AN EVALUATION OF COMPOSITE RESINS AND GLASS POLYALKENOATE CEMENTS IN PAEDIATRIC DENTISTRY

R. Richard Welbury

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For all my patients

especially

Tom, Emma, Annabel

Jenny, Sylvie and Jonathan

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ABSTRACT

This study comprised five clinical trials in children and young adults, and a series of supporting laboratory investigations.

The first trial compared a second generation glass polyalkenoate cement with amalgam as a restorative material in the deciduous dentition. The glass polyalkenoate material underwent a more rapid loss of anatomical form and marginal integrity, and also had a higher failure rate than amalgam.

The second trial compared a minimal composite restoration/ fissure sealant technique with a conventional amalgam restoration as treatment for occlusal caries in permanent molars. Although there has been some loss of anatomical form and marginal integrity of the amalgam restorations, and loss of the fissure sealant component of the composite restorations, only 11 amalgam and 8 composites have failed. There was no statistical difference in terms of failure between the two techniques.

The third trial involved a study of glass polyalkenoate-composite resin class II sandwich restorations in premolar and molar teeth. Results showed that a layer of glass polyalkenoate cement brought out to the approximal tooth surface in the box areas was not a reliable method of restoration and certainly not a solution to cervical gap formation found with composite resins alone in the class II cavity.

The fourth trial involved a study of a microfilled composite resin veneer technique for improving the aesthetics of anterior teeth. Results showed a low failure rate and high patient satisfaction over a 30 month period.

The fifth trial involved the use of a hydrochloric acid-pumice abrasion technique for removal of superficial enamel stains. The

technique was quick and easy to perform, and results were impressive. Patient satisfaction and appreciation was very high.

Laboratory investigations were largely centred around the use of glass polyalkenoate cements in the sandwich technique. Results showed that etching of glass polyalkenoate cement with acid gave no advantages over a simple wash with water, prior to bonding to composite resin. Also that etching before the manufacturers recommended time, and failure to use an unfilled intermediate resin resulted in a poorer bond between glass polyalkenoate cement and composite resin.

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1.

INTRODUCTION

'If dentistry does not keep abreast of scientific advance, it will become a technology and can scarcely continue to be regarded as a learned profession.'

Sir Robert Bradlaw 1983.

The benefits of the scientific advances in dental materials technology which have occurred in such great strides in the last decade are no more keenly appreciated than in the field of paediatric dentistry.

Firstly, the glass polyalkenoate cements (glass-ionomer cements) have the ability to bond to enamel and dentine by virtue of an interaction between the polyalkenoic acid molecule and both the inorganic and organic components of tooth tissue. The precise mode of adhesion remains unclear, but ionic bonds, hydrogen bonds and metallic ion bridging are thought to play a part. Secondly, the refinement and development of composite resins, based either on Bisphenol-A-glycidyl-methacrylate (Bis-GMA), urethane diacrylate, or triethylene glycol dimethacrylate resins, used in conjunction with acid etching of tooth enamel has resulted in successful micromechanical retention of resin onto existing enamel. Both of these tooth coloured restorative materials occupy important positions in the armamentarium of the paediatric dentist. Apart from their obvious aesthetic appeal, cavity preparation time is reduced and less sound tooth tissue is removed in order to achieve retention of the restoration. Consequently less time is spent in the dental chair and often local analgesia may not be necessary, both these points are highly significant to an anxious child and parent. Removal of less sound tooth tissue with a so-called 'conservative cavity design' and restoration with an adhesive material

also maintains the strength of the tooth, renders it less likely to fracture compared to a tooth restored with non-adhesive material (Morin et al 1984), and leaves more sound tooth tissue for preparation of an extended cavity if this becomes necessary at a later date. Finally, the potential for adhesive materials to prevent marginal leakage and hence recurrent decay should result in the frequency of need for localised repair of restorations instead of a total replacement that would inevitably remove considerable amounts of sound tooth.

'Stock-taking' in dentistry has been the exception to the rule. In over 150 years of clinical use of amalgam as a restorative material there exist only about 20 in vivo trials pertaining to its durability. However, dentistry in 1988 is more accountable for its actions. Extensive testing including clinical trials are necessary before a new material can obtain a product licence and this fact, together with media generated public awareness of aesthetic restorative possibilities, have resulted in the publication of more data concerning durability of polyalkenoates and composites in the last 10 years than for amalgam in 150 years. However, the prospective clinical trial remains a rarity because of its very nature. From the operator's point of view it is tedious and saps the enthusiasm - even if the patients attend for follow-up. Nevertheless, it assumes an unparalleled level of importance in the prediction of durability of dental restorations. The bulk of this study investigates by prospective clinical assessment, various techniques for treating children's teeth, some of which have been in use for 10 years, others which have only recently been suggested, and one old technique that has recently been re-evaluated.

The objectives of this study are:

A. **IN THE CLINIC**

1. To evaluate the durability and clinical efficiency of a glass polyalkenoate cement as a definitive restorative material for Class II cavities in deciduous molar teeth, compared to amalgam in matched paired cavities.
2. To determine whether a minimal cavity preparation associated with a composite resin restoration and fissure sealant is as acceptable as a Black's Class I amalgam restoration in the management of occlusal caries.
3. To evaluate the durability and clinical performance of the Class II sandwich (combined composite and polyalkenoate) restoration in premolars and first permanent molars of adolescent patients.
4. To establish the durability and clinical performance of a microfilled composite resin veneer system on upper anterior teeth in adolescents and young adults used to mask discolouration, hypoplasia and to improve the aesthetics of spaced and rotated teeth.
5. To evaluate the success of the hydrochloric acid-pumice abrasion technique in removing stains of superficial enamel origin in upper anterior teeth of adolescents and young adults.

B. **IN THE LABORATORY**

1. To investigate some materials properties of glass polyalkenoate cements pertaining to their use with composite resin in the sandwich technique, especially those factors affecting the bond formed between glass polyalkenoate and composite resin.
2. To investigate some materials properties of a microfilled

composite resin relevant to its use as an anterior veneering agent.

3. To investigate the depth of enamel removed during the hydrochloric acid-pumice abrasion technique.

2.

LITERATURE REVIEW

INTRODUCTION

The purpose of the work described in this thesis was to evaluate the durability of certain restorative materials in vivo, to ascertain modes of failure where this occurs, and to relate performance in vivo to certain in vitro characteristics.

The literature review deals mainly with the recorded in vivo data available for each type of material studied. In order to make correlations with in vitro performance a knowledge of structure property relationships is obviously required. A review of the structure of each material has been completed and relevant reports of in vitro work are cited where necessary in both the literature review and discussion. No attempt, however, has been made to present a comprehensive review of the literature on in vitro performance of polyalkenoates and composite resins. Such a task is considered beyond the scope of this thesis and much data is available in recently published reviews.

Polyalkenoate Cements: Walls 1986
McLean 1988

Composite Resins: Vanherle and Smith 1985.

A separate section in the literature review is devoted to the 'sandwich technique' even though this technique uses both glass polyalkenoate cements and composite resins which have been covered previously. This is because it is necessary to review individually:

(a) the shortcomings of composite resin restorations in the deep Class II cavity - the 'raison d'etre' for the 'sandwich technique' being suggested in this situation;

(b) the enamel/dentine/cementum - glass polyalkenoate interface; and

(c) The glass polyalkenoate-resin interface.

Finally, at the end of the literature review, is a section concerned with the treatment of intrinsic enamel staining by application of acids. This topic finds a place in this thesis because an old technique more recently reported and re-evaluated, came to the attention of the author during the second year of the clinical trial involving the placement of microfilled composite veneers to mask discolouration. Because of the apparent simplicity of the technique and the number of patients still being referred to the author in the clinic, it was decided to carry out an appraisal of the technique under controlled conditions.

2.1. AMALGAM RESTORATIONS

2.1.1. INTRODUCTION

The period of Pierre Fauchard (1678 - 1761) can be considered to be the beginning of dentistry as a healing art and during the seventeenth and eighteenth centuries a material known as D'Arcets Mineral Cement was used by French dentists to restore cavities. This material consisted of eight parts bismuth, five parts lead, three parts tin and one part mercury. The mixture became plastic at 100°C and could apparently be poured directly into the cavities! In 1826 Traveau advocated the union of pure silver and mercury for restorations, but drawbacks to this included its marked expansion and black appearance. Although tin was added which improved appearance, amalgamation and handling characteristics of the material was not universally accepted. In 1885 Flagg commercially analysed available alloys and altered their compositions to contain 60% silver and 40% tin instead of vice versa. Each alloy was apparently tested by current laboratory techniques and five year clinical studies. Further work by one G.V. Black resulted in amalgam gaining widespread acceptance amongst the profession and culminated in 1900 in the production of 'True Dentalloy' by the S.S. White Company.

Despite the inauspicious start during the 19th century when the use of early amalgam was considered malpractice by the American Society of Dental Surgeons, it very soon gained widespread acceptance and became the mainstay of restorative dentistry. Until recently, the restoration of posterior teeth in both the permanent and the deciduous dentitions was almost exclusively with dental amalgam, and only in the last decade have materials with apparently adequate properties been

marketed to challenge it in this area.

It was not the aim of this thesis to study the durability of dental amalgam nor to investigate the factors which control durability. However, a conventional lathe cut alloy (Amalcap) has been used as a control against which a glass polyalkenoate cement (Ketac-Fil) and a composite resin (Prisma Fil) have been compared and the literature review has been prepared to this end.

2.1.2. CLASSIFICATION AND CHEMICAL COMPOSITION

Dental amalgam consists essentially of mercury combined with a silver-tin alloy. The composition and morphology of the alloy powder particles varies from one product to another and forms the basis for classification.

2.1.2.1. CLASSIFICATION ACCORDING TO COMPOSITION

1. CONVENTIONAL ALLOYS

   These are based on the original formulation by G.V. Black (Black 1908) of a minimum of 65% silver, 29% tin (maximum), 6% copper (maximum), and 3% mercury (maximum). The alloy is formed by melting the consistent metals together to form an ingot. However, at the relevant temperatures oxidation of the consistent metals may occur, which would cause serious detriment to the materials properties. To overcome this problem, zinc is included which acts to combine preferentially with availabe oxygen forming a slag of zinc oxide that can be removed from the melt.

2. COPPER ENRICHED ALLOYS

   As the name suggests, these have a higher copper content than

conventional alloys. Two types are recognised:

(a) SINGLE COMPOSITION ALLOYS

The basic composition of the alloy is altered to contain more copper. Asgar in 1974 described an alloy containing (by weight) 13% copper, 60% silver, and 27% tin, while in other commercial alloys the copper content may be increased up to 30% with an attendant reduction in the amount of silver (Beech 1982).

(b) ADMIXTURES

These consist of a blend of conventional and high copper alloy particles. Beech (1982) reported an increase in the clinical longevity of a material made by blending a conventional lathe cut alloy with stronger, harder spherical particles of a 72% silver, 28% copper alloy in the ratio of 2:1 by weight.

2.1.2.2. CLASSIFICATION ACCORDING TO MORPHOLOGY

Two particle types may be distinguished:

1. LATHE-CUT ALLOY PARTICLES

These are formed from shavings cut from an ingot of alloy. These particles are irregular in shape, and may be graded according to particle size as either coarse or fine grain.

2. SPHERICAL ALLOY PARTICLES

These are obtained by spraying the molten alloy onto a column filled with inert gas. This produces rapid solidification of the alloy resulting in alloy particles of numerous spheroidal shapes.

2.1.3. THE SETTING REACTION

Upon mixing, mercury diffuses into the alloy particles. The surface layer alloy structure becomes disrupted and the metals undergo amalgamation with mercury. The reaction products crystallise to give 'new phases' in the set amalgam and on completion of setting a large proportion of the initial alloy remains unreacted. These unreacted cores are embedded within a matrix of reaction products. For conventional alloys the reaction may be summarised as:

$$Ag_3Sn + Hg \rightarrow Ag_2Hg_3 + Sn_7Hg + Ag_3Sn$$

Phase γ γ_1 γ_2 γ

The presence of γ_2 phase is thought to encourage corrosion, bulk fracture and marginal breakdown in the oral cavity (Jorgensen 1965, Sarker et al 1983), and when the γ_2 phase corrodes releasing free mercury and tin salts voids are left which weaken the materials structure (Jorgensen 1965, Marshall and Marshall 1980). The purpose of high copper alloys was to eliminate the γ_2 phase. The extent of elimination is dependent upon the amount and distribution of copper within the alloy and in order to be effective a copper content in excess of 12% is usually required (Beech 1982). In this case, Cu_6Sn_5 is formed in preference to the γ_2 phase, thus changing the physical and mechanical properties of the amalgam and significantly improving the corrosion resistance (Marshall and Marshall 1980). Gold, manganese, palladium and indium have also been used to reduce the phase.

As amalgam alloy sets dimensional changes occur. When mercury diffuses into the alloy particles a small contraction occurs, but as crystallisation proceeds the outward growth of crystals results in

expansion. A final slight contraction or expansion will depend on individual alloy characteristics.

2.1.4. LONGEVITY OF AMALGAM RESTORATIONS

Considering the number of years that amalgam has been in use, there are few published papers on its durability and longevity and these have mostly been retrospective longitudinal studies.

Restorations fail or are replaced (or both) for many reasons and at different times of service. The terms 'failure' and 'replacement' seem to be used synonomously in dental literature, and in clinical practice there are few specific points of measurable failure. Failures such as fracture, loss of a restoration and missing contact points are generally agreed on by the profession, but discrepancies in anatomical form, marginal deterioration and tissue response to restorations elicit a wide spectrum of responses. The decision to call a discrepancy a failure and to recommend replacement draws an individual clinical judgement that is highly variable and not clearly defined. This was highlighted in a 5 year follow-up study of dental treatment provided in the General Dental Service in Scotland (Elderton and Davies 1984) where 50% of all tooth surface filled were for just 12% of the patients. It is further illustrated in a short-term clinical study by Bailit et al (1979) who looked at data from different dental practices in order to determine the length of time amalgam restorations lasted before replacement. Although on average 13% of the amalgams required replacement after 20 years, some dentists replaced 30% and others only 5%.

Discussion of the literature concerning the longevity of amalgam restorations is best conducted in 3 categories:

(a) adult;

(b) child and young adult - permanent dentition;

(c) child - deciduous dentition.

2.1.4.1. ADULT STUDIES (Table 2.1.)

The 11 published longevity studies concerning the performance of amalgam as a dental restorative show an overall survival rate of about 50% at 5 - 10 years. Within this figure, single surface restorations performed better than more complex designs. The findings of the various studies are relatively consistent despite intra-study variables such as different operators and different types of amalgam and inter-study variables such as operators, types of amalgam, place of restoration placement (general practice or dental hospital) and country of placement.

2.1.4.2. CHILD AND YOUNG ADULT STUDIES - Permanent Dentition (Table 2.2.)

There are only 3 studies that fall into this category and all used survival analysis in order to predict the Median Survival Time (MST) of amalgam restorations. Unlike Paterson (1984), the studies of Hunter (1982) and Walls et al (1985) were able to show that the durability of restorations was dependent on the age of the patient at the time of placement. This fact comes as no surprise to the clinician, nevertheless it took over 150 years to be stated scientifically. Walls et al (1985) were also able to

conclude that the relative survival of restorations was reduced by 23% from the mean if local analgesia was not used and increased by 16% from the mean if it were.

2.1.4.3. STUDIES OF THE DECIDUOUS DENTITION

With one exception (Holland et al 1986), there are virtually no studies available relating to the survival of amalgam restorations in the deciduous dentition. In a pilot study, Llewellyn (1977) found that 10% of 230 'consecutively examined' restorations were classified as having failed at between 3 and 60 months after placement and two groups of workers (Braff 1975; Dawson et al 1981) have demonstrated that stainless steel crowns exhibit superior performance when compared to multi-surface amalgam restorations in primary molars, especially the first deciduous molar.

Holland et al (1986) reported the results of a retrospective study of 1,139 amalgam restorations placed in deciduous molars of 317 patients aged 1 - 10 years at initiation of treatment, during a 7 year period. The durability of the restorations was assessed by life table analysis. The mean survival time for all 1,139 restorations was 30 months; 46% survived for 3 years. The median survival time increased from only 11 months in the youngest age group (3 years of age) to 44 months for children aged 7 - 8 years. For each group, Class I restorations showed greater durability than Class II restorations. These survival rates are compared to those in first permanent molars in the studies of Walls et al (1985) and Hunter (1982) in Table 2.3.

Table 2.1.

ADULT STUDIES ON THE LONGEVITY OF AMALGAM RESTORATIONS

Study and Location	Survival Rate
Teaching Hospitals	
(a) **U.K.**	
Allan D.N. 1969	49% at 10 years
Crabb H.S. 1981	44% at 10 years
(b) **U.S.A.**	
Dennison and Straffon 1984	80% at 7 years
Scottish Dental Service	
Elderton R.J. 1983	50% at 5.5 years
N.E. England general practice	
(a) Paterson N. 1984	50% at 7.7years
(b) Allan D.N. 1977	
(i) 15 year study	50% at 5 years 10% at 15 years
(ii) 20 year study	50% at 8 years 10% at 20 years
London Suburban Practice	
(a) N.H.S.: Robinson A.D. 1977	57% at 7 years
(b) Private: Reuter J.E. 1985	89.4% at 7.6 years
Canadian General Practice	
Lavelle C.L. 1976	10% at 20 years
United States General Practice	
Bailit et al 1979	87% at 2 years
Armed Forces	
(a) U.K.: Gray J.C. 1976	50% at 10 years
(b) Holland: Meeuwissen 1985	50% at 10 years

Table 2.2.

CHILD AND YOUNG ADULT STUDIES (Permanent Teeth)
ON THE LONGEVITY OF AMALGAM RESTORATIONS

STUDY AND LOCATION	AGE RANGE (years)	LENGTH OF FOLLOW UP (years)	RESULTS: MEDIAN SURVIVAL TIME = M.S.T. (months)
Hunter 1982	8	20	42
Dental	9 - 11		72
Practice	12 - 14		90
	15 - 17		120
	18 - 20		150
Paterson 1984 Dental Practice	6 - 12	16	66
Walls et al	5 - 6 11/12	12	26
1985	7 - 8 11/12		33
Dental	9 - 10 11/12		77
Hospital	11 - 12 11/12		107
	13 - 14 11/12		77

Table 2.3.

Survival patterns for occlusal restorations in first and second deciduous molars (D's and E's) compared with that for occlusal amalgam restorations in first permanent molars of 5 - 8 year old patients.

