces)	*Chi^2=1.759*	*DF=1*	*P>0.05*

Table 7.8 **Surfaces with completely or partially lost sealant form sealant restorations involving the enamel biopsy technique. Results after 2 years.**

It would appear that as the surface area of the composite filling increases from the small intra-enamel sealant restorations to the larger laminate restorations, a significantly greater loss of sealant occurs from this surface ($P<0.05$).

There is a danger of deterioration of the restorative material and subsequent marginal leakage if the fissure sealant covering is lost. The performance of the two groups of composite restorations are shown in Table 7.8 and the results would indicate no deterioration had taken place in marginal integrity, marginal stain or surface wear. Following the loss of the overlying sealant, no cases of secondary caries were noted.

Minimal re-treatment was required to the composite restorations: after 6 months, one laminate restoration needed addition of further fissure sealant and after 12 months, two restorations needed small additions of sealant material. Table 7.5 shows that no interim treatment was required to the smaller type 2 sealant restorations. It was estimated that all composite and fissure sealant restorations should survive for at least another two years.

7.3.4 Performance of Type 3 sealant restorations.

Twenty six glass ionomer sealant restorations were placed in the hospital clinical trial - this comprised 17.3% of all restorations placed. All restorations were successfully recalled at each review appointment.

As recommended for this restorative technique, the width of the glass ionomer filling did not exceed 1mm and less than one-third of the fissure pattern was removed during cavity preparation. The gradual loss of fissure sealant over the three review examinations is shown in Table 7.4 This loss was predominantly from the surface of the glass ionomer restoration (Table 7.7). Surface loss of fissure sealant was significantly greater from this surface than from similar sized surfaces of composite resin placed in the type 2 sealant restoration technique ($P<0.05$) but was not different from that with the larger surface area of composite resin placed in the laminate restorations ($P>0.05$).

Restoration type

	Type 2	Type 3	Type 4
Marginal Integrity			
F.S. intact over restn	15 (100%)	19 (73.1%)	65 (69.9%)
Marg. Integ excellent	0	4 (15.4%)	28 (30.1%)
Visible crevice	0	3 (11.5%)	0
Marginal discolouration			
F.S. intact over restn	15 (100%)	19 (73.1%)	65 (69.9%)
No marginal discol.	0	7 (26.9%)	28 (30.1%)
Marg. discol. present	0	0	0
Restoration wear			
F.S. intact	15 (100%)	19 (73.1%)	65 (69.9%)
No surface wear	0	3 (11.5%)	28 (30.1%)
Surface wear present	0	4 (15.4%)	0
Secondary caries			
F.S. intact	15 (100%)	19 (73.1%)	65 (69.9%)
No secondary caries	15 (100%)	7 (26.9%)	28 (30.1%)
Second. caries present	0	0	0

Table 7.8 **Performance of the restorative materials used in sealant restoration technique after two years.**

Although there was no statistical difference between the retention of fissure sealant to the surfaces of Visible Light Cured glass ionomer cement and encapsulated glass ionomer cements formulated as lining materials ($P<0.05$), the treatment requirements after 12 and 24 months indicate the need for additions of further fissure sealant. This was not due to the presence of decalcification of exposed fissures or to this group of patients having a higher DMFT, but to a deterioration in the visible light cured glass ionomer cement surfaces after exposure to the oral environment.

In Table 7.8, the performance of the glass ionomer sealant restorations is shown. Deterioration in marginal integrity and surface wear was due entirely to the plasticising of light cured cement surfaces. All of the encapsulated glass ionomer cement sealant restorations had a life expectancy of greater than two years while 76.9% of the visible light cured glass ionomer cement restorations had a similar life expectancy. The remaining light cured restorations were estimated to have a future life - after repair with further fissure sealant - of 1 to 2 years.

7.4 DISCUSSION.

7.4.1 The clinical trial patient treatment group.

In the hospital clinical trial, the ages of patient in whom sealant restorations were placed was higher than that of those who attended the Community Dental Services for treatment. The mean age of the group of patients was 22.28 to 25.68 years. Similar changes were also observed in the distribution and type of restorations placed and teeth restored. More than 60% of the teeth restored were laminate restorations. The criteria for the use of each restorative technique was strictly adhered to in the clinical trial, whereas it was frequently observed that glass ionomer restorations placed in the field trial were larger than that recommended for the technique.