	TOOTH	NUMBER OF RESTORATIONS	MEDIAN SURVIVAL TIME (Months)	5 YEAR SURVIVAL RATE %
Holland et al 1986	D's	69	36.9	-
	E's	279	43.9	43
Hunter 1982	6's	57	26.0	32
Walls et al 1985	6's	281	39.0	42

2.2. GLASS POLYALKENOATE (GLASS IONOMER) RESTORATIONS

2.2.1. INTRODUCTION

Glass polyalkenoate (glass ionomer) cement was first described by Wilson and Kent in 1972. The first commercial product ASPA (De Trey Division, Dentsply Limited, Weybridge, United Kingdom) was marketed in 1976 after an improvement in its physical properties (Crisp et al 1975). This cement had physical properties that lay midway between silicates and polycarboxylates, but handling characteristics were not ideal. Nevertheless, ASPA gave satisfactory results when used to restore cervical margin lesions (McLean and Wilson 1977c; Mount and Makinson 1978; Charbeneau and Bozell 1979; Lawrence 1979). However, the reactivity of the aluminosilicate glasses in this early cement was difficult to adjust, resulting in lengthy setting times. This led to problems of high water sorption, solubility and poor wear resistance (McLean et al 1984; Atkinson and Pearson 1985).

The development of glasses that leached ions (ion-leachable) in the presence of aqueous polyacrylic acid copolymers (Wilson and Kent 1972, 1973) heralded the birth of the current generation of glass polyalkenoate cements with enhanced physical and clinical handling properties (Knibbs et al 1986a, b).

2.2.2. CLASSIFICATION AND CHEMICAL COMPOSITION

Glass polyalkenoate dental cements consisting of an ion leachable glass and a polyacid or copolymer may be supplied in powder and liquid form (conventional glass polyalkenoate) or as a powder containing both the glass and freeze dried polymer (water hardening

glass polyalkenoate). Activation occurs on mixing the two components of the conventional type or on addition of water in the water hardening type.

2.2.2.1. THE ION-LEACHABLE GLASS POWDER

This forms the basis of the powder in glass polyalkenoate cements. It is an aluminosilicate glass with a high fluoride content, formed by the fusion of quartz, alumina cryolite, fluorite, aluminium trifluoride and aluminium phosphate (Crisp and Wilson 1976). The glass consists of two phases (Barry et al 1979), a continuous calcium aluminosilicate matrix and partly crystalline droplets rich in calcium fluoride. The nature of the droplets and the final chemical composition of the glass is influenced by the glass fusion temperature. During the early stages of cooling to the glassy state droplets form that are rich in calcium and fluoride. These may be wholly amorphous, totally crystalline (fluorite) or amorphous with a crystalline core. As the fusion temperature is increased the droplet size and degree of crystallisation decreases (Barry et al 1979). Glasses quenched at 1,150°C contain some large irregular inclusions of fluorite, while those quenched at 1,300°C - 1,500°C have smaller fluorite inclusions, relatively more aluminium and less fluorine than lower temperature melts. The changes in composition may be accounted for by 3 mechanisms:

1. At high temperatures, fluorine and silicon are lost by volatilization of SiF_4.
2. Fluorine is lost by hydrolysis of the fluoride by water present in the batch or atmosphere.

3. The sillamanite crucible gains in aluminium oxide and silicon oxide as it is attacked by the melt.

Glasses formed from higher melts are more reactive and as such are unworkable as they set too quickly (Barry et al 1979).

The incorporation of non-matrix-forming inclusions into the glass has been found to improve the physical properties of the set cement. These inclusions are of two types:

1. METALLIC INCLUSIONS

Small metallic particles have been incorporated into the glass during fusion to impart improved physical properties. Such metal reinforced materials have been given the name Cermet cements (Wilson and Prosser 1984; McLean and Gasser 1985a). Any of the precious metals used in dentistry may be used, but gold and silver are the most suitable (McLean and Gasser 1985a). Compressed pellets of the metal-glass powder mixture are fused at around 800°C and the resultant sintered metal-glass composite is then ground to a fine powder. The best results were obtained using pure silver and glass powders of 3.5μm. average particle size. The colour of the cement may be improved by incorporation of up to 5% by weight of titanium dioxide in the glass powder.

2. CRYSTALLINE INCLUSIONS

The inclusion of a variety of dispersed-phase-crystallites in the glass structure has been investigated (Prosser et al 1978). The incorporation of crystallites of corundum, rutile, aluminium titinate and baddelyite within the glass were all found to enhance the flexural strength of the set cement.

2.2.2.2. THE POLY (ALKENOIC ACID)

The first poly (alkenoic acid) used to form glass polyalkenoic cements was a 50% aqueous solution of polyacrylic acid (Fig. 2.1.). Unfortunately, this solution was not ideal as it was viscous, and tended to gel on standing due to the formation of intermolecular hydrogen bonding between polymer chains (McLean and Wilson 1977a). Methylation of some of the carboxyl groups conferred stability, but increased the uptake of stain on the set material surface and reduced its physical properties (Crisp et al 1975, McLean and Wilson 1977a). Copolymers of acrylic and other polyalkenoic acids (e.g., polymaleic acid) were investigated with a view to improving the shelf life and properties of the material (Crisp et al 1980). These resulted in the development of a series of copolymers of acrylic acid with itaconic acids in a molar ratio of 2:1 (Fig. 2.2.), and with some of the alkenoic acids notably maleic and fumaric. The stability of the itaconic acid copolymers with lower viscosity and longer shelf life was attributed to intermolecular binding within itaconic acid units which reduced the incidence of intramolecular hydrogen binding. Prosser et al (1984) considered the lowering of the molecular weight by these copolymers to be detrimental to cement strength, but Crisp et al (1980) considered this to be offset by the greater cross linking potential of the itaconic acid groups. It is these polyacids, in association with vacuum dried poly (acrylic acid) which now form the basis of modern polyalkenoate cements.

The setting characteristics and physical properties of the early cements were improved by the addition of small quantities of the optically active isomers of tartaric acid (Fig. 2.3.) (Wilson et al

Fig 2.1

Polyacrylic Acid.

Fig 2.2

Copolymer of Acrylic and Itaconic Acids.

Fig 2.3

Tartaric Acid.

Fig 2.1

Polyacrylic Acid.

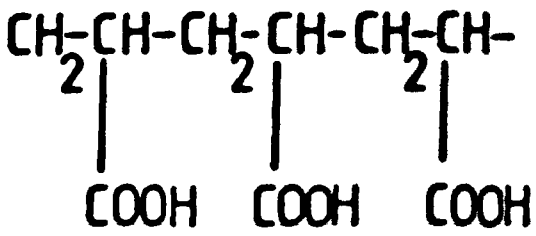


Fig 2.2

Copolymer of Acrylic and Itaconic Acids.

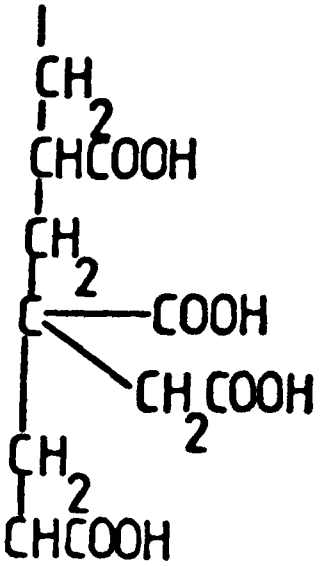
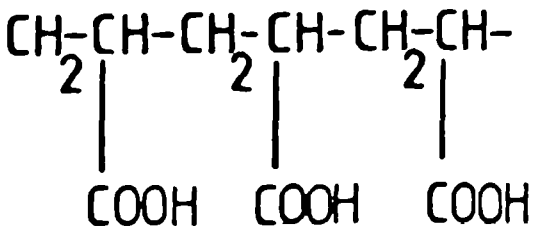
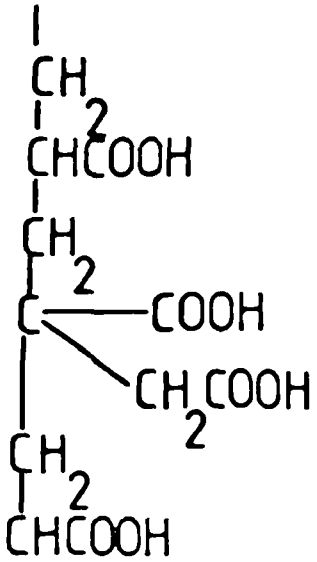


Fig 2.3

Tartaric Acid.





1976). This chelating comonomer is now present in most of the commercially available forms of this material. In addition, the use of poly (maleic acid) in one formulation (Ketac Fil) has sharpened set (McLean 1988). Poly (maleic acid) contains twice as many carboxyl groups as poly (acrylic acid) and is a stronger acid. Ketac Fil is the glass polyalkenoate used in the clinical trial concerning the restoration of deciduous teeth in this thesis.

Recent advances have allowed the preparation of both the glass and polyacid in powder form. Activation of this system is achieved by mixing with either distilled water or an aqueous solution of tartaric acid and are said to have a virtually unlimited shelf life if dry (McLean et al 1984).

2.2.3. THE SETTING REACTION

Glass polyalkenoate cements set as a result of an acid-base reaction between the ion leachable glass and a polyalkenoic acid. Two markedly different cations in the glass (calcium and aluminium) complicate the matrix formation. Three overlapping phases of the reaction may be distinguished (Crisp and Wilson 1974b):

1. The initial acid attack on the glass in which ion leaching occurs (the dissolution phase).
2. A precipitation process resulting in the formation of a salt hydrogel (the gelation phase).
3. Longterm reactions and diffusion processes that continue for many months.

2.2.3.1. THE INITIAL ACID ATTACK

The polyalkenoic acid selectively attacks the outer non crystalline portion of the glass which is rich in calcium. The calcium ion concentration of the cement sol rises much more rapidly than the aluminium ion concentration which is released from the inner continuous phase of the glass. During the early stages of the setting reaction, the polyacrylic acid chains unwind from a tight ball to adopt a more linear format which allows far much greater access to the carboxylic groups by the metallic ions.

2.2.3.2. THE FORMATION OF THE SALT HYDROGEL

The liberation of cations from the glass is facilitated by the addition of chelating agents such as D-tartaric acid (Wilson et al 1986). The metallic cations liberated may be precipitated as insoluble salts such as fluorides, phosphates or fluorophosphates, or alternatively as salts with polyacrylic acid (Fig. 2.4.). These salts act as bridges between the polymer chains and contribute to binding the matrix into a salt hydrogel.

In the early stages of the reaction, the calcium salt alone is formed and this corresponds to gelation and the initial set of the material (Crisp et al 1974). Final hardening occurs as the aluminium salt is formed. D-tartaric acid forms chelate bridges between aluminium ions which act as flexible bridge structures linking the polyanion chains together (Fig. 2.5.) (Wilson et al 1976). The initial set of the material is rapid, forming a hard cement within 10 minutes from the start of mixing. However, these divalent linkages are not stable and setting thus continues within the apparently hard

Fig 2.4

Salts formed between metal ions (M) and polyacrylic acid.

a) Pendant half salt.

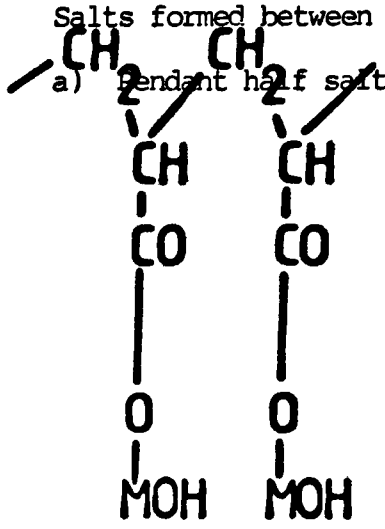
b) Inter and Intraionic di-salts.

c) Cross chain di-salt.

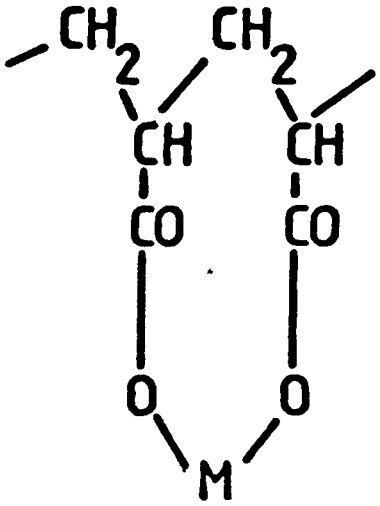
Fig 2.4

Salts formed between metal ions (M) and polyacrylic acid.

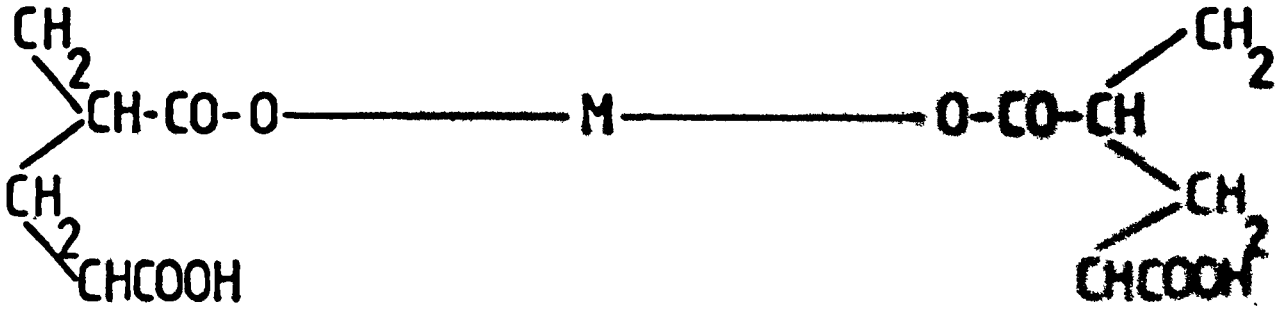
a) Pendant half salt.

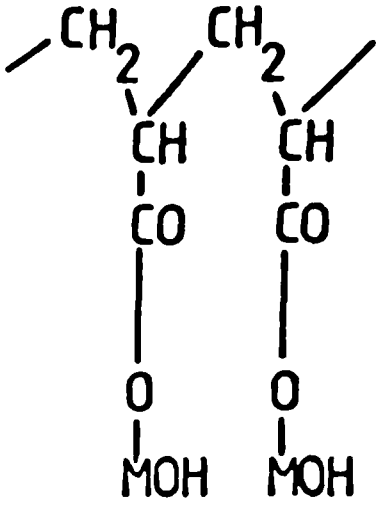


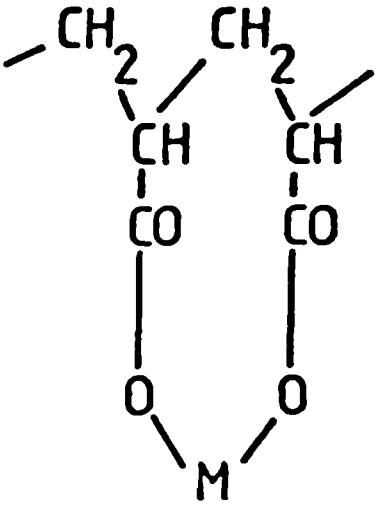
b) Inter and Intraionic di-salts.



c) Cross chain di-salt.




CH2
CH2
CH
CH
CO
CO
O
O
MOH
MOH


CH2
CH2
CH
CH
CO
CO
O
O
M

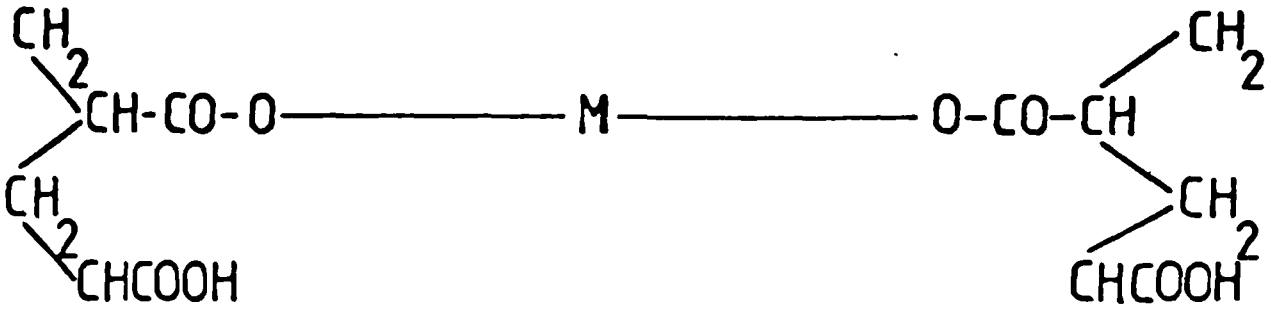
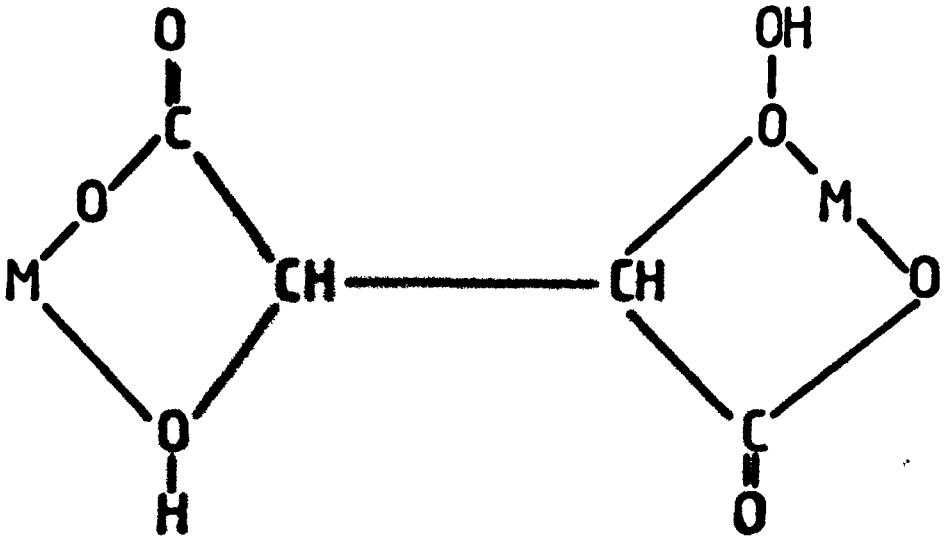

CH2
CH-CO-O
M
O-CO-CH
CH2
CH2
CHCOOH
CH2
CHCOOH

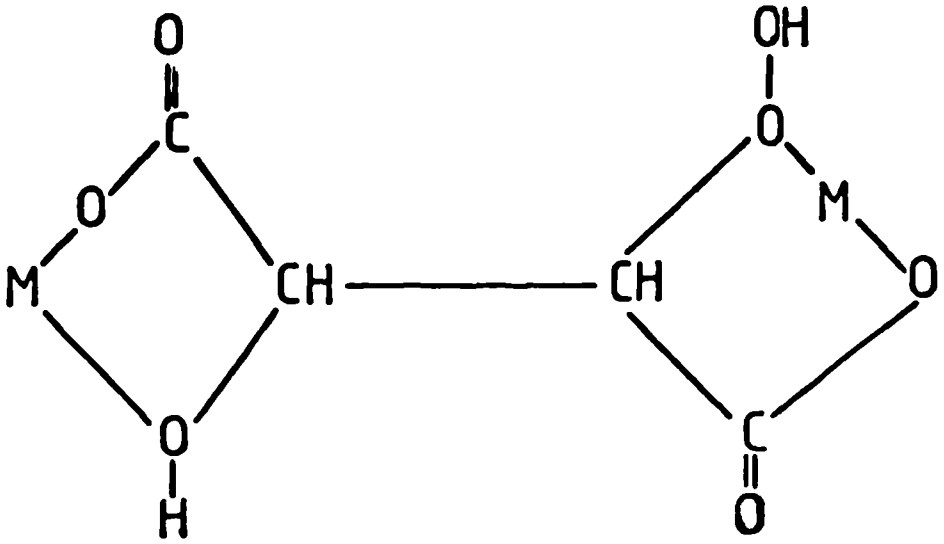
Fig 2.5

Tartaric Acid flexible bridge.

Fig 2.5

Tartaric Acid flexible bridge.




O
C
O
M
CH
O
H
CH
OH
O
M
O
C
O

mass with further cross linking by the less mobile trivalent aluminium ions. This second phase of setting produces a dramatic rise in the physical properties of the cement and results in a stable hard brittle material with a highly cross linked polyacid salt matrix.

2.2.4. THE MICROSTRUCTURE OF THE SET MATERIAL

The microstructure has been described as resembling that of a composite material consisting of particles of unreacted glass surrounded by a siliceous hydrogel matrix (McLean and Wilson 1977a; Barry et al 1979). The glass grains consist of a distinct outer layer (the zone attacked by the polyacrylic acid), and an unreacted glassy core. They contain calcium, aluminium and silicon, whereas the salt hydrogel matrix contains only aluminium and calcium as major constituents. Some areas of siliceous hydrogel without a glassy core may be detectable in the matrix. These areas represent small glass particles that have been completely degraded by the polyacid. A diagrammatic representation of the structure is shown in Fig. 2.6.

2.2.5. THE LONGEVITY OF GLASS POLYALKENOATE RESTORATIONS

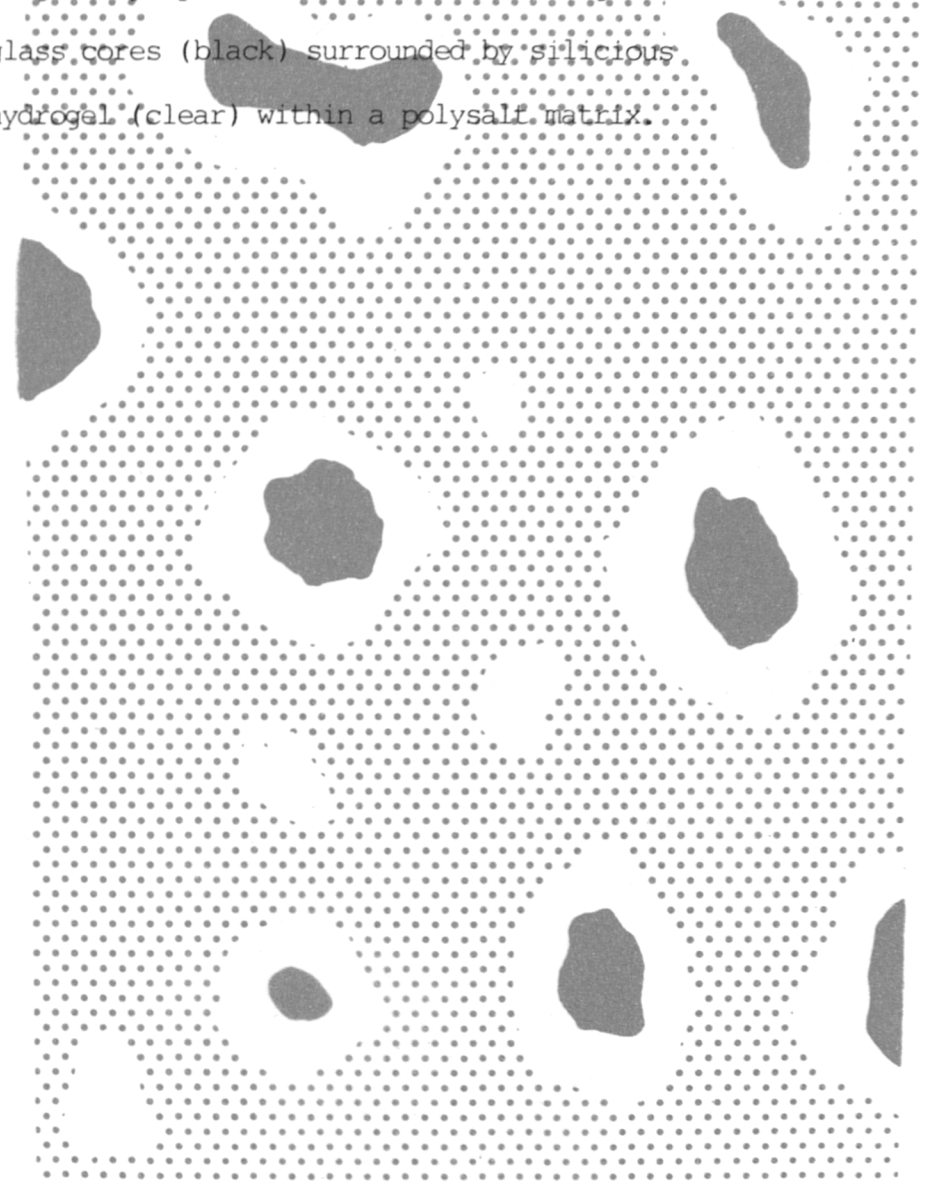
Polyalkenoate cements are satisfactory for use in Class III and V cavities in the permanent dentition (Smales 1981; Osborne et al 1985; Matis and Phillips 1986; Knibbs 1986b and d; and Mount 1986), and Class I and Class II cavities in the deciduous dentition (Plant et al 1977; Vleistra et al 1978; Knibbs et al 1986a; and Walls et al 1988). However, their use in the permanent dentition as Class II restorations is not advisable due to a high failure rate in such cavities (Knight 1984) and as both Class I and Class II restoratives due to poor wear resistance (Smales 1987; Knight 1984).

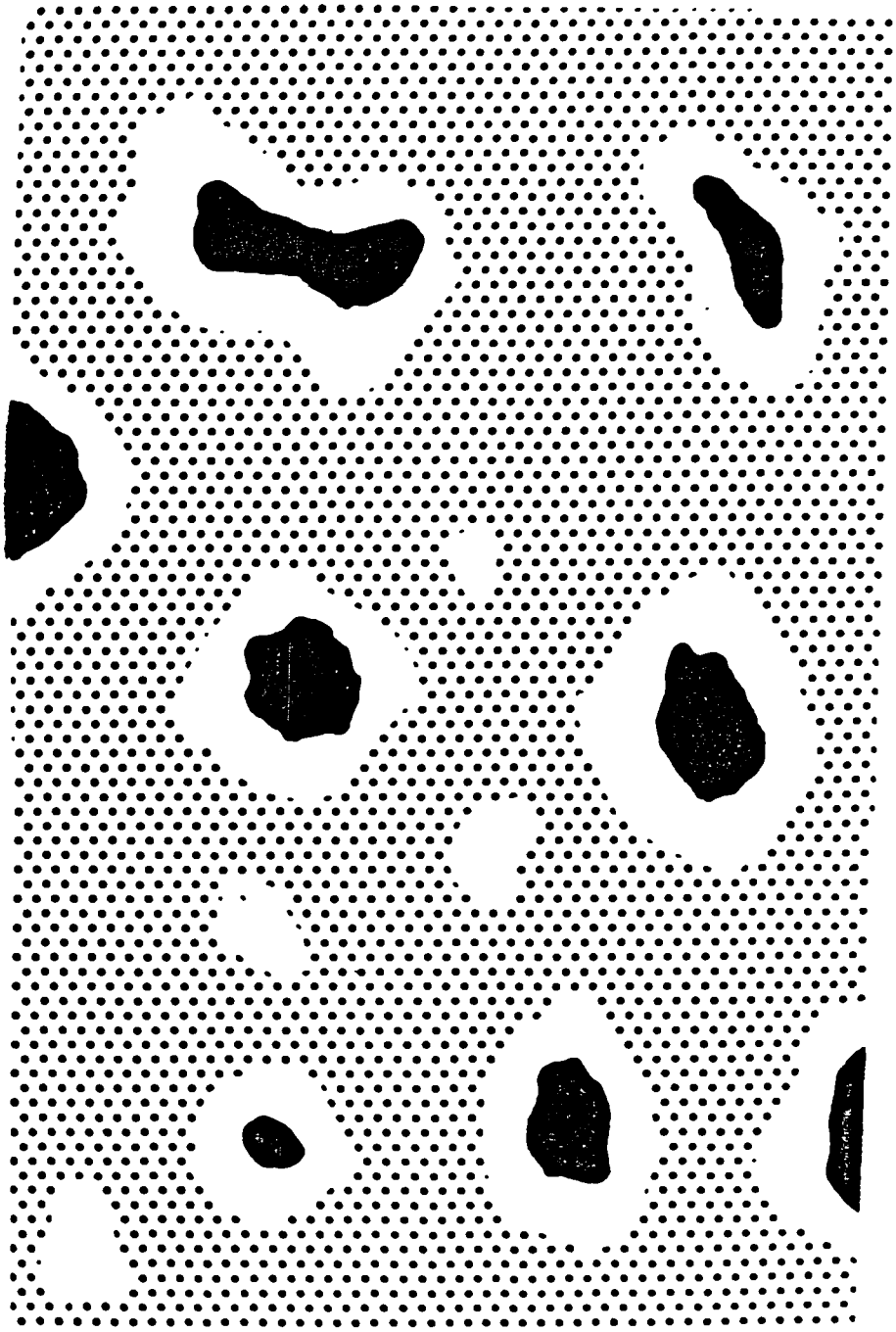
Fig 2.6

Diagrammatic representation of the set structure of glass polyalkenoate cement featuring unreacted glass cores (black) surrounded by silicious hydrogel (clear) within a polysalt matrix.

Fig 2.6

Diagrammatic representation of the set structure of glass polyalkenoate cement featuring unreacted glass cores (black) surrounded by silicious hydrogel (clear) within a polysalt matrix.





2.2.5.1. THE PERMANENT DENTITION

1. THE CLASS III CAVITY

Polyalkenoate cements offer a satisfactory alternative to composite resins in the restoration of Class III cavities, but on occasions their relative opacity may lead to difficulty in achieving an aesthetically satisfactory result, especially in extensive cavities (Mount and Makinson 1978; Saito 1979). In the last decade, a number of clinical trials have been published (Table 2.4.) which quote survival rates of restorations. Mount and Makinson (1978) reported no failures after 12 months in 13 restorations and in 3 studies Knibbs et al (1986a, b, c) reported failure rates of 0 - 12% after a maximum of 2 years in service. Osborne et al (1986) at a 2 year evaluation of 72 restorations reported no failures and no change in colour match, anatomic form and marginal adaption from baseline, but they did find a non-significant increase in marginal discolouration for glass polyalkenoates [Chelon (ESPE) and Ketac Fil (ESPE)] in comparison to composite resin [Adaptic (Johnson and Johnson)] restorations. However, in the 3 year clinical evaluation of these restorations (Osborne et al 1987), the glass polyalkenoate cements had a statistically significant increase in the amount of staining and marginal breakdown. Adaptic restorations also increased in these 2 categories, but not significantly. In a slightly longer review period, Knibbs et al (1986d) reported on 332 Class III glass polyalkenoate restorations reviewed over 42 months. The cumulative percentage of clinical failure was 5.4%, and it was concluded that glass polyalkenoate cement is a suitable material to restore Class III cavities. However, the authors added that it was not ideal with regard to abrasion resistance and translucency, but it

did compare favourably with alternative restorative materials for us in the Class III situation. Mount (1986) in the longest review period of all (6 years) reported survival rates for ASPA, Fuji II and Ketac Fil of 92, 100 and 99.5%.

TABLE 2.4.

SURVIVAL RATES FOR CLASS III RESTORATIONS IN THE PERMANENT DENTITION

AUTHOR	NUMBER OF RESTORATIONS	SURVIVAL RATE (PERCENTAGE)
Mount & Makinson 1978	13	100 at 12 months
Knibbs et al 1986a	275	97 at 7 months
Knibbs et al 1986b	74	88 at 24 months
Knibbs et al 1986c	41	100 at 12 months
Osborne et al 1986	72	100 at 24 months
Knibbs et al 1986d	332	94.6 at 42 months
Ngo et al 1986	30	97 at 12 - 24 months
Mount 1986	38	92 at 72 months
	54	100 at 72 months
	374	374 at 72 months

2. THE CLASS V CAVITY

The polyalkenoates offer considerable improvement aesthetically over amalgam and gold and their intrinsic adhesive properties giving a bond to dentine and cementum are an advantage over composite resins in the Class V situation.

In the last decade, a number of clinical trials have been published (Table 2.5.). The number of restorations and their survival rates after a specific length of time are shown. A survived restoration was one that was deemed clinically acceptable and rates of 75 - 99%, after lengths of service between 6 months and 6 years were found. A number of restorations placed in saucer-shaped erosion cavities which had been finished to a knife edge were noted to have small marginal fractures, but these were usually amenable to refinishing and this was always done when a ledge was in association with mild gingival inflammation. A generalised loss of polyalkenoate material with time, related to its low abrasion resistance and the ability to stain both on abraded surfaces and at small marginal fractures was recognised. Poor colour match to an adjacent tooth tissue was universally recognised, this being due to the inherent opacity and relative lack of translucency of the polyalkenoate cement, but most of the colour discrepancies were present at restoration placement and had not changed in the interim period. Recurrent caries and tooth symptoms after restoration placement were reported on only a couple of occasions. One study (Smales 1981) reported a failure rate of 71:8% after 3 years' service, but this was attributed to the material's lack of abuse tolerance, inadequate clinical instructions from the manufacturer and lack of experience in its use by the operators.

TABLE 2.5.

SURVIVIAL FOR CLASS V RESTORATIONS IN THE PERMANENT DENTITION

AUTHOR	NUMBER OF RESTORTIONS	SURVIVAL RATE (PERCENTAGE)
McLean & Wilson 1977	90	91 at 36 months
Mount & Makinson 1978	102	99.2 at 12 months
Charbeneau 1979	113	95 at 6 months
Lawrence 1979	175	90.6 at 6 months
Low 1981	189	86.2 at 6 - 15 months
Smales 1981	99	28.2 at 36 months
Tyas 1983	44	95 at 6 months
Brandau et al 1984	84	75 at 48 - 60 months
Tyas & Beach 1985	100	92 at 24 months
Knibbs et al 1986a	466	98 at 7 months
Knibbs et al 1986b	165	95.5 at 24 months
Knibbs et al 1986c	57	98.2 at 12 months
Ngo et al 1986	78	95 at 12 - 24 months
Mount 1986	328	85 at 72 months
	246	96 at 72 months
	802	98 at 72 months
Knibbs 1987	142	93.5 at 16 months

McLean and Wilson (1977c) reported that the majority of their failures occurred within 6 months and this they attributed to early mechanical fracture or lack of adhesion. However, this point of view was not shared by Brandau et al (1984), who found that most of their failures occurred between 24 - 54 months. Whilst stringent measures to control water contamination both during placement and subsequent setting is vital to immediate survival, other factors including oral hygiene and toothbrushing technique are probably relevant to longer survival.

Class V erosion cavities have been restored both with prepared margins (McLean and Wilson 1977; Ngo et al 1986; Knibbs 1987) and without any mechanical preparation (Mount and Makinson 1978; Charbeneau 1979; Lawrence 1979; Low 1981; Tyas 1983; Brandau 1984; Ngo et al 1986). A comparison of these studies in Table 2.5. reveals no difference in retention rates. One author (Knibbs 1986a) compared retention rates after 7 months' service in a controlled trial between prepared margins and unprepared margins and found no difference.

2.2.5.2. THE DECIDUOUS DENTITION

Restorative procedures constitute a major proportion of clinical paedodontic practice, especially in non-fluoridated areas (Klein et al 1981). Dental amalgam was the dominant restorative material until the 1980's when a new generation of glass polyalkenoate cements became commercially available. These can now be used in clinical practice in the National Health Service for Class I and Class II restorations in deciduous molars.

The main reasons for amalgam failure in Class II cavities are isthmus fracture and proximal marginal defects (McRae et al 1962).

Marginal leakage may be reduced to a certain extent by proper selection of the alloy and the application of a copalite varnish (Cothren et al 1978; Osborne et al 1980), but it would be ideal to have a restorative material with adhesive properties, to eventually eliminate this problem. Other important advantages in using a material with adhesive properties in the young child are that: cavity preparation would involve removal of less sound tooth tissue, a shorter period in the dental chair would be required, and local anaesthesia may not be necessary.

McLean and Wilson (1977b) give some general guidelines for the use of glass polyalkenoate restorations in the deciduous dentition. They advise that it is essential to provide bulk for the restoration and that shallow keyways and narrow isthmuses should be avoided. They also state some mechanical retention may be required for large restorations. The need for bulk in the restoration was re-emphasised by Saito (1979) who felt that polyalkenoate cements were difficult to use in the deciduous dentition due to the need for protection of the cement surface from moisture contamination for some time after placement.

Very few clinical trials have been reported using glass polyalkenoate cements in the deciduous dentition. Plant et al (1977) and Vliestra et al (1978) reported on a general practitioner trial of ASPA cement as a restorative material in the deciduous dentition. They also described a modification to conventional cavity design without any undercuts and with a chamfered margin for use on areas of 'low occlusal stress'. 75% Of their restorations were intact 1 year after placement, of which 90% had 'fair to good' marginal adaptation,

contour and surface finish. There was no difference between the modified and conventional cavity designs.

Kullman and Freers (1984) compared the performances of Ketac-Fil with Dispersalloy a non gamma-2-amalgam, and found no significant differences in clinical behaviour after 6 months in 13 paired Class I and 26 paired Class II cavities.

Fuks et al (1984) assessed 101 Class II restorations with GC Fuji Ionomer Type II 12 months after placement under rubber dam and found that only 9% met all criteria. The study was originally designed to be a matched pair study using amalgam as the homologous contralateral control but, due to the 67.3% failure after 6 months of the glass ionomer, this was discontinued. However, three years after placement, 90% of the amalgam restorations met all standards. The authors did not recommend polyalkenoate cement for restoration of Class II cavities in deciduous molars.