Almost half of the teeth restored in this age group were second permanent molar teeth. This would support the observations made by Stamm (1984) who reported that the incidence of carious lesions in patients over the age of twelve increased in second molar teeth.

Ripa *et al* (1988a) reported that the time since tooth eruption does not influence the susceptibility of pits and fissures to caries. This observation was supported by Arthur and Swango (1987) who reported a high incidence of occlusal carious lesions among U.S. Navy recruits in their late teens and early twenties. The decayed, missing and filled teeth of 1100 Royal Australian Navy recruits was measured by Morgan *et al* (1992) who reported an increase in each element of the DMFT with increasing age. Untreated decay accounted for 32.8% of the DMFT in the 20-24 year old age group and 31.8% in the 25 - 29 year olds. With the general reduction in caries prevalence, it is likely that most of the caries will be pit and fissure lesions.

7.4.2 Differences between the clinical and field trial.

Following on the results of the field trial, where the restorations were not always placed under ideal conditions, it came as no surprise that the fissure sealant portion of the restoration was the most accurate predictor of the success of the sealant restorations. Unlike the conditions that prevailed in the field trial, the restorations were placed using a strict protocol which stipulated that rubber dam isolation had to be achieved. After six months, 96.8 to 100% complete retention of fissure sealant was found in all four types of sealant restoration but this gradually deteriorated by the loss of sealant from the surfaces of glass ionomer and the larger laminate restorations. After 24 months, 66.7 to 100% complete retention of fissure sealant was recorded. Other workers have measured success by the fissure sealant retention after given periods. After 2 years, Walls *et al* (1988) reported that 28% of their minimal composite sealant restorations had undergone partial loss of fissure sealant material. After 1.5 to 2.5 years, reports of 84% to 97% complete success have been published (Raadal 1978b, Simonsen and Jensen 1979, Houpt *et al* 1982 and Walls *et al* 1988). Success may be viewed as the prevention of further caries developing in the tooth.

7.4.3 Differences in performance among sealant restoration types.

The data in Table 7.4 show that the predominant areas of sealant loss were from over the glass ionomer or larger composite restoration. Despite the similarity in size of the glass ionomer and the smaller composite restorations (type 2 and 3 restorations), significantly more sealant was lost from the surface of the glass ionomer cements. When this data was further analyzed, no difference could be found between the small composite restorations and the encapsulated glass ionomer cements. Loss of sealant from the surface of visible light cured glass ionomer cement was significantly greater than from the composite surfaces.

The only difference between the smaller type 2 and the larger type 4 restorations is the surface area occupied by the composite restoration. The greater loss of sealant from the surface of the larger laminate restorations mirrors the results observed in the field trial, where there was a significantly greater rate of sealant loss from the surface of restorations occupying a larger proportion of the occlusal surface. Walls *et al* (1988) noted surface wear of composite sealant restorations which had larger surface areas.

This would imply that the sealant was lost or abraded in these restorations.

The pattern of sealant loss noted from the surfaces of both glass ionomer and composite resin in the current clinical trial, indicates that surface wear has not been responsible for the sealant loss. Sealant loss was exactly limited by the periphery of the restorative material indicating a adhesive failure of the sealant to the restorative material. The reasons for failure have been discussed in Chapters 4 and 5. Loss of sealant from the restoration surface could allow microleakage to occur around the periphery of the sealant restoration. This may manifest as secondary caries or reactivation of residual caries, since cavity size is limited and careful inspection of the enamel dentine junction is difficult. It could be argued, that under ideal conditions at the time of placement, fissure sealant could have flowed in to crevices around the periphery of the restoration and sealed the margin of the composite to enamel surfaces. After the sealant covering was lost, sealant in the crevices may remain thereby preventing microleakage.