However, the conclusions of another trial (Knibbs et al 1986a) employing a different cement (Chemfil) were that the material can be satisfactorily used for the restoration of Class I and Class II cavities in deciduous teeth. Of 62 restorations assessed after 7 months, the failure rate was 8%. Restorations in this trial were often placed without use of local anaesthetic or a matrix band.

Walls et al (1988) reported 23 month results of a clinical trial involving Ketac Fil in Class II cavities using amalgam (Amalcap) as the homolgous contralateral control. Of 117 restorations placed there were very few failures and no differences in failure rate between the two materials, or in the rate of loss of marginal integrity between the materials. However, the glass polyalkenoate cement restorations underwent greater loss of anatomical form during

the early stages of the follow-up than the amalgam restorations.

Most recently Hassan and Nathanson (1988) reported that in occlusal cavities in primary molars Ketac Fil was performing similarly to Ful-Fil composite after 1 year.

2.2.5.3. CLINICAL TRIALS USING KETAC FIL GLASS POLYALKENOATE CEMENT

The published clinical trials utilising the glass polyalkenoate cement Ketac Fil in both the permanent and deciduous dentitions are shown in Table 2.6. Survival percentages where stated have been shown in Tables. 2.4. and 2.5., but Table 2.6. includes the assessment criteria used by each author(s) and also the principal findings other than survival from these studies.

TABLE 2.6.

Published clinical trials involving Ketac Fil.

AUTHOR(S)	DURATION	TEST MATERIALS	CAVITY	ASSESSMENT CRITERIA	PRINCIPAL FINDINGS
Osborne et al (1985, 1986, 1987)	3 year report	Ketac Fil, Chelon Adaptic (control) 66 restorations each at 3 years	Class III permanent dentition	USPHS SEM of replicas	At 1 and 2 years no changes in base-line USPHS ratings At 3 years both glass ionomers displayed marginal breakdown
Matis and Philips (1986)	2 year report	Ketac Fil, Chelon Crevident (composite). Number not stated	Class V permanent dentition	Retention anatomic form and marginal adaptation	Significantly better retention was demonstrated by the glass ionomers. No other significant findings
Mount (1986)	6 year report	ASPA (38 III) (328 V) Fuji II (54 III) (246 V) Ketac-Fil (374 III) (802 V)	Class III and V permanent dentition	Retrospective analysis	Ketac-Fil lowest number of failures compared to ASPA (and Fuji. Attributed to a higher powder: liquid ratio due to proportioning and mechanical mixing

Hassan and Nathanson (1988)	1 year report	Ketac-Fil compared to Fulfil (composite)	Class I permanent and deciduous dentition	USPHS modified criteria SEM analysis of replicas	No difference in performance
Walls et al (1988)	2 year report	Ketac-Fil Amalcap (control) 54 pairs	Class I Class II deciduous dentition	Modified USPHS	Ketac-Fil no worse than amalgam after up to 24 months in service

4.2.2. COMPOSITE RESIN RESTORATIONS

4.2.3.1. INTRODUCTION

A composite has been defined as "A combination of two chemically different materials with a distinct interface separating the components and having properties which could not be achieved by any one of the components acting alone".

(Bowen et al 1972)

The development of restorative materials based on synthetic polymers was initiated for 2 major reasons. Firstly, a material was required that would overcome the major deficiencies of the silicate materials, namely erosion, brittleness, acidity and moisture sensitivity which demanded very careful manipulation, and secondly, advances in polymer technology produced resins that could be cured easily at mouth temperature, and with the aid of pigments and fillers, these could be made to resemble the natural tooth in appearance. The first materials used were the unfilled acrylic resins based on Methyl Methacrylate, but these were superceded by 'composite' materials consisting of a heterogeneous blend of organic resin, inorganic filler, and coupling agent (Bowen 1963, 1964, 1965). The addition of reinforcing fillers to resins can have significant effects on their properties, depending on the type, shape, size and amount of filler incorporated and the existance of efficient coupling between the filler and resin.

2.3.2. COMPOSITION

Dental composites consist of 2 phases, the matrix and a dispersed filler, with a distinct interface separating them.

2.3.2.1. THE MATRIX

1. RESINS

The nature of the resin may alter slightly from one product to another but, essentially, they all contain a modified difunctional methacrylate or acrylate and each carbon-carbon double bond is able to take part in a free radical addition polymerisation, to give a highly cross-linked resin after setting (Fig. 2.7.). On polymerisation, the large size of these molecules reduces with polymerisation contraction and cross-linking, thus enhancing the chemical resistance of the set resin.

Addition of a second lower molecular weight difunctional acrylate such as BIS-MA (Fig. 2.8.) may be required to give more rigidity and scratch resistance to the final product (Craig 1981).

2. VISCOSITY CONTROLLERS

Low viscosity diacrylate are often used as diluents to reduce the viscosities of highly viscous and difficult to handle diacrylates. Such diluents include Ethyleneglycol Dimethacrylate (EDMA), Triethleneglycol Dimethacrylate (TEGDMA) (Fig. 2.9.), and Methyl Methacrylate (MMA) (T.E.G.D.M.A. being the most widely used).

Fig 2.7

Molecular structures of three modified methacrylate or acrylate resin monomers used in composite materials.

a. BIS-GMA addition product of Bispherol A and glycidylmethacrylate. 2, 2 bis 4 (2 hydroxy 3 methacryloxypropyloxy) phenyl propane.

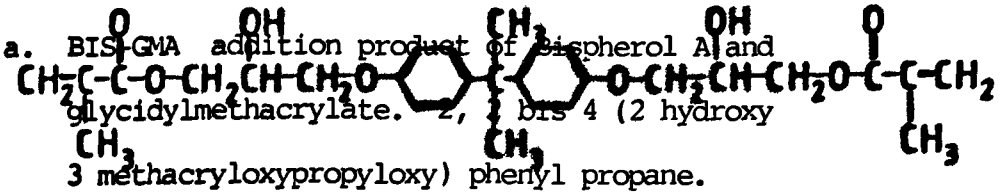
b. Urethanediacrylate.

c. Triethyleneglycoldimethacrylate.

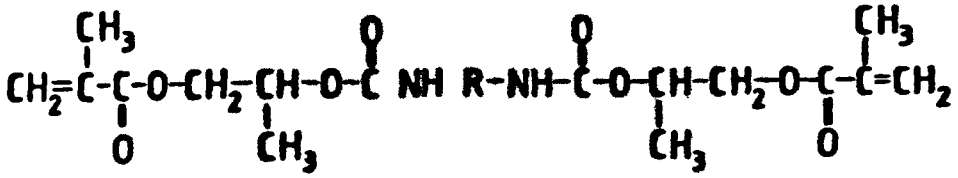
Fig 2.7

Molecular structures of three modified methacrylate or acrylate resin monomers used in composite materials.

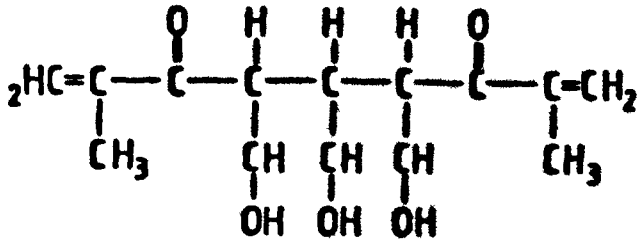
a. BIS-GMA addition product of bispherol A and glycidylmethacrylate. 2, 2 bis 4 (2 hydroxy 3 methacryloxypropyloxy) phenyl propane.

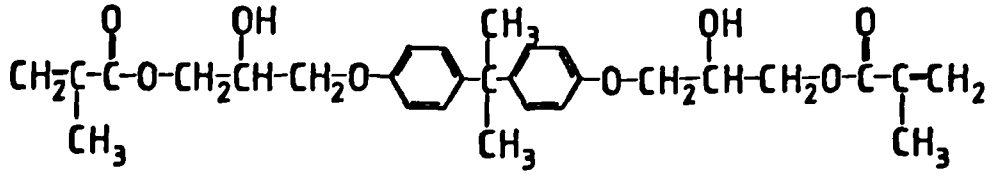


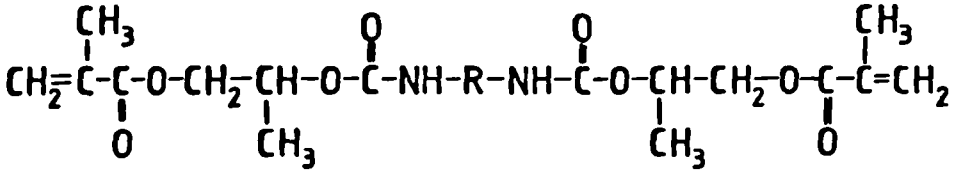
b. Urethanediacrylate.



c. Triethyleneglycoldimethacrylate.







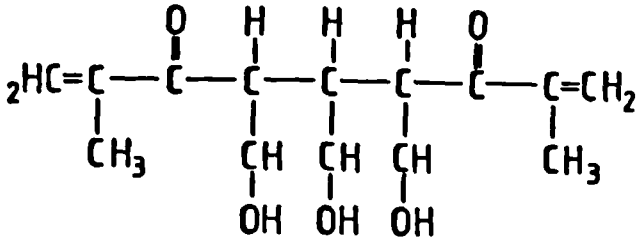


Fig 2.8

Bis-MA difunctional acrylate. 2, 2-bis (4 methocryloyloxy-phenyl) propane.

Fig 2.9

TEGDMA Triethyleneglycoldimethacrylate.

Fig 2.8

Bis-MA difunctional acrylate. 2, 2-bis (4 methocryloyloxy-phenyl) propane.

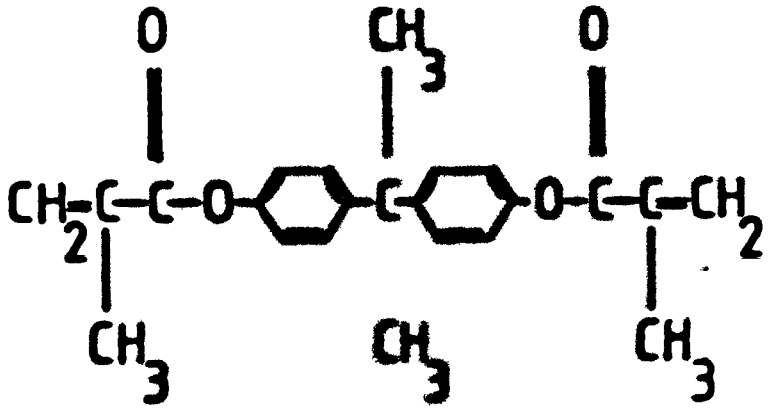
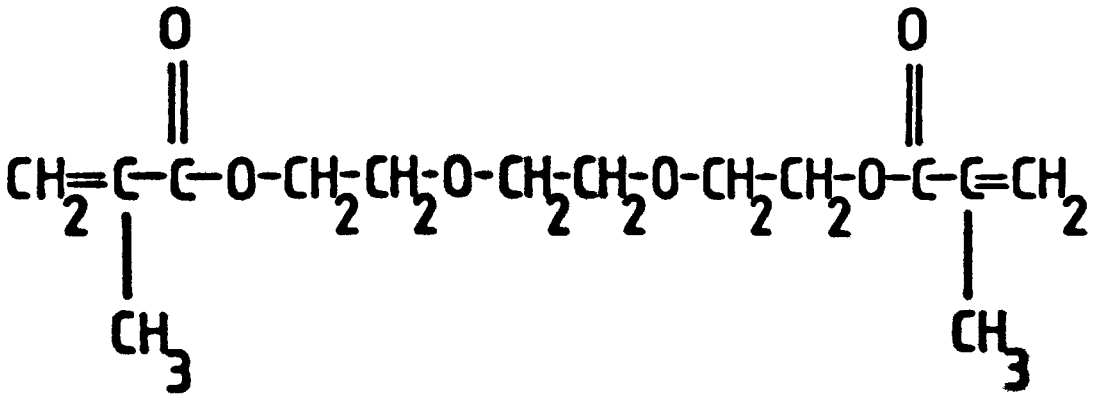
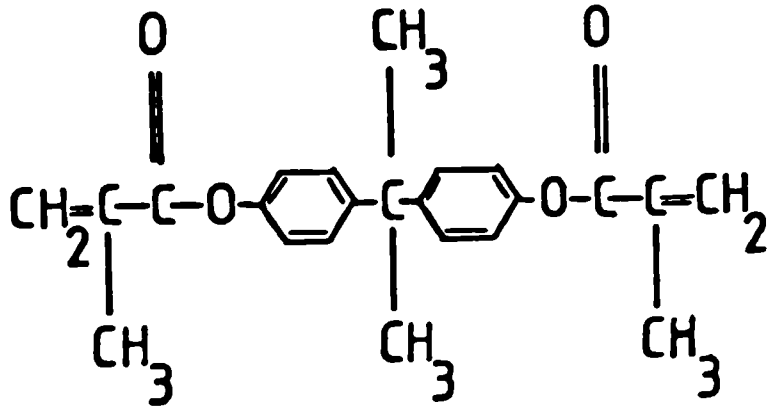
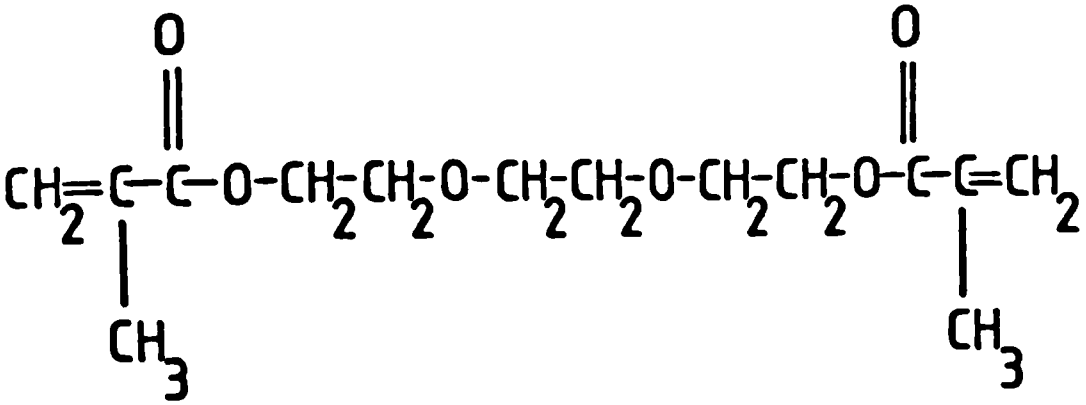


Fig 2.9

TEGDMA Triethyleneglycoldimethacrylate.







3. INITIATOR

Polymerisation of the resin matrix is by free radicals generated by chemical or light mechanisms. The most common chemical initiator is Benzoyl Peroxide (Fig. 2.10.). The Tertiary aromatic amines such as N N-Dihydroxyethyl-p-Toluidine or N N-Dimethyl-p-Toluidine (Fig. 2.11.)[1] interact with Benzoyl Peroxide[1] at room temperature to initiate matrix polymerisation.

Alternatively, initiation can be by an external ultraviolet or visible light source. The use of ultraviolet activated materials has diminished greatly since the possible dangers of longterm exposure to ultraviolet radiation were highlighted. The initiator system in light-activated systems comprises a mixture of a diketone and an amine. Camphorquinone (Fig. 2.12.) is a commonly used diketone which rapidly forms free radicals in the presence of an amine and radiation of the correct wavelength and intensity.

4. INHIBITORS

These extend the shelf life and working time of the material and are included due to the instability of chemical initiators which would result in premature polymerisation, e.g., PMP and BHT (Fig. 2.13.).

2.3.2.2. THE FILLER CONTENT

The type, concentration, particle size and particle size distribution of the filler used in a composite material are major factors controlling properties. Composite resins can be classified into 3 major groups.

Fig 2.10

Generation of free radicals from Benzoyl Peroxide.

Fig 2.11

Tertiary aromatic amines a) N,N dihydroxyethyl - p - toluidine

b) N,N dimethyl - p - toluidine

Fig 2.10

Generation of free radicals from Benzoyl Peroxide.

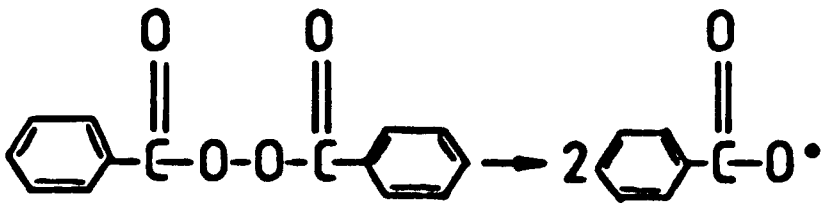
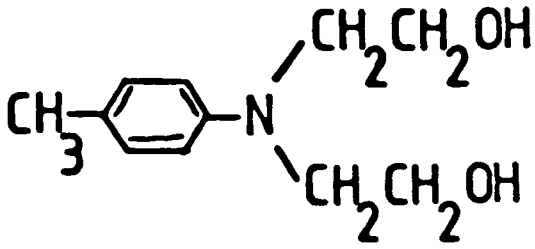
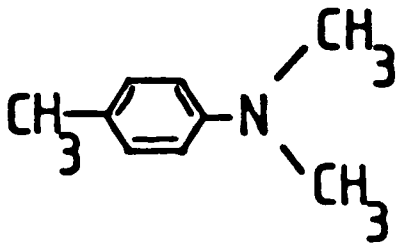


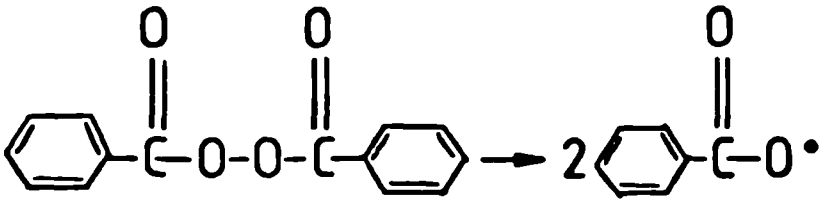
Fig 2.11

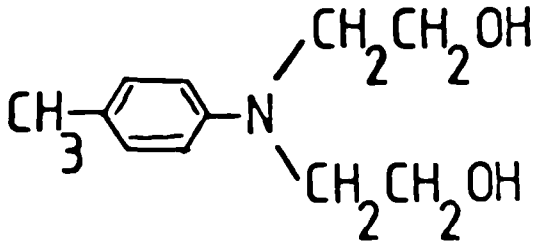
Tertiary aromatic amines a) N,N dihydroxyethyl - p - toluidine



b) N,N dimethyl - p - toluidine







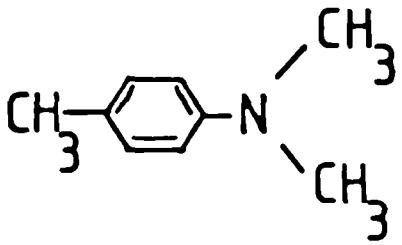


Fig 2.12

Camphorquinone diketone.

Fig 2.13

Inhibitors

a) PMP 4 - p - methoxyphenol

b) BHT 2.4.6 - tritertiary butyl phenol

Fig 2.12

Camphorquinone diketone.

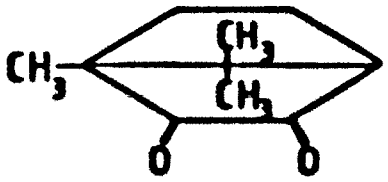
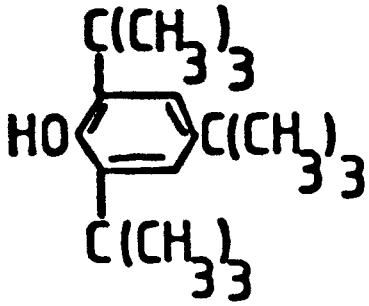


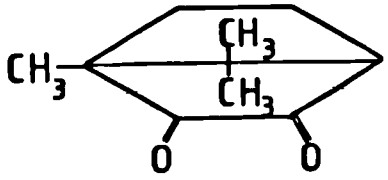
Fig 2.13

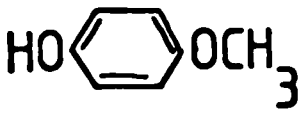
Inhibitors

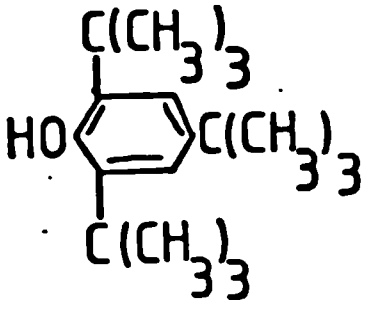
a) PMP 4 - p - methoxyphenol

b) BHT 2.4.6 - tritertiary butyl phenol




CH3
CH3
CH3
O
O


HO
OCH3


C(CH3)3
HO
C(CH3)3
C(CH3)3

1. MACROFILLED RESINS (TRADITIONAL COMPOSITE)

These materials contain mill ground particles of quartz and/or glass as filler. The particles are sharp, irregular and solid, with a random size distribution range from 1 to 100 μm., with a relatively high proportion of particless less than 40 μm. (Draughn and Harrison 1978). However, currently marketed macrofilled resins rarely have particles greater than 30 μm. (Jordan et al 1986). The particles are randomly distributed within the organic matrix, and are interspersed with matrix resin (2.14.). Available products contain 60 - 80% by weight of filler. Some macrofilled resins have been produced with geometric filler forms in addition to ground material, without any apparent increase in mechanical properties, and some decrease in abrasion resistance (Macchi and Craig 1969, Draughn and Harrison 1978) during in-vitro testing. Jordan et al (1986) further subdivides this category according to the size of the macrofiller.

(i) Small particle macrofilled systems in which the size of the inorganic filler particles is between 1 and 8 μm. Such materials may be finished to a smooth topography, but the surface is duller and less reflective than is observed with microfilled materials. They are regarded as semi-polishable.

(ii) Large particle macrofilled systems in which the inorganic filler particle is greater than 10 μm. These are essentially non-polishable.

Fig 2.14

Traditional composite: organic matrix & macrofillers.

Fig 2.15

Homogeneous microfilled composite.

Fig 2.14

Traditional composite: organic matrix & macrofillers.

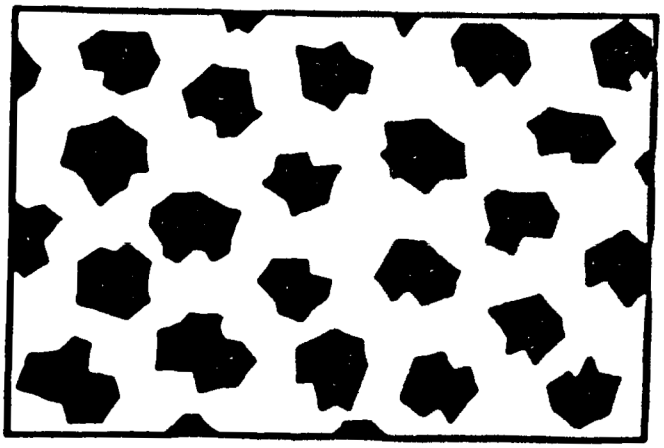
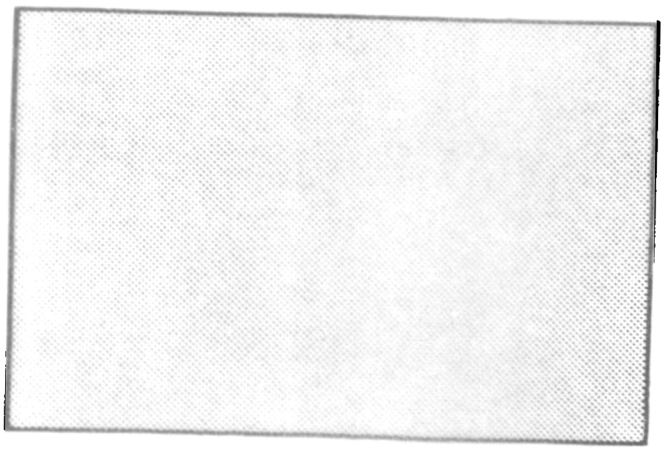
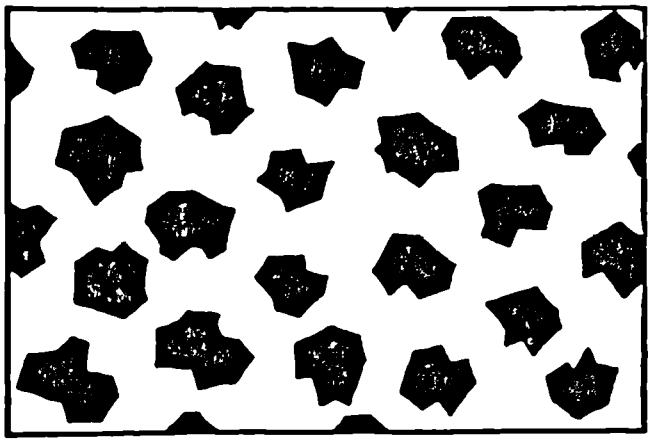
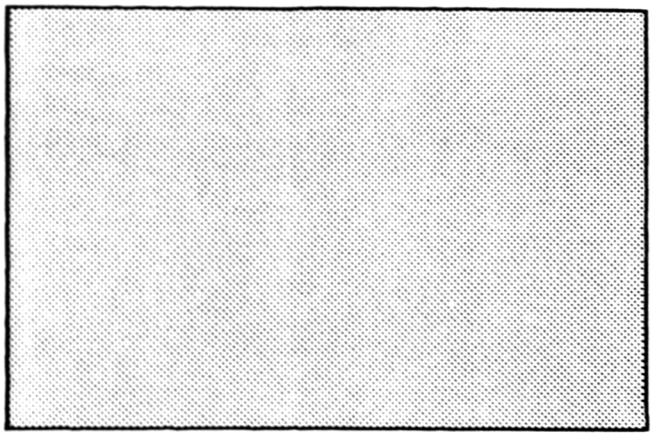


Fig 2.15

Homogeneous microfilled composite.







2. MICROFILLED RESINS

The large surface area of the pyrogenic silica particles (0.01 - 0.1 μm., mean diameter 0.04 μm.) utilised in microfilled resins, produces a material with very high viscosity at low filler loadings. Thus, although it is theoretically possible to produce a resin with homogeneously dispersed microfiller particles, a material of this type would either be unacceptably viscous, or have too little filler. Therefore, products contain only 30 - 60%, by weight of filler. Lutz et al (1983) have further subdivided this category according to the distribution of filler within the resin matrix.

(i) Homogeneous microfilled composites which contain particles of equal size with a maximum size of 0.04 μm. (Fig. 2.15.). The small filler particles present a large surface area to the resin matrix so limiting maximum filler loadings.

(ii) Inhomogeneous microfilled composites contain particles of different shape and size. They may be splintered prepolymerised complexes (ground up complexes), spherical prepolymerised complexes or agglomerated microfiller complexes (Fig. 2.16.). These microfilled complexes allow an increased filler loading.

3. HYBRID RESINS

In an endeavour to retain the excellent surface 'polishability' of the microfilled materials, in a composite with similar physical properties to the macrofilled resins, microfillers

Fig 2.16

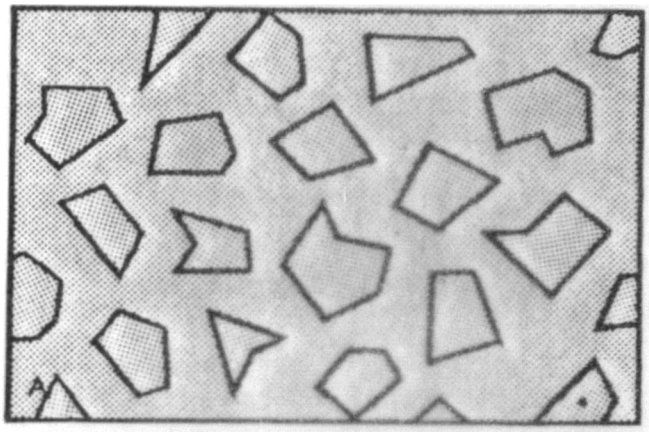
A. Inhomogeneous microfilled composite with splintered prepolymerised particles: organic matrix & microfillers & splintered prepolymerised microfilled complexes.

B. Inhomogeneous microfilled composite with splintered prepolymerised particles: organic matrix & microfillers & spherical polymer-based microfilled complexes.

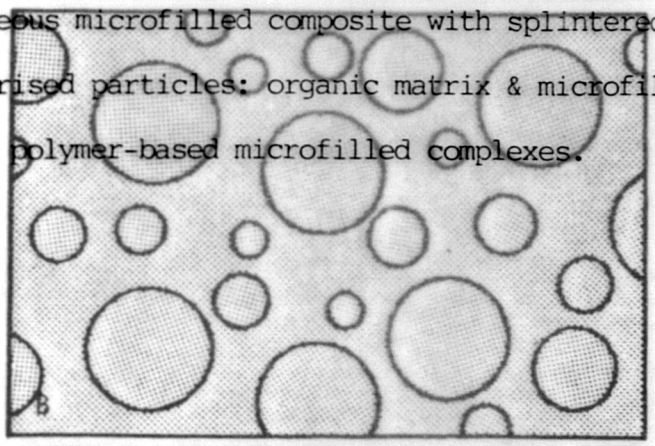
C. Inhomogeneous microfilled complexes with agglomerated microfiller complexes: organic matrix & microfillers & agglomerated microfiller complexes.

Fig 2.16

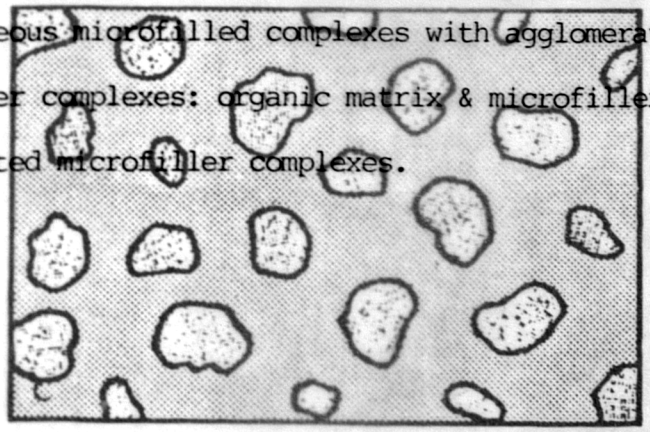
A. Inhomogeneous microfilled composite with splintered prepolymerised particles: organic matrix & microfillers & splintered prepolymerised microfilled complexes.

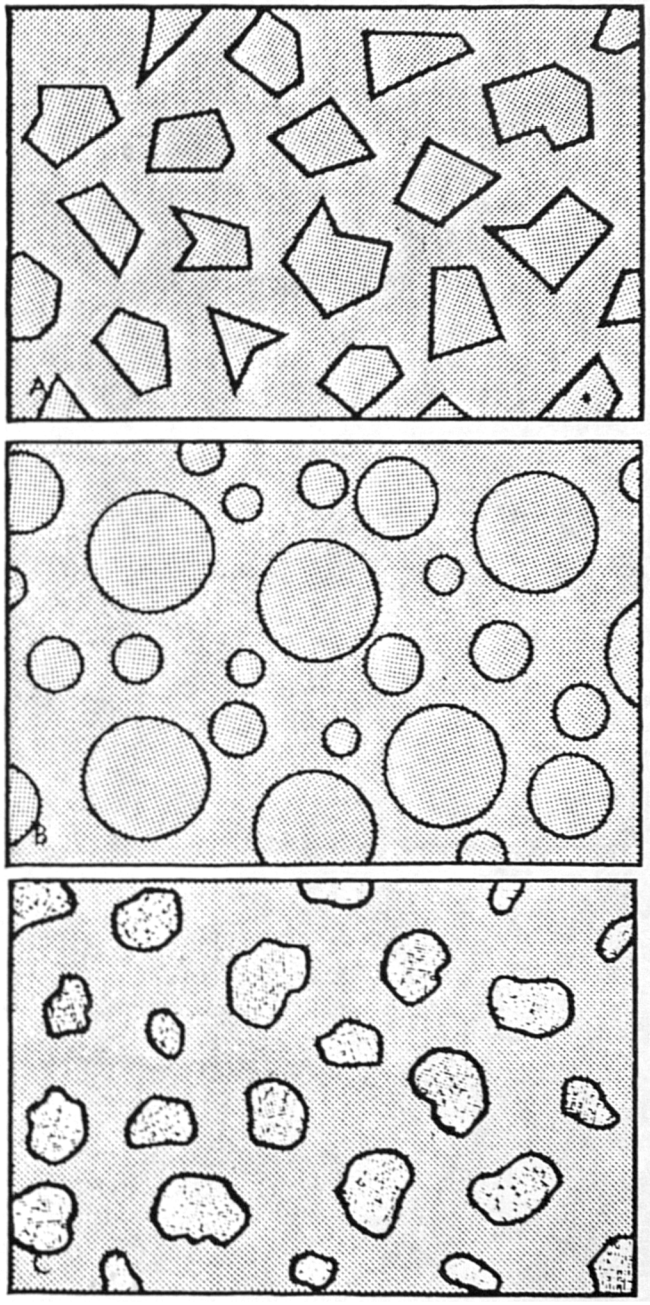


B. Inhomogeneous microfilled composite with splintered prepolymerised particles: organic matrix & microfillers & spherical polymer-based microfilled complexes.



C. Inhomogeneous microfilled complexes with agglomerated microfiller complexes: organic matrix & microfillers & agglomerated microfiller complexes.




A
B
C

have been mixed with conventional macrofillers - with relatively low mean particle size - to produce the hybrid group of materials. Using filler loadings of about 75% conventional size (1 - 50 μm.) and 8% submicron size (0.40 μm. average) a total filler content of 83% or more can be achieved. The use of relatively large and very small filler particles gives scope for the development of sophisticated particle size distributions within the filler to give optimal particle packing. The majority of hybrid composites simply consist of conventional macrofillers within the same resin matrix. In addition, some of the materials also contain splintered prepolymerised microfilled particles or microfiller agglomerates similar to those found in the inhomogeneous microfilled resins (Lutz et al 1983) (Fig. 2.17.).

2.3.2.3. THE INTERFACE

A good bond is paramount between polymer matrix and inorganic filler so that stresses generated under loading in the mouth can be transferred from the rigid and brittle filler to the more flexible and ductile polymer matrix. The most common coupling agent that reacts with the resin and attaches to the inorganic filler is - Methacryloxypropyl Trimethoxysilane (Fig. 2.18.). The coupling mechanism may involve hydrolysis of the methoxy groups of the resin matrix with silanol or aluminol groups of the coupling agent, or with bound surface water on the reinforcing filler. On polymerisation, the methacrylate group is incorporated into the resin matrix.

Fig 2.17

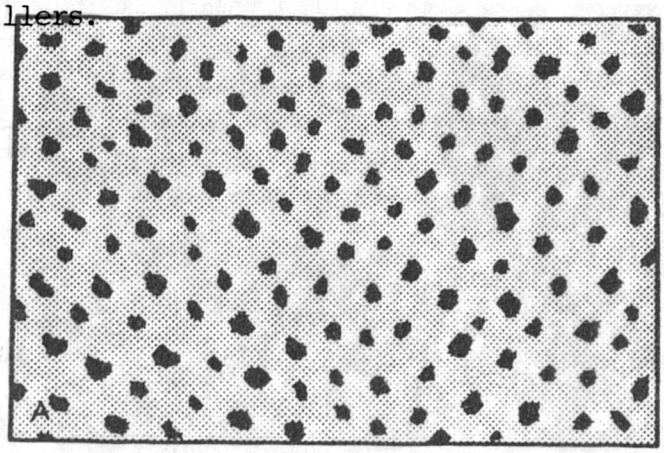
A. Hybrid composite: organic matrix & traditional macrofillers & microfillers.

B. Hybrid composite with microfiller-based complexes: organic matrix & traditional macrofillers & microfillers & splintered prepolymerised particles.

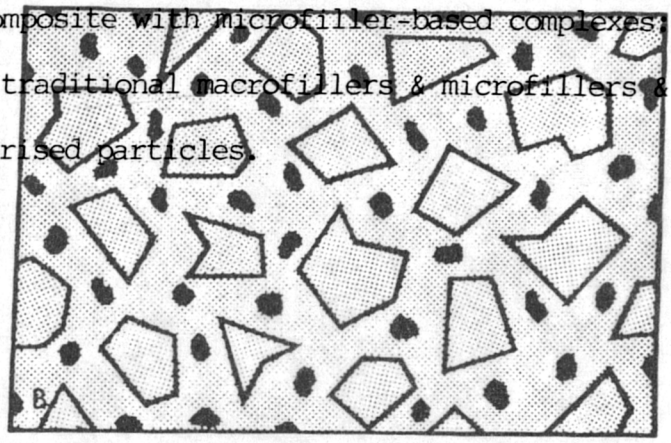
C. Hybrid composite with microfiller based complexes: organic matrix & traditional macrofillers & microfillers & agglomerated microfiller complexes.