7.4.4 Visible light cured glass ionomer cement restorations.

The results after 2 years indicate that sealant loss from the surface of light cured glass ionomer cement restorations was significantly greater than that from the surface of similar sized composite resins. In Table 7.8, the performance of the glass ionomer cement restorations is shown. The deterioration in the surface of the visible light cured cements resulted in surface wear and loss of marginal integrity. Clinical examination of these surfaces showed them to have plasticised, but exposing the subsurface layer by removing the plasticised layer with a round steel bur, revealed a hard material which was deemed suitable for further service after etching the enamel walls and applying a new layer of fissure sealant resin. As these restorations will be subject to further periodic examination, it was felt that this minimally invasive treatment option should be explored. Nicholson *et al* (1992) reported on the plastic deformation of two light cured glass ionomer cements when tested *in vitro* after storage in water. The change in the mode of failure of the water storage specimens correlated with the uptake of water which acted as a plasticiser and reduced the compressive strength of the material. Light cured glass ionomers should be protected in clinical use to ensure swelling of the material does not occur. Swelling in saliva, however, may be less than that reported in laboratory experiments.

7.4.5 Loss of fissure sealant from sealant restorations.

Loss of sealant does not necessarily indicate failure of the sealant restoration. Of the 150 restorations placed and reviewed after two years, 40 had lost some sealant: 35 from the surface of the restorative material, 3 from buccal surfaces of mandibular molar teeth and 2 from occlusal pits and fissures. It is conceivable that the loss of sealant from tooth surfaces could result in new caries attack but this did not appear to have occurred as no new lesions or areas of fissure decalcification developed. This may indicate the continued protection of these surfaces due to presence of resin tags within the enamel structure (Ripa 1973) or the low prevalence of new caries in the participating patients. If new caries had occurred, the tooth could have been re-treated using the sealant restoration technique. It would appear that these restorations serve the primary purpose for which they were intended, which was to conserve tooth structure while removing morbid tissue but still maintaining the strength of the restored tooth.

As there was a 98.3% successful recall after 2 years, the evaluation of the restorations in this clinical trial is entirely representative of the performance of sealant restorations placed by a single operator working to a strict clinical protocol. In view of the poorer results of sealant retention in the field trial, greater emphasis must be placed on the need for impeccable isolation. Similar etching and curing times were used in the two trials, but the use of rubber dam isolation and extended washing regimes after etching, suggest areas where attention is required to obtain the ultimate in clinical performance. It is critical that sealant restorations be carefully monitored and where required should have further additions of sealant material where this has been lost.

7.4.6 Controversy over the use of amalgam restorations.

The controversy over the use of mercury containing restorations has been emphasised recently in a television documentary ("Panorama", BBC TV July 1994) and focused media attention on alternative restorative materials. Most of the attention was centred on experimental studies on animals which has produced results from which amalgam restorations could produce impaired renal function, cause spontaneous abortion and non-congenital abnormalities.

In 1992, the Swedish Medical Research Council reported that the available data on mercury toxicity did not justify discontinuing the use of amalgam fillings. Sweden's forthcoming ban on the use of amalgam was highlighted in the programme by a parliamentary delegate but the Swedish Ministry of the Environment and Natural resources has reported:

"Amalgam is being phased out primarily for environmental reasons."

In view of the controversy and the decision of certain dental material manufacturers (e.g. Degussa) to cease production and marketing of amalgam, it is important to establish the viability of alternative materials and techniques for the restoration of posterior teeth.

The survival of amalgam restorations has been reported in a number of clinical studies. Estimates of median survival time vary from four years and eight months (Elderton 1983) to almost ten years (Hunter 1981). Most of the available information on the life expectancy of amalgam restorations has been based on adult patients and very little data is available about restorations placed in paediatric populations. Patterson (1984) estimated the life expectancy of occlusal amalgam restorations placed in two groups of children, aged six to twelve years and thirteen years or more, and reported significant differences between children and adult patients. Hunter (1982) reported on the median survival times of similar restorations in the same age range and observed that the survival time improved with increased age.