Fig 2.17

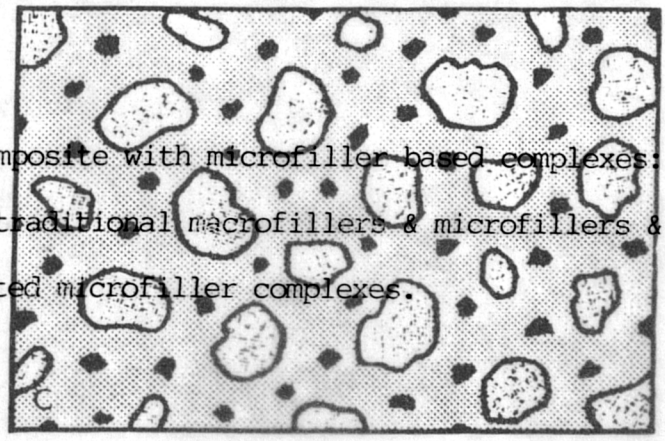
A. Hybrid composite: organic matrix & traditional macrofillers & microfillers.



B. Hybrid composite with microfiller-based complexes: organic matrix & traditional macrofillers & microfillers & splintered prepolymerised particles.



C. Hybrid composite with microfiller based complexes: organic matrix & traditional macrofillers & microfillers & agglomerated microfiller complexes.



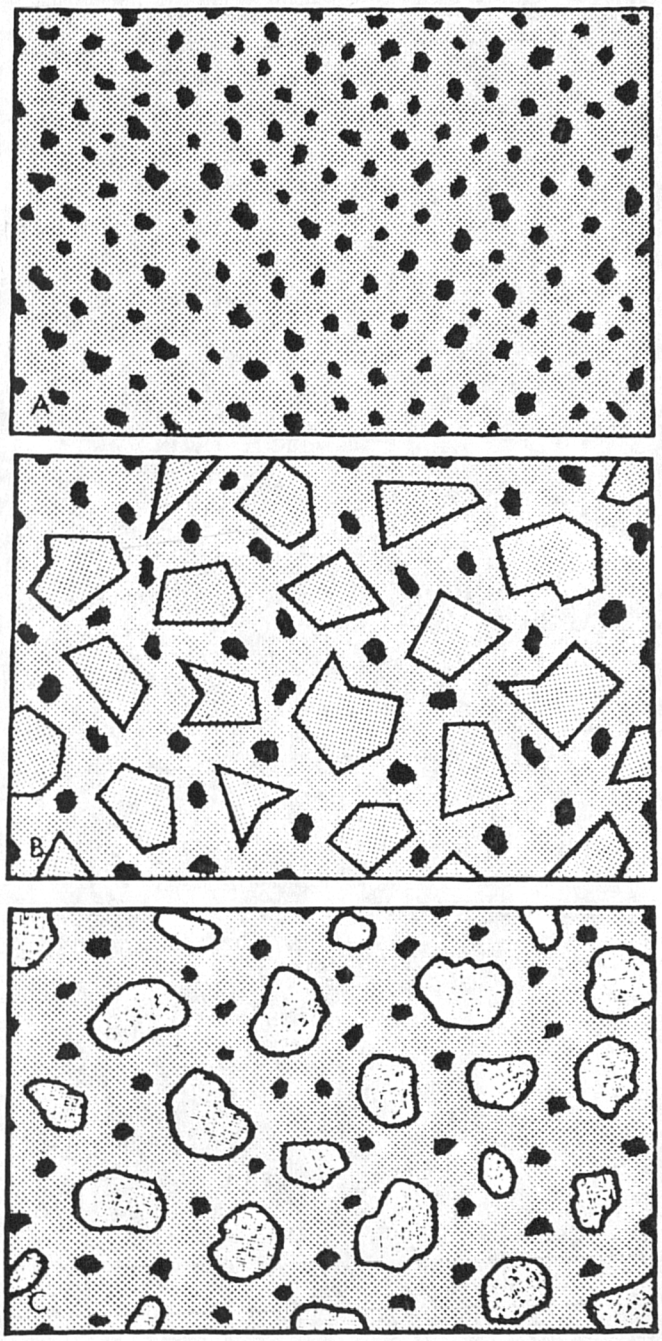
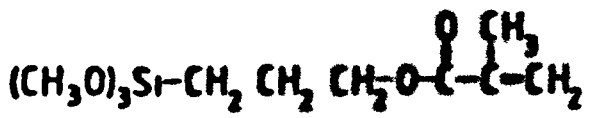

A
B
C

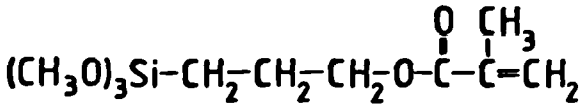
Fig 2.18

γ-methacryloxypropyltrimethoxysilane coupling agent

Fig 2.18

γ-methacryloxypropyltrimethoxysilane coupling agent





2.3.3. ABRASION RESISTANCE AND SURFACE FINISH

A major failing of the composite resins is their inability to withstand abrasion in vivo, which results in an unacceptably high rate of wear, especially when used in stress bearing locations in the posterior teeth. In addition to this, the abrasive wear may produce a markedly roughened surface depending upon the type of filler used in the material. Abrasion and a roughened surface were also problems encountered when the early macrofilled resins were used as anterior veneers.

In addition to abrasion, other factors will influence the total rate of material loss, or wear, of the composite resin. Chemical degradation of the binding matrix of a composite by environmental factors, or physical alteration of the resin as a result of mechanical fatigue or thermal and humidity cycling, will all have a role in influencing the rate of wear of the material.

Irrespective of the structure of the resin, there are 5 factors which will influence the surface finish and/or abrasion resistance of the composite:

(a) The best surface is that achieved with a suitable matrix material, however, it is important that the matrix does not react with the composite resin.

(b) Large, 'hard' filler particles, occupying a high volume fraction of the composite appear to confer abrasion resistance to a material (Draughn and Harrison 1978) (in-vitro).

(c) The localised heat generated during dry polishing of composite resins may be sufficiently large to exceed the glass transition

temperature of the resin phase of 140°C or greater. This results in recrystallisation of the resin at the composite surface, with an accompanying increase in matrix cross linking. These reactions give rise to a surface smear layer - up to 5 μm. thick - which has enhanced surface hardness and hence abrasion resistance (Davidson et al 1981, Lambrechts and Vanherle 1982b).

(d) The setting reaction may be affected by chemical components in the lining material used to protect the pulpal tissues (Millstein and Nathanson 1983), producing marked surface roughening of the resin resulting in discolouration of the finished restoration.

(e) Environmental factors will play a role in mediating any deterioration of the resin matrix, e.g., acids and acidulated fluoride gels have a deleterious effect upon surface integrity. This susceptibility to acidic attack may be related to the type of glass or ceramic used for the filler material (Kula et al 1984, McKinney 1984). In addition, organic solvents in saliva may cause softening of the organic matrix of the composite, predisposing to a more rapid rate of wear.

The resultant progressive loss of the composite material, irrespective of mechanism, is at a rate which exceeds that of enamel or of an amalgam restoration in-vivo (Walls 1985). The morphology of the composite surface after abrasion and the rate of abrasion varies between the different groups of composite materials.

(i) MACROFILLED COMPOSITES

Abrasion of this group is characterised by the preferential loss of the soft resin matrix (Dennison and Craig 1972, Wettmann and Eames 1975, Lambrechts and Vanherle 1982a, b, Valcke and Duggan 1981), exposing the much harder filler particles. The retention of an individual filler particle will thus be gradually reduced until the retentive forces are insufficient to withstand the forces of displacement at which point the filler will be torn from the surrounding resin. This process results in a roughened surface which is prone to plaque accumulation and staining, but not to greater bacterial adhesion (Wettman and Eames 1975, Skjorland 1982, McCabe and Geffner 1983).

(ii) MICROFILLED COMPOSITES

The microfilled resins are capable of accepting a durable lustre when finished with appropriate instruments due to their smaller filler particle size (Valcke and Duggan 1981, Lambrechts and Vanherle 1982b). This lustre is retained during both in-vitro and in-vivo abrasion (Christensen and Christensen 1982). Indeed the rate of wear of the microfilled resins is less than that for conventional composites in contact free areas on both anterior, and 'protected' posterior restorations (Christensen and Christensen 1982, Jorgensen et al 1979, Lutz et al 1979). However, there is some evidence that the rate of wear may increase dramatically after a period in service, and this may reflect a fatigue effect within the matrix on this group of materials, or a time dependent breakdown in the interface

between the resin and the prepolymerised particles within the inhomogeneous microfilled resins (Lambrechts et al 1984, McComb and Brown 1985).

(iii) HYBRID COMPOSITES

This group of materials tend to fall between the macrofilled and microfilled resins in terms of their surface finish. It is possible to produce an acceptable lustre during professional finishing procedures, but the inherent wear pattern of resins containing macrofiller particles is such that a roughened surface will be the result of wear. These materials have been heralded as potential amalgam substitutes (Lutz et al 1983), and early clinical results were promising (Cunningham et al 1984, Derkson et al 1984, Wilson et al 1985), but more recent, and longer term reports (Wilson et al 1987, 1988, Heyman et al 1987) have demonstrated high wear rates and marginal deterioration after 5 years clinical use. As a result, some clinicians do not now advocate their use for large stress bearing posterior restorations.

2.3.4. RESINS USED IN THE CLINICAL TRIALS IN THIS STUDY

The following data has been compiled from information supplied by the respective manufacturers.

2.3.4.1. PRISMA-FIL (MINIMAL COMPOSITE RESTORATIONS)

Manufactured by De Trey Dentsply, Primsa-Fil is a light cured small particle macrofilled resin which is radiopaque and is dispensed

in a compule so requires no proportioning of components at the chairside. Prisma-Fil is classified as a Type II Composite Resin according to the American Dental Association Specification 27. It is recommended by its manufacturers for use in Class III, IV and V restorations and aesthetic veneering, and for limited use in Class I restorations in premolars.

FEATURES

Resin	- Urethane modified BIS - GMA
Filler	- Barium glass particles 76% W/W
Filler Size	- 3 - 5 μm. (small particle macrofilled resin)
Diametral Tensile Strength	- 48 - 55 MPa
Compressive Strength	- 276 - 345 MPa
Water Sorption mg/cm^2 (ADA Spec. 27)	- 0.7
Colour Stability (ADA Spec. 27)	- Pass
Thermal Expansion ppm/°C	- 31
Radiopaque	- Yes

2.3.4.2. OCCLUSIN (SANDWICH TECHNIQUE)

Manufactured by I.C.I., Occlusin is light cured posterior hybrid resin. It is recommended by its manufacturers for use in Class I, II, and V cavities in posterior teeth in both the primary and adult dentition, and has just satisfied the A.D.A. 3 year guidelines for posterior composites.

FEATURES

Resin	- Urethane Dimethacrylate
Filler	- Barium glass particles 86% W/W 69% V/V
Filler Size	- 0.04 μm. - 15 μm. (Hybrid resin)
Diametral Tensile Strength	- 52 - 56 MPa
Compressive Strength	- 300 - 320 MPa
Flexural Strength	- 150 - 160 MPa
Flexural Modulus	- 16 - 18 GPa
Surface Hardness (KNOOP)	- 80 - 90
Watersorption (ADA Spec. 27)	- 0.46 - 0.50
Colour Stability (ADA Spec. 27)	- Pass
Thermal Expansion ppm/°C	- 24
Radiopaque	- Yes

2.3.4.3. HELIOCOLOR (ANTERIOR VENEERING MATERIAL)

Manufactured by Vivadent, Heliocolor is a complimentary kit of light cured microfilled resins which are radiopaque. They are recommended by their manufacturers for use in Class III, IV and V restorations and for aesthetic veneering.

FEATURES

Resin	- Urethane Dimethacrylate
Filler	- Pyrolytic Silicium Dioxide 40% W/W) Aggregate Prepolymerised Material 40% W/W) 80%
Filler Size	- 0.04 μm. (Inhomogeneous microfilled resin)
Radiopaque	- Yes

2.3.5. THE LONGEVITY OF COMPOSITE RESIN RESTORATIONS

The work described in this thesis involved the use of composite resins in 3 different situations in the permanent dentition: in minimal composite restorations, in larger posterior restorations (in the sandwich technique), and as an anterior veneering material. The following literature review will cover previously published work concerning these 3 applications.

2.3.5.1. COMPOSITE RESIN IN MINIMAL COMPOSITE RESTORATIONS

The prevention of pit and fissure caries has for many years been the primary aim of research workers and clinicians in the dental profession. In the early part of the century, a number of workers attempted to prevent the onset of decay by applying silver nitrate (Miller 1905; Prime 1937; Klein and Knutson 1942; Miller 1950). Only Miller (1905) reported any benefit stating that he found silver nitrate useful in preventing the onset of occlusal caries. Nitrocellulose (Gore 1938), zinc chloride (Ast et al 1950) and black copper cement (Miller 1950) have also been used in an attempt to prevent the onset of decay, but none proved beneficial. These methods were employed when the proteolytic theory of caries initiation was in vogue and their intended mode of action would be to precipitate inorgance material onto the tooth surface and block potential organic pathways into the tooth. An alternative suggestion, the ablation of the fissure pattern and its restoration with amalgam prior to caries developing was made by Hyatt (1923). This 'prophylactic odontotomy' was not well received by the profession who objected to cutting a caries-free tooth in an era with very high occlusal caries experience. Hyatt's argument whilst attractive, ignors the fact that placement of durable restorations is more difficult in the young patient (Hunter 1985; Walls et al 1985).

The concept of bonding a thin layer of composite resin to etched enamel and thus effectively 'sealing' caries prone fissures was first introduced towards the end of the 1960's. After initial favourable indications, trials of cynaoacrylate resins (Cueto and Buonocore 1967; Ripa and Cole 1970; Parkhouse and Winter 1971) and

polyurethane materials (Rock 1974) revealed poor retention rates even with prior acid etching of enamel. Early trials of acid etched retained Bis-GMA resins (Buonocore 1970, 1971; Rock 1972, 1973, 1974; McCune et al 1973) demonstrated retention rates of greater than 50% over 1 to 2 years. Gordon (1983) has reported the large number of subsequent trials involving Bis-GMA resins over different lengths of time and very satisfactory retention rates are seen in the short and medium term. Naturally, variation in retention rates does occur in different studies and this is usually attributable to patient co-operation, operator experience and material under test (Stephen et al 1976, 1978). However, retention rates of 50% and greater can be achieved when sealing the first permanent molars of patients under 10 years old after 4 years in service (Charbeneau and Dennison 1979; Richardson et al 1980; Williams and Winter 1981; Erdogan and Alacam 1987; Mitchell 1987).

Some studies have been performed where a tooth with partial sealant loss has been 'topped up' with fresh resin after re-etching (Bagramian et al 1978, 1979; Rantala 1979; Isler et al 1980; Straffon et al 1985). The results from these studies are encouraging and demonstrate a high success rate in terms of caries reduction.

Other studies have shown that teeth with apparent total loss of fissure sealants are no more susceptible to decay than unsealed controls (Horowitz et al 1977) and resin tags remaining in situ within the enamel after sealant loss probably protect the tooth from acidic attack (Silverstone 1974). Criticisms or reservations about fissure sealing are invariably linked to the problem of diagnosing early carious lesions. However, there is now considerable evidence that inadvertent sealing over an early carious lesion will result in

cessation of caries progression and gradual death of the associated bacteria (Jeronimus et al 1975; Handelman et al 1976, 1981; Harris et al 1976; Thielade et al 1977; Going et al 1978; Jensen and Handelman 1980; Mertz-Fairhurst et al 1979a, 1979b, 1986). As long as the sealant layer remains intact, there is a decrease in the number of viable organisms in affected dentine and the metabolic activity of remaining bacteria is reduced.

In conclusion, a dramatic reduction of caries after sealant use has been shown during periods of 1 - 7 years (Houpt and Sheyz 1983; Ripa 1985).

A natural extension from the preventive philosophy of sealing caries - susceptible pit and fissures was advocated by Simonsen and Stallard (1977) Simonsen (1978a, b) Raadal (1978a). The minimal composite restoration involves the removal of carious tissue within the fissure pattern together with any grossly undermined enamel, but without ablation of the fissure pattern. After acid etching, the resultant cavity is restored with a fissure sealant, or a diluted composite, and the remainder of the fissure pattern sealed with a conventional sealant.

The conventional material for most posterior restorations remains amalgam, as amalgam has proven durability during years of clinical experience. However, drawbacks to its use are recognised (Simonsen 1978a; Simonsen 1982; Simonsen and Jensen 1979) and include:

(a) amalgam preparations require removal of a portion of healthy tooth structure. Even small, conservative restorations can significantly weaken the tooth;

(b) secondary caries may occur at the margins of a restoration and in unprepared pits and fissures; and

(c) marginal leakage and breakdown of amalgam can contribute to recurrent caries;

(d) amalgam is not an aesthetically pleasing material; and

(e) mercury toxicity and/or sensitivity.

The minimal composite restoration can eliminate these problems in certain cases, and indications for their use include:

(a) questionable caries or an explorer catch in a pit or fissure;

(b) minimal, shallow pit and fissure caries;

(c) deep pits and fissures that could inhibit complete penetration of sealant material or could be carious at their bases;

(d) deep pits and fissures with extensive supplemental fissuring and small areas of decay; and

(e) an opaque chalky appearance along pits and fissures that could indicate incipient caries.

However, drawbacks to the use of the minimal composite restorations include large, or multi-surface carious lesions (Simonsen 1978a). They are, therefore, not intended as a substitute for amalgam, but as an alternative treatment in selected cases. Placement requires meticulous adherence to the principles of acid etch technique (isolation from moisture).

Results of observations on this type of restoration are few,

but over 3 years (Simonsen 1980; Houpt et al 1984), 4 months to 5½ years (Walker et al 1987) and 7 years (Simonsen and Landy 1984) are very encouraging. Most failures seem to be related to improper techniques, such as lack of adequate moisture control (Raadal 1978a; Walker et al 1987). In vitro studies (Raadal 1978b. 1979; Hicks 1984) indicate that microleakage around such preparations is minimal. An 18 month clinical study comparing preventive resin restorations with amalgam restorations in contralateral teeth found that the marginal integrity of the resin restorations was better. The same study also rated the wear of the composite resin/sealant restorations as excellent (Azhdari et al 1979).

The minimal composite restoration has more recently been divided into 3 sub-types (Simonsen 1985). Type 1 is within enamel and restored with pit and fissure sealant. Type 2 embraces the situation where decay has progressed into dentine, but is still confined to a small area. The restoration involves the use of a wear resistent composite resin designed for posterior use and an unfilled resin. Calcium hydroxide is used to line the base of the cavity and a dentine bonding agent and unfilled resin are applied prior to the filled composite resin. The filled resin occupies the cavity and adjacent fissures. Unfilled resin sealant is then used on separate fissures of the same tooth. In Type 3 the filled resin is used only to restore the cavity preparation. Pit and fissure sealant is then applied to seal adjacent and separate fissures.

This conservative approach to fissure caries combines the removal of caries with the prevention of its occurrence in the remainder of the fissure pattern giving a restored tooth with minimal

tooth destruction, maximal strength (Simonsen and Landy 1984) and good aesthetic appeal. As less mechanical preparation is required, the patient suffers less discomfort and may not require anaesthesia. Finally, the minimal composite restoration may be added to, replaced or repaired without further tooth preparation (Simonsen 1978a, 1982; Ripa 1985).

In summary, the proven success of pit and fissure sealants has led to the development of the relatively new restorative technique, the minimal composite restoration. In selected cases, the technique appears to be effective in terms of both caries prevention and preservation of tooth structure.

2.3.5.2. COMPOSITE RESIN AS A POSTERIOR RESTORATIVE MATERIAL

In the last 5 years, the commercial market has been inundated by a plethora of composite resin posterior restorative materials. Careful appraisal of clinical reports for these tooth coloured and aesthetically pleasing materials is necessary. After all, amalgam has and is serving patient, practitioner and profession extremely well. A summary of clinical studies of at least 3 years duration published since 1983, including the composite materials used, the control material, the investigators' assessment criteria and the principal findings are presented in Table 2.7.

A further summary of the 4 and 5 year results of multicentre clinical trials using Occlusin as a posterior restorative is shown in Table 2.8. (Norman et al 1988; Wilson N.H.F. et al 1985; Wilson M.A. et al 1987, 1987, 1988; Michotte-Theal and Vreven 1988; Leinfelder et al 1986). The table shows the performance of Occlusin compared with amalgam. Results are shown as the percentage of restorations showing

no deterioration with the number of restorations analysed in brackets.

TABLE 2.7.

SOME CLINICAL TRIALS OF COMPOSITE RESINS AS POSTERIOR RESTORATIVES IN THE PERMANENT DENTITION

AUTHOR(S)	DURATION	TEST MATERIAL(S) NUMBER OF RESTORATIONS	CONTROL MATERIAL	ASSESSMENT CRITERIA	PRINICPAL FINDINGS
Derkson et al (1984)	4 Years	Profile (101)	Amalgam (Dispersalloy)	Own subjective	Profile inferior to Amalgam
Moffa et al (1984)	5 Years	Strontium glass filled composite (356)	Amalgam (314)	USPHS (United States Public Health Service)	44% Of composites showed evidence of occlusal wear
Brunson et al (1985)	3 Years	P10 (90)	Compared to data from other studies using USPHS criteria	USPHS	P10 displayed superior properties compared to other autopolymerised resins
Christensen and Christensen (1985)	3 Years	Strontium glass filled composites (230)	Amalgam (Dispersalloy)	Clinical ranking, SEM analysis of replicas	Amalgam superior in retaining anatomic form and marginal integrity
Boksman et al (1986)	3 Years	Fulfill (79)		Modified USPHS Standard casts to estimate wear	Mean wear rate of 135 μm. Rate of wear decreases with time

AUTHOR(S)	DURATION	TEST MATERIAL(S) NUMBER OF RESTORATIONS	CONTROL MATERIAL	ASSESSMENT CRITERIA	PRINCIPAL FINDINGS
Derkson and Richardson (1986)	3 Years 3 Years	Fulfil (29) 1 P10 (43)		USPHS	Both clinically acceptable. Fulfil slightly greater wear than P10
Hendriks et al (1986b)	5 Years	Estic Microfill Profile (Total 232)	Dispersalloy Adaptic	USPHS	Composites inferior wear resistance to Amalgam
Leinfelder et al (1986b)	3 Years	Fulfil (60) X55 (60) H120 (60) P10 (60) P30 (60) Occlusin (60)		USPHS Wear estimated by comparison with standard casts	Most wear in First Six months. Direct evaluation showed the wear rate to increase with time whereas indirect evaluation showed a decrease with time
Smith et al (1986)	3 Year Results	Occlusin (55)		Subjective criteria	Restorations classified as large showed more deterioration than those in smaller cavities. 'Size of restoration may be found to be a significant factor in the ongoing clinical trial.' Material performing well

AUTHOR(S)	DURATION	TEST MATERIAL(S) NUMBER OF RESTORATIONS	CONTROL MATERIAL	ASSESSMENT CRITERIA	PRINCIPAL FINDINGS
Timmons et al (1986)	3 Years	Estilux Posterior (42) (Class I 19) (Class II 23)	cf. Data of Wilder et al (1984)	Estimate of wear rate by comparison with standard casts Ryge and Snyder criteria (1973)	At 3 Years 40% of the restorations showed signs of wear
Wilson et al (1987)	4 Year Results	Occlusin (Class 1 40) (Class II 37)		Clinical ranking Estimate wear by reference to standard replicas	Mean wear 94 μm. +- 60 μm. 48% deterioration at margins. 2% Deterioration of anatomic form occlusally and 5% interproximally
Brunson et al (1987)	3 Years	P30 (67)	Compared to other resins evaluated in the same manner	USPHS	Demonstrated more wear than other light cured resins
Dilley et al (1987) (children's permanent molars)	3 Years	Caulk H-120 (79)	Amalgam (Sybralloy)	USPHS	H-120 inadequate wear resistence

AUTHOR(S)	DURATION	TEST MATERIAL(S) NUMBER OF RESTORATIONS	CONTROL MATERIAL	ASSESSMENT CRITERIA	PRINCIPAL FINDINGS
Boksman et al (1987)	5 Years	Fulfil (Class II 55) (Class I 43)		USPHS Compared to standard casts to estimate wear rate	Wear rate decreases with time μm. / yr. 1 Year 57 2 Years 47 3 Years 31 4 Years 28 Total 163
Heyman et al (1987)	5 Years	Nimetic (40) Nimetic Dispers (40) Visiofil (40) Visio Dispers (40) Visio Radiopak (40)		USPHS Compared to standard casts to estimate wear state	Mean wear over 5 Years (μm.) Visio Dispers 126 Nimetic Dispers 150 Nimetic 228 Visio Radiopak 242 Visioroll 247
Wilson et al (1988)	5 Years	Occlusin (Class I 38) (Class II 19)		Clinical ranking Estimate wear by reference to standard replicas	Mean wear 155μm. 100μm. 35% deterioration at margins 35% deterioration of anatomic form occlusally and 5% interproximally

AUTHOR(S)	DURATION	TEST MATERIAL(S) NUMBER OF RESTORATIONS	CONTROL MATERIAL	ASSESSMENT CRITERIA	PRINCIPAL FINDINGS
Michotte-Theall and Vreven (1988)	4 Years	Occlusin (Class I 42) (Class II 58)		USPHS	86.9% of Occlusal (I) and 97.6% proximal (II) restorations maintained anatomic form. Marginal adaptation was maintained in 82.6% (I) and 90.7% (II) of restorations
Pallensen and Qvist (1988)	3 Years	Miradapt (33) P10 (33) P30 (33)		Epoxy resin and die stone models compared with standard casts	All 3 had a mean wear rate of less than 50 μm./yr. Molars had higher wear rate than premolars
Robinson et al (1988)	3 Years	Occlusin (98)	Aristalloy (27)	USPHS criteria wear estimated by comparison of resin replicas with a series of standard replicas	Occlusin showed similar wear resistance, but better marginal integrity compared to amalgam. Wear at 36 months: Composite: 70 +- 36μm. Amalgam: 67 +- 36μm.
Norman et al (1988)	3 Years (Multi-centre)	Occlusin (Class I 281) (Class II 729) At 3 years 193 (I) and 523 (II) evaluated		USPHS Replicas used to estimate wear by reference to standard casts	Satisfied A.D.A. 3 year guidelines for posterior composites

TABLE 2.8.

SUMMARY OF 4 AND 5 YEAR OCCLUSIN RESULTS

Percentage of restorations showing no deterioration (number analysed)	OCCLUSIN		amalgam	
	4 year	5 year	4 year	5 year
ANATOMIC FORM				
Occlusal	72.2(663)	74.5(188)	79.6(167)	66.7(12)
Interproximal	93.6(471)	94.6(112)	92.6(127)	83.3(12)
MARGINAL ADAPTATION				
Occlusal	84.3(663)	70.7(188)	62.3(167)	25.0(12)
Interproximal	90.9(471)	78.6(112)	81.9(127)	58.3(12)
COLOUR MATCH	88.8(663)	91.1(188)	-	-
MARGINAL DISCOLOURATION	69.7(663)	55.3(188)	-	-
SURFACE ROUGHNESS				
Occlusal	79.4(141)	70.6(119)	66.7(18)	50.0(12)
Interproximal	93.8(97)	89.8(69)	94.4(18)	83.3(12)
TEMPERATURE SENSITIVITY	99.2(663)	98.9(188)	100.0(12)	100.0(12)
GINGIVAL CONDITION				
Buccal	96.9(663)	96.8(188)	100.0(167)	100.0(12)
Lingual	98.0(663)	97.3(188)	100.0(167)	" "
Mesial	96.4(663)	95.2(188)	99.4(167)	" "
Distal	96.0(663)	93.6(188)	98.8(167)	" "
INTERPROXIMAL CONTACTS*				
Mesial	85.8(290)	86.1(65)	81.3(80)	87.5(8)
Distal	88.3(324)	89.2(74)	87.2(102)	100.0(9)
	Number detected to date/number placed			
SECONDARY CARIES (Total International Programme 12 centres)	11/1045	2/254		

2.3.5.3. COMPOSITE RESIN IN VENEERING SYSTEMS

Composite resins have been used with great success to restore Class IV cavities in fractured or decayed incisors for the last 10 to 15 years. This success has been due not only to the acid etch technique, but also to the inherent physical strength of the composite resins. A logical extension from the treatment of the traumatic or carious cavity has been the use of labially applied composite resins to mask staining, hypoplasia, or fluorosis and to correct diastema or rotated teeth.

Successful veneering can be achieved by direct application of composite resin onto the etched enamel surface (Mink and McEvoy 1977; Spengler and Tullin 1975; Widdop 1979), but the early macrofilled resins suffered from poor long-term colour stability and surface roughness resulting in unacceptable staining and plaque accumulation (Buonocore 1975). In an attempt to find a more durable and aesthetic system preformed surface laminates of highly cross linked polymethylmethacrylate, either in the form of hollowed out denture teeth (Faunce and Myers 1976, Rakow, Light and Condello 1978), preformed acrylic facings (Mouradian et al 1976, 1978; Faunce 1977; Avery 1980; Johnson 1982), custom made polymethylmethacrylate veneers (Rouk 1981; Rakow, Silverstein and Silverstein 1982; Weiner and Rakow 1983), or veneers reinforced with a glass fibre network (Ehrnford 1983) were tried. These veneers were primed with ethyl acetate, methylene chloride or methyl methacrylate and a filled composite resin was used to lute the veneer to an etched tooth. This system utilised a chemical bond between the veneer and the luting resin and a mechanical bond between the resin and the etched tooth. Veneering techniques such as

these, utilising using some form of plastic coating became widely accepted and well documented (Roberts 1980, Heyde and Cammarato 1981, Mink and Timmons 1984).

Some authors claim that properly fitted and finished laminate veneers show excellent acceptability by the gingival tissues (Barnham et al 1983; Roberts 1983; Rivken and Warren 1985; Jensen and Soltys 1986), but this was disputed by Walls (1985). In vitro studies (Cannon 1981; Hembree 1982) demonstrated that preformed laminates were significantly more susceptible to brushing wear than a conventional composite and exhibited greater microleakage than did conventional direct composite veneers, the microleakage being more pronounced at the bonding agent - enamel interface than at the veneer - bonding agent interface (Perez, Bassiouny and Carrell 1980). In spite of this potential problem of microleakage and abrasion early clinical reports were favourable. Roberts (1983) reported an 85.8% retention rate after 2 years for 175 preformed veneers placed in 49 patients and noted some minor deterioration in colour match and marginal integrity. Jordan et al (1977) reported 94.4% retention of laminate veneers over a 3 year period with the largest percentage of dislodgement occurring in the first year after placement and Fleming et al (1984) noted some preliminary bond failure and marginal discolouration in 40 veneers placed in 8 patients after 45 months, although giving no 'failure rates'. In contrast to the above reports, Walls (1987) reported that of 273 veneers followed for 2 years, 52% of lateral incisors and 79% of central incisors and canines had lost some veneer material and Calamia (1985) sited 'numerous failures of laminates usually at the laminate composite margin'. Walls (1985) also reported progressively

deteriorating gingival health in his large series of laminates which were all placed without prior reduction of enamel.

The shortcomings of the laminate veneering systems are now well recognised and they have been largely superceded by the microfilled composite resin systems and the etched porcelain veneers. The latter are luted to the tooth with composite resin.

There are few published longevity studies on the use of composites as labial veneers, but Jordon (1981) in a 5 year study of 148 veneer restorations fabricated using 3 different resin materials (an ultra-violet light-cured composite, a chemically cured composite and an unfilled resin material) recorded encouraging results. The overall retention rate was 94%, but large differences in colour stability and abrasive wear were seen. The unfilled resin was most colour stable, but also more prone to abrasion. Because colour stability is of absolute paramount importance in restorations in which there is extensive display of material, the superiority of the unfilled resin is significant. Possibly a major contributing factor to stability of colour is smooth surface finishing ability, which is an advantage of unfilled resin materials.

The microfilled composites produce a highly polished abrasion resistant surface compared to the dull and monochromatic appearance of the laminates. It is now possible to build up a tooth incorporating opaque resin to replace dentine, transparent resin to simulate incisal edges, standard opacity resin to simulate enamel and various tinting shades to enhance characterisation. One such system available commerically is 'Heliocolor' (Vivadent Schaan-Liechtenstein). A clinical trial on this material used to mask staining, hypoplasia or fluorosis and to correct diastema or rotated teeth forms part of the

work reported in this thesis.

The concept of the acid etching of porcelain was introduced by Simonsen and Calamia (1983). The use of porcelain veneers had the potential for life like aesthetics, colour stability, wear resistance and soft-tissue acceptability. Although Simonsen and Calamia (1983) believed that the bond strengths between etched porcelain and composite resin would be sufficient for retention of the veneers they found that the use of silane coupling agents with etched porcelain increased the bond strength (Calamia and Simonsen, 1984), thus endorsing the work of other authors (Rochette 1975; Eames and Rogers 1979; Nowlin, Barghi and Norling 1981; Barreto and Bottaro 1982). Calamia (1985) recorded 'fine physical and aesthetic results' with porcelain veneers, but because this is a new technique that has only recently become available to practitioners, longer appraisals of its durability are awaited.

One area of controversy with regard to all facing materials is whether or not reduction of the labial enamel is required prior to placing the restoration. There are advocates of both methods and Calamia (1985) has placed porcelain veneers with and without removing enamel. However, it is recognised that any overcontouring will increase plaque retention and stagnation at the gingival margin, especially in those persons with poor oral hygiene, (Sacket and Gildenhuys 1976) and also that the bond strength of composite resin to enamel is significantly increased after partial removal of buccal enamel (Aker, Aker and Sorensen 1979; Schneider, Messer and Douglas 1981). These are two very good reasons why some enamel reduction would be beneficial, but any reduction must take into account the age of the patient and the proximity of the dental pulp.

2.4. THE SANDWICH TECHNIQUE

2.4.1. INTRODUCTION

This technique utilises the beneficial properties of both glass polyalkenoate cement and composite resin when restoring a tooth. Glass polyalkenoate cement, which bonds to existing dentine, is used as a lining material and effectively replaces the lost dentine. Composite resin is then placed on top of the etched glass polyalkenoate cement and so effectively replaces the lost enamel. The composite resin then achieves micromechanical retention on all its surfaces, be it to the enamel cavity margins or to the underlying glass polyalkenoate cement.

Initially, this technique was advocated for class I and class V cavities, but more recently commercial manufacturers have recommended its use in the class II cavity in a bid to overcome the shortcomings of composite resin in this situation. It is suggested that the glass polyalkenoate cement is placed on the cervical floor of the cavity out to the cavosurface margin, so that after acid etching and bonding to composite resin the glass polyalkenoate forms part of the approximal restorative wall (Fig. 2.19.).

The literature review concerning this technique is divided into three sections:

(a) 'Cervical gap formation in Class II composite resin restorations' which explains 'the problem' and the methods that have been tried in a bid to overcome the problem prior to the sandwich hypothesis.

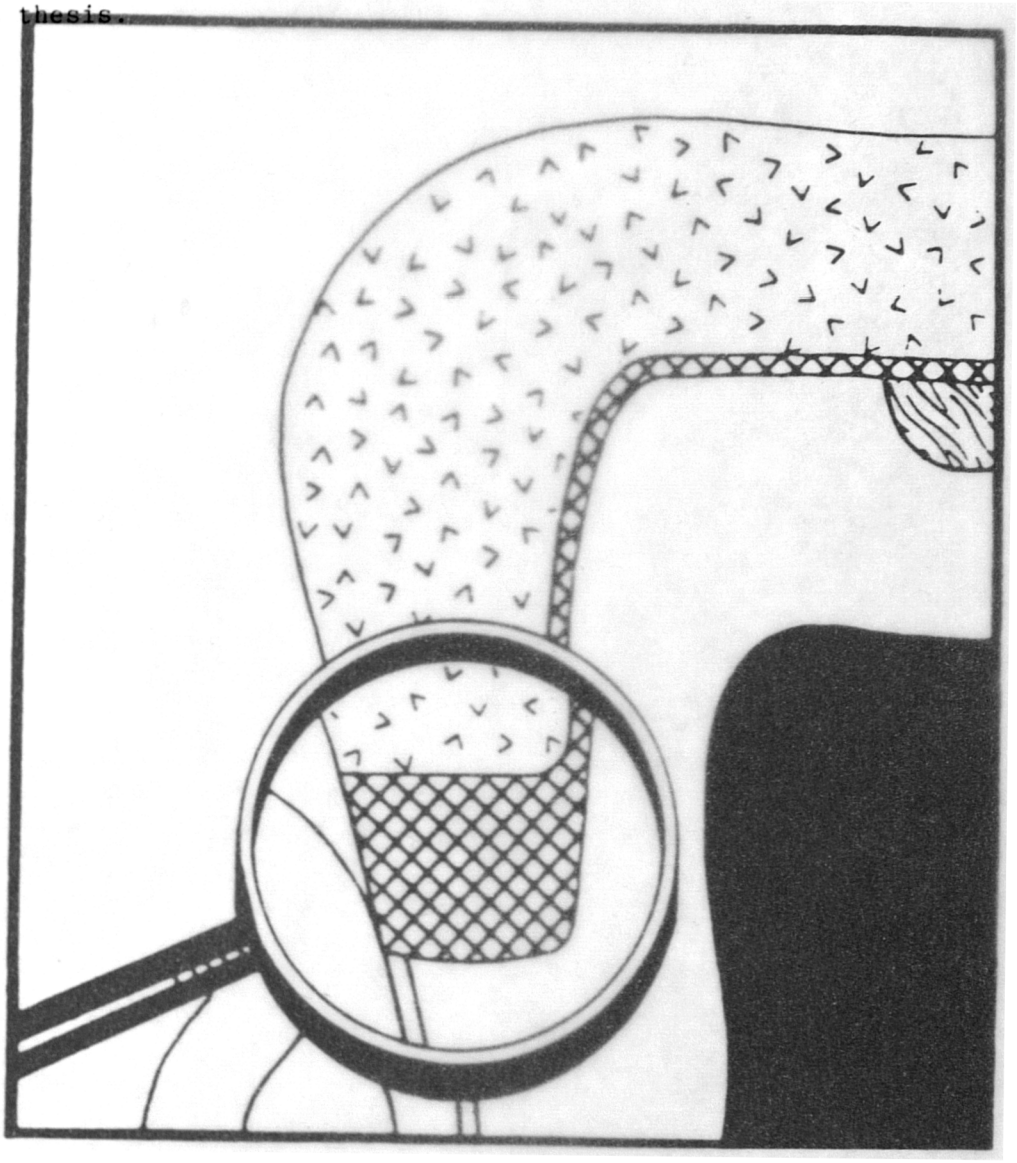
(b) 'The bond produced between glass polyalkenoate cement and enamel and dentine'.