Walls *et al* (1985) retrospectively studied the longevity of 1031 occlusal amalgam restorations in first permanent molar teeth placed by undergraduate dental students. These authors concluded that class 1 amalgam restorations placed in six year olds, had a life expectancy of 26 months, while similar restorations placed in twelve year old patients, had a median survival time of 107 months. The latter survival time is similar to that observed in adult patients (Patterson 1984).

7.4.7 Performance of sealant restorations compared to amalgam fillings.

If alternative materials and techniques could be shown to have at least as good a longevity, or preferably a better life expectancy than amalgam, there would be a cost saving. Improved performance of sealant restorations has been shown with increasing age of child patients treated in the field trial which is also presented in this thesis. This mirrors the findings for amalgam restorations reported by Walls *et al* (1985). The advantage of sealant restorations over amalgam fillings lies in the reduced requirement for preparation to provide retention which often weakens the remaining tooth structure. Replacement of amalgam and composite resin restorations has been shown to increase the dimensions of the cavity (Elderton 1977 and Millar *et al* 1992). When Walls *et al* (1991) reviewed 150 paired composite sealant restorations and amalgam fillings, the study showed comparable and favourable results over a five year evaluation period. The parity of sealant restorations to amalgam fillings was achieved with significantly less destruction of tooth structure.

In the current field and clinical trials, the re-treatment rate involving invasive procedures is low and compares favourably with those reported from studies investigating the longevity of amalgam restorations. It would appear reasonable to argue that sealant restorations provide a suitable alternative to amalgam restorations for the management of fissure caries.

7.5 CONCLUSIONS.

1. The performance of sealant restorations placed using a strict clinical protocol were better than that achieved from a field trial where restorations were placed by a group of Community Clinical Dental Officers.

2. The presence of small composite restorations did not adversely affect the retention of fissure sealant compared to a group of sealant restorations where fissure sealant alone was placed in the management of fissure caries.

3. Retention of the sealant overlying the surface of composite was affected by the size of the restoration. Significantly more laminate sealant restorations had lost sealant covering than those from a group of small composite and sealant restorations.

4. Despite the loss of sealant from the composite surface of laminate restorations, no deterioration in the performance of the composite fillings was noted.

5. Loss of sealant from the surface of glass ionomer cement restorations was greater than that observed from the similar sized composite restorations.

6. Following the loss of sealant from the surface of three light cured glass ionomer cement restorations, the surface deteriorated by plasticising. These restorations required significant modification.

7. Where a tooth was scored as having lost some fissure sealant material, the partial loss was noted most frequently from the surface of the restorative materials used in the restoration of discrete fissure lesions.

8. In contrast to the field trial, loss of sealant from the buccal fissure of mandibular molar teeth was not observed.

9. The age of patients treated in the hospital clinical trial was greater than those treated in the Community Dental Services: this reflected in a difference in the distribution of teeth restored. Almost 50% of the teeth restored in this age group were permanent second molar teeth.

10. In the hospital clinical trial, significantly more sealant was lost between 6 and 12 months than during any other review period. This differed from the early loss of sealant in the field trial.

Chapter 8

Clinical recommendations.

Clinical Recommendations.

Fissure caries now accounts for over 80% of all new caries lesions in the permanent dentition. Increasing difficulty is being reported with the diagnosis of new lesions with large dentine cavities being present under virtually intact enamel surfaces.

As a result of the literature review and the studies carried out in this thesis, the following guidelines are presented in the management of fissure caries.

8.1 Prevention.

8.1.1 Fluoride.

The maximum effect of fluoride has been demonstrated against smooth surface lesions. It has been suggested that fluoride is responsible for the problem of large dentine lesions underlying very small enamel cavities in fissure caries - the so called "occult lesion".

8.1.2 Diet and Oral Hygiene.

Children and their parents should be encouraged to reduce the frequency of sugar consumption.

It should be emphasised that maintaining good oral hygiene practices alone is not sufficient in the prevention of caries. It is impossible to cleanse the fissures. Regular dental check-ups are advocated for the monitoring of caries.

8.1.3 Fissure Sealants.

In the West of Scotland, which is a non-fluoridated area with high levels of fissure caries, it would seem appropriate to recommend that first and second permanent molar teeth should have fissure sealants placed as a **preventive** measure shortly after eruption.

The buccal pit and fissure should also be sealed as soon as adequate isolation can be achieved.

Data from the current investigation into **therapeutic** fissure sealants suggests that 40% of these sealants may require additions or replacement within two years. This technique is simple to execute, is non-invasive and has been shown to be completely effective in preventing fissure caries when the sealant remains intact. Fissure sealants should be recommended as part of a caries management regime in dental health promotions.

8.2 Fissure caries diagnosis.

8.2.1 Methods of diagnosis.

There is considerable concern over the validity of fissure caries diagnosis. The possibility of missing large dentine lesions under intact occlusal surfaces is a particular challenge. Traditionally, diagnosis of fissure lesions was achieved by use of a dental explorer. When the tine of the explorer resisted removal from a fissure, a positive diagnosis was made. Field trial data has shown that the dental probe offers no advantage over a visual inspection of cleaned and dried tooth surface. The dental probe has been shown to be destructive by enhancing breakdown of enamel surfaces and its use for the diagnosis of fissure caries cannot be supported. Visual inspection of the cleaned and dried surface (plus an assessment of the overall caries risk) should be the main method of diagnosis of fissure caries. Other methods of diagnosis include Fibre Optic TransIllumination (FOTI), radiography, and a method of electronic caries detection are currently being evaluated.

8.2.2 Radiography.

The use of bitewing radiographs provides one of the few methods for screening for "occult lesions" yet is not routinely employed by the staff in the Community Dental Services.

Superimposition of enamel over the enamel-dentine junction in bitewing radiographs results in difficulty in accurate diagnosis, until the lesion has progressed into the outer dentine.

Radiographic diagnosis is of no benefit, therefore, in the detection of early fissure caries.

8.2.3 Enamel biopsy.

Fissure caries commences as a paired lesion on the side walls of the fissure. In the early stages, these lesions are difficult to see. When a fissure lesion is suspected, local investigation using a small bur (ISO 008) is advocated. If the lesion is confined only to enamel, the procedure can be abandoned at an early stage without jeopardising the integrity of the tooth and a minimal cavity can be prepared.

8.2.4 Diagnostic accuracy.

The accuracy with which smaller fissure caries lesions may be diagnosed is good but with larger lesions, cavity size may be poorly estimated. Many diagnostic cavities will be larger than anticipated.

Clinicians are advised to exercise caution with diagnosis of fissure caries in right mandibular first molar teeth and both mandibular second molars.

8.3 Management of fissure caries.

8.3.1 Intra-enamel lesions.

Early decalcification in fissures can be managed by the application of fissure sealant as suggested by the BDA Working Party. Clinicians are advised to consider radiographic assessment to eliminate the possibility of missing large dentine lesions or the presence of approximal caries, before fissure sealing.

The patient's age and isolation method at the time of fissure sealing influences the retention of the sealant: sealants placed in children younger than 12 years will require more maintenance than those placed in older children.

When cavitation is suspected, an enamel biopsy technique is recommended to locally investigate the suspect area. When the lesion is limited to enamel, the lost tissue can be replaced using composite resin.

In place of extending the cavity outline into all adjacent fissures, a pit and fissure sealant may be used over the restoration and in all neighbouring fissures as a means of preventing further caries.

8.3.2 Minimal dentine lesions.

A minimal cavity which extends into dentine may be restored with glass ionomer cement if the margins of the cavity are not in occlusal function.

Following preparation of the cavity, the position of occlusal stops should be established using articulating paper. Cavities which show minimal lateral spread can be restored using glass ionomer cements.

When larger cavity types are restored in glass ionomer cement, loss of the overlying fissure sealant may predispose the glass ionomer filling to early deterioration.

8.3.3 Large dentine lesions.

Where carious lesions are more extensive, a laminate restoration is recommended. In this type of restoration, a glass ionomer cement is used to line the cavity and to replace the missing dentine before the cavity is restored using composite resin. A covering of fissure sealant is then applied.

8.4 Selection and use of materials.

8.4.1 Fissure sealants.

The improved clinical performance of filled fissure sealants is now recognised. Retention is achieved by etching the tooth using buffered phosphoric acid. The control of gel etchants is superior to that of liquid materials and therefore their use is recommended. No improvement in sealant retention can be demonstrated by extending etch times beyond twenty seconds.

It has been shown that the use of opaque fissure sealant is easier to detect at subsequent review. Improved agreement among operators examining for its presence has been demonstrated. However, use of opaque resins may interfere with the collection of epidemiological data where sealants have been applied over the surface of small composite resin or glass ionomer cement restorations.

When clear sealants are used, one of the commonest errors is to incorrectly diagnose the presence of fissure sealant. This may be overcome by visually inspecting the tooth surfaces after a short etch. Following examination, lost mineral content is thought to be replaced rapidly if the surface is coated with a fluoride varnish.

8.4.2 Glass ionomer cements.

The use of radio-opaque glass ionomer cements is recommended as this will avoid future diagnostic problems during radiographic examination. Encapsulated glass ionomer cements are easier to manipulate when restoring narrow cavities and their use will ensure a uniform mix is achieved for all restorations.

The surface of the glass ionomer cement should be protected from etchant materials as this practice can adversely affect the physical properties of the cements.

The application of an enamel dentine bonding resin has been shown to improve the shear bond strength between cement and fissure sealant and may also be used to protect the cement during etching of the enamel. It is advisable to leave the bonding resin on the surface of the cement for approximately 30 seconds to allow it to penetrate the surface layer of the restorative material before light curing.

Light cured glass ionomer cements (compomers) have the advantage of command curing and improved handling characteristics but the findings in this clinical trial and from literature reports suggest this material requires further investigation. Plasticising of the resin component when stored in water, or exposed to the oral environment, may lead to early failure of restorations using this material.

The use of glass ionomer cement as a structural lining in laminate restorations is advocated. This material is ideal for this purpose as it has a similar expansion co-efficient as dentine, bonds to calcified tooth structure, releases fluoride which has a cariostatic effect and forms a union with overlying composite restoration. The glass ionomer lining should be protected from etchant by the application of an enamel-dentine bonding resin to the cement surface using an absorbent paper point. Following etching, it is recommended that the cavity walls and cement lining are coated in bonding resin and light cured before the cavity is restored with composite resin.

8.4.3 Composite resins.

The original macrofilled composite resins showed early wear but with the development of hybrid materials where filler particles of differing sizes are employed, significantly improved clinical performance can be achieved. The use of radio-opaque materials is advocated to avoid diagnostic confusion during radiographic assessment.

Improved retention and reduced microleakage around composite restorations can be achieved by etching enamel margins and applying an unfilled bonding resin. This material should be light cured before the resin restoration is inserted.

Light curing of the restoration should be performed initially from both buccal and lingual surfaces to allow curing of the composite towards the cavity walls. A final cure for 60 seconds should then be performed from the occlusal surface with the light guide held close to the composite surface.

Simultaneous polymerisation of the fissure sealant and composite resin is not recommended as this may lead to stresses at the interface between the materials. This could occur, theoretically, due to the value of their differing polymerisation shrinkages.

8.5 Clinical performance.

The results of this clinical and field trail of sealant restorations support the growing evidence which shows that these techniques are suitable alternatives to the placement of amalgam restorations in the management of fissure caries. The success of the techniques is heartening in view of the controversy over the use of mercury containing restorative materials. The use of sealant restorations for fissure caries would allow the use of amalgam alloys to be restricted to the larger class II lesions where preventive management has failed. This would delay the date of first exposure to amalgam to the late teens.

It is important that teeth restored with all types of sealant restorations should be reviewed periodically, subject to the individual caries experience of the patient. It is advocated that previously sealed fissure surfaces should be resealed in those patients who have more than two other active lesions elsewhere in their dentition.

Loss of sealant from the surface of composite resin or glass ionomer restorations should be individually assessed for deterioration of marginal seal which may manifest as a degeneration in the marginal integrity, the presence of marginal stain or secondary caries.

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