Fig 2.19

The class II sandwich restoration used in the clinical trial reported in this thesis.

Fig 2.19

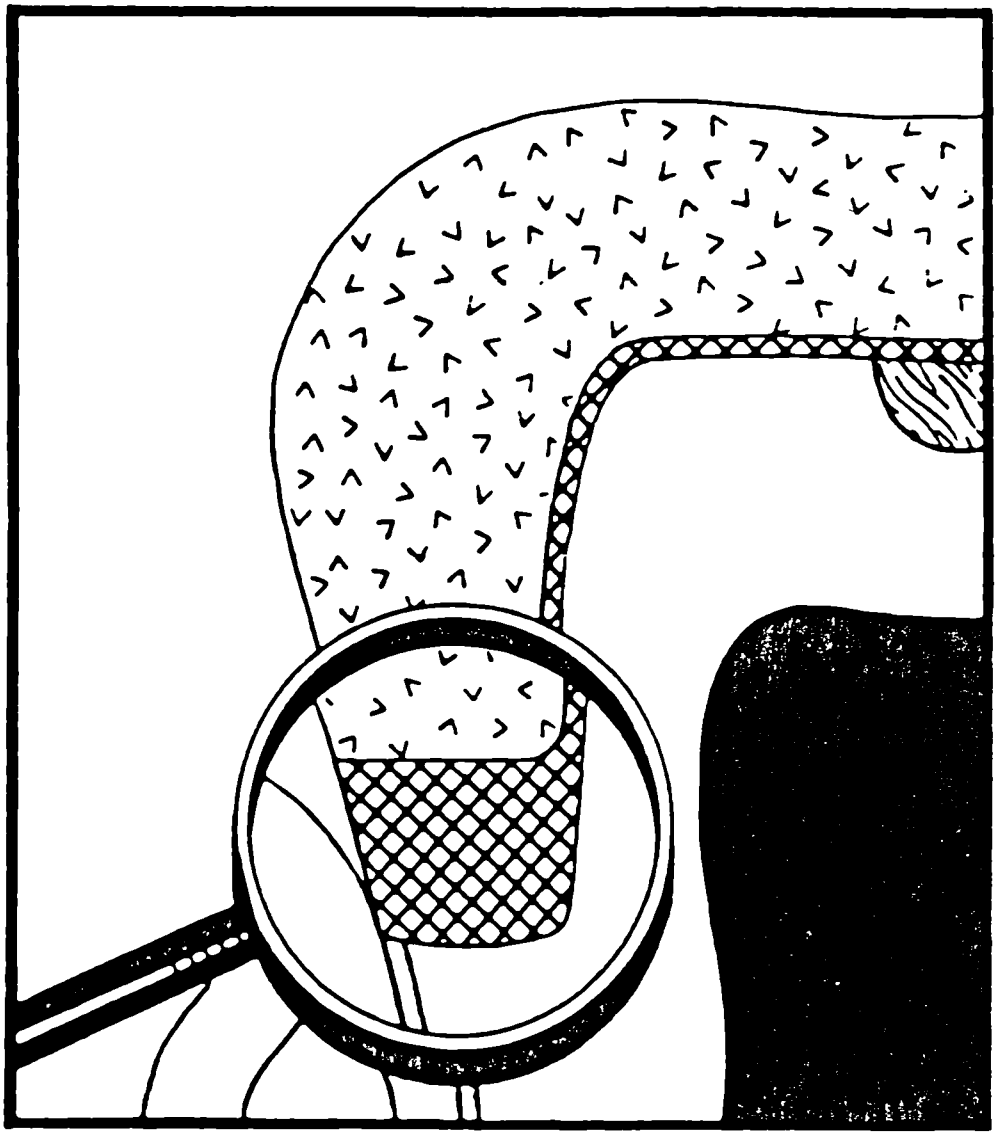
The class II sandwich restoration used in the clinical trial reported in this thesis.



Ketac Bond polyalkenoate cement

Occlusal hybrid composite resin

Calcium hydroxide cement



Ketac Bond glass polyalkenoate cement

Occlusin hybrid composite resin

Calcuim hydroxide cement

(c) 'The bond produced between etched glass polyalkenoate cement and composite resin'.

2.4.2. CERVICAL GAP FORMATION IN CLASS II COMPOSITE RESIN RESTORATIONS

A good marginal seal between tooth and restoration is required to minimise cavomarginal discolouration and the risk of secondary caries (Going 1972). An inadequate adaptation between tooth and restorative material may lead to ingress of micro-organisms, oral fluids and other agents which can cause pulpal reactions (Brannstrom and Nyborg 1971, Bergenholtz and Lindhe 1975, Brannstrom and Vojinovic 1976, Bergenholtz 1977, Mejare et al 1979). Microbial microleakage has subsequently been identified as a major factor in the pulpal reaction to composite resin restorations (Brannstrom 1984a).

In recent years, there has been a marked increase in the use of resin based materials for restoration of posterior teeth. This has arisen due to a combination of 3 factors:

(a) an increased demand for aesthetic dentistry from the public;

(b) a growing concern about the risk of mercury toxicity from silver tin amalgam restorations;

(c) an increased availability of composite resin materials specifically designed for the restoration of posterior teeth.

The acid etch technique can afford a good marginal seal for composite resin restorations placed in enamel bounded cavities. However, when cavities are extensive, especially in posterior teeth, greater demands are placed upon the integrity of the marginal seal. The larger the size of cavity, the greater the dimensional changes in the resin either on its setting polymerisation or consequent to thermal fluctuation. Polymerisation shrinkage is always directed toward the centre of material bulk, consequently the loss of volume is adjusted from the periphery and free surface. An additional factor in large

complex cavities is an element of flexion on polymerisation contraction and this will also stress the marginal seal (Forsten et al 1982). Gaps around composite resin restorations, as a result of polymerisation shrinkage, are recognised (Asmussen and Jorgensen 1972). However, they can be inhibited if the resin is bonded to a sufficiently wide zone of acid etched enamel (Asmussen 1974, Oilo and Jorgensen 1977). If not wide enough, contraction gaps will appear due to fracture of the enamel (Oilo and Jorgensen 1977). Due to the irregular fracture surfaces, these gaps in the enamel will probably not close completely on subsequent water absorption and swelling of the filling (Ehrnford and Derand 1984).

Conventional Class II cavities mostly have too little enamel available cervically to prevent gaps by the use of the acid etching technique. Such gap formation has previously been shown by dye penetration tests (Lutz et al 1976, 1977; Lutz and Kull 1980). To resist the contraction stresses in a conventional Class V composite resin restoration, a wide enamel bevel of minimum 0.5 - 1.0 mm. has been recommended (Oilo and Jorgensen 1977). A wide enamel bevel has also been suggested for so-called adhesive Class II restorations (Lutz et al 1986), but has since been questioned for a number of reasons (Ehrnford and Derand 1984; Boksman and Jordan 1985). Bevelling of occlusal cavity margins results in a wider functional occlusal surface of the restoration, makes precise finishing more difficult and creates problems with thin sections of marginal excess which may fracture under occlusal loading. Bevelling of proximal and cervical enamel cavosurface margins in extensive Class II cavities can lead to difficulties with effective isolation, can create problems in regard to matrix placement and stabilisation, may hinder accurate

reproduction of existing tooth contours, but most importantly of all, may eliminate any remaining enamel available for bonding with the acid etch technique.

In many posterior cavities, removal of caries or existing restorations results in a gingival floor situated below the cemento enamel junction. In this situation, the use of acid etch technique may lead to an increase in the magnitude of the contraction gap formation at the cervical wall of approximal composite resin restorations (Brannstrom et al 1984). There are 3 reasons why etching should not be used to achieve dentine-resin bonding:

1. The calcium content of dentine is much less than that of enamel and the water and organic matter content higher than enamel. Removal of the supporting organic matrix of dentine, unlike enamel, will leave an easily destroyed structure which will not stand on its own. Further, it is known that application of a low viscosity monomer to etched dentine will allow penetration of the monomer into the tubules, where polymerisation will take place and a large number of tags will form. However, this bond is very poor, probably as a result of the poor structural strength of etched dentine (Stanford 1985). Alternatively, the tags may be poorly polymerised due to the presence of oxygen on the surface of the dentine and the liquid in the dentinal tabules.
2. Dentine is hydrophilic in nature and has a very low surface energy. Bonding a hydrophobic resin to such a surface is difficult.
3. Etching of dentine may promote an undesirable pulpal response (Stanley et al 1975) and the 'Council on Dental Materials and

Devices' (1978) advised that etching procedures should be confined to enamel.

Recently, dentine bonding agents have been developed in order to offset the problems created by a lack of adhesion between composite resin restoratives and dentine cavity surfaces. The bonding agents bond to dentine by physio-chemical interaction while bonding chemically to composite resin. At the present time, controversy exists concerning the role of the smear layer in this bonding process. This layer is formed as a result of the cutting of dental tissues, which produces an altered surface layer involving the plastic flow of hydroxyapatite and entrapment of cutting debris (Eick et al 1970; Elrich 1976). Some authors recommend removal of the smear layer in order to optimise the bonding of restorative materials to enamel and dentine (Gwinnett 1984; Brannstrom 1984b), while others consider that the preservation of the smear layer actually enhances bonding (Powis et al 1982; Causton 1984; Newman and Porter 1986; Tao and Pashley 1988). Indeed, other investigators have demonstrated the importance of retaining the smear layer not connected with bonding, but to reduce pulpal sensitivity and inhibit the ingress of oral fluids (Boyer and Svare 1981; Pashley et al 1983; Ostro et al 1984). In a recent publication, it was determined that the ability of Scotchbond to seal dentinal margins was not improved, but generally diminished, when the smear lay was altered or removed (Crim and Shay, 1988).

Five bonding systems are currently available:

(a) Phosphate Ester System, e.g., Scotchbond (3M U.K. plc).

(b) Urethane/Isocyanate Systems, e.g., Dentin-Adhesit (Vivadent, Liechtenstein).

(c) Aldehyde Systems, e.g., Gluma (Bayer Dental, Lever Kusen, West Germany).

(d) Maleic acid, HEMA + BIS GMA, HEMA, e.g., Scotchbond 2 (3M. U.K. plc).

(e) Oxalate dentine bonding, e.g., Tenure (Denmat Corp., Santa Maria, C.A., U.S.A.).

The various systems of bonding to dentine are carried out using similar principles to that illustrated in Fig. 2.2 0. A functional group (F) reacts to the dentine, providing adhesion. An intermediate group (I) in turn, bonds to the functional group and the resin bonds to (I). The various dentine bonding agents vary with respect to (F) and (I) and also as to whether the bonding is to either the inorganic or the organic constituents of the dentine surface. The phosphate ester system, e.g., Scotchbond, chelates in some manner to calcium and actually forms a stronger bond to enamel than dentine but the complete mechanism of the bond is not fully understood. Causton (1984) has shown that Scotchbond significantly improves the bonding of composite resin to dentine and that deep dentine had a bond strength of 60% lower than that of dentine near the enamel dentine junction. Isocyanate derivatives form Covalent bonds to the hydroxyl groups in collagen (Asmussen and Munksgaard, 1985). Dentin Adhesit is a one component isocyanate agent containing low molecular weight polyurethane in methylene chloride solvent and bond strengths approaching that of etched enamel to composite resin have been claimed by manufacturers. More recently, research has concentrated on adhesives which are operational in aqueous environments, since water is present on the dentine surface. It is known that aldehydes may react with collagen under moist

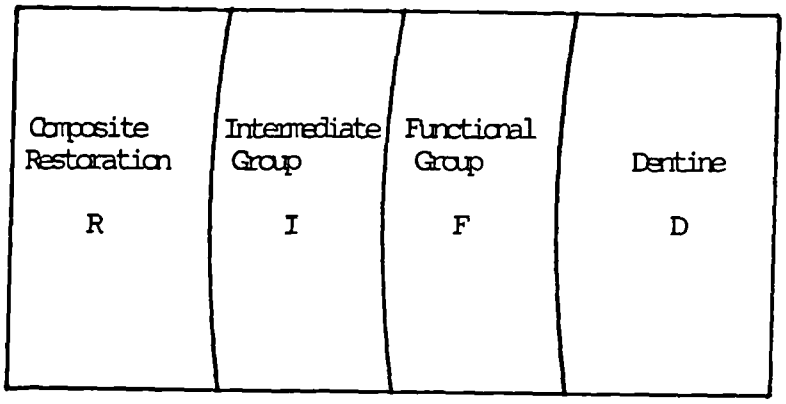


Fig 2.20

Dentine adhesives vary only in respect of the functional (F) group of film-forming agents: the intermediate group (I) may or may not be required for bonding to the composite restoration (R).

conditions and Munksgaard and Asmussen (1984) found that the bond strengths of aqueous mixtures of aldehydes and certain active monomers compared favourably with the strength of bonds between resins and etched enamel. Among the aldehydes, glutaraldehyde was especially effective when coupled with the hydroxyethyl methacrylate (HEMA) monomer, and this is the product commercially avilable as GLUMA. It is suggested that GLUMA acts by forming a chemical bond of HEMA - molecules to a collagen-glutaraldehyde reaction complex. Subsequently, applied resin will then copolymerise with the collagen-linked methacrylate groups (Munksgaard et al 1983). In experiments, the affectiveness of the GLUMA system was such that in about half of the cases, the dentine itself, and not the bond, was ruptured (Asmussen and Munksgaard 1985). The mechanism of adhesion of the newest 3M U.K. bonding agent Scotchbond 2 is not fully known. It can be theorised that the dentine primer containing HEMA and Maleic acid which is both hydrophilic and acidic, thoroughly wets and solubilises the dentine smear layer. The adhesive with HEMA, BIS-GMA resin and photoinitiator then penetrates the solubilised layer and when polymerised, is locked into this and tends to seal this surface. Composite resin then chemically bonds to the adhesive through the methacrylate groups by free radical polymerisation. The oxalate dentine bonding system consists of aluminium oxalate and N. phenyl glycine glycidal methacrylate. The aluminium oxalate removes the dentinal smear layer which is then reprecipitated with N. phenyl glycine, while the glycidal methacrylate residue bonds to the composite resin.

The microleakage of posterior composite restorations using dentine bonding agents has been evaluated in several in vitro studies

(Meetz and Douglas 1983; Cooley and Barkmeier 1988; Depew and Pashley 1988) and, although the use of bonding agents resulted in a reduction of microleakage, further development is still necessary in order to create acceptable margins of composite restorations in dentine (Blunck and Roulet 1988). Munksgaard et al (1984) found the diammeter of cavities to be a critical factor, and although many adhesives could form a bond to dentine initially, this faculty was reduced the larger the cavity became. A new bonding agent has been reported recently (Beech et al 1988), which is a combination of polyacrylic acid (PAA) with methacrylate groups (MA). The PAA bonds to tooth structure and the MA to composite resin, and after extensive successful in-vitro testing, a clinical trial is now proceeding (Beech et al 1988).

Glass polyalkenoate cements first described by Wilson and Kent (1972) and commercially introduced in 1975 as ASPA had the ability to bond to dentine. Further development led to the production of an anhydrous glass polyalkenoate cement, Chemfil in 1981. This was recommended for use on Class III and V cavities and Class I and II cavities in deciduous teeth. These materials were based on polyacrylic acid. Another manufacturer (ESPE, Seefeld, West Germany) used polymaleic acid in its glass polyalkenoate cement Ketac Bond which became available in 1984. The glass polyalkenoates assumed further importance when McLean et al (1985) showed that by acid-etching glass polyalkenoate cements, bonding to composite resin could be achieved. This combination since named the 'sandwich technique' may be used:

(i) to place composite restorations in cavities where no retention is available, such as Class V abrasion cavities using the glass ionomer cement as a dentine bonding agent.

(ii) when the cement is used as a structural base under composite restorations in posterior teeth.

In this latter application, the manufacturers now recommend that 1 - 2 mm. of Ketac Bond can be placed on the cervical floor of a Class II box out to the cavosurface margin, so that after acid etching and bonding to composite resin, the Ketac Bond forms part of the approximal restorative wall (Fig. 2.19.).

This then is the latest method being employed to prevent cervical gap formation in class II composite resin restorations. Published in vitro studies of cavities extending below the cemento-enamel junction, using dye penetration after thermocycling to assess marginal gap formation, have shown less microleakage at dentine/glass polyalkenoate junctions than at dentine/composite junctions that used dentine bonding agents (Leirskar and Eriksen 1986, Walker and Lacy 1986, Fayaad and Shortall 1987, Kanca 1987, Darbyshire et al 1987, Merlo et al 1987, Hembree 1987). An in-vivo clinical trial of Class II sandwich restorations forms part of the work reported in this thesis.

2.4.3. THE BOND PRODUCED BETWEEN GLASS POLYALKENOATE CEMENT AND ENAMEL AND DENTINE

One very important and clinically relevant property of glass polyalkenoate cements, which they share with the polycarboxylate cements is their ability to adhere to enamel and dentine. The precise mode of adhesion of the glass polyalkenoates is unclear. Smith (1968) in his original description of the polycarboxylate cements suggested that the polyacrylate molecule would chelate with the surface calcium of enamel and dentine. However, this would involve formation of an eight-membered ring structure which is both rare and unstable and instead, Beech (1973) proposed that the acid interacted with apatite producing ionised carboxyl groups which could form strong ionic bonds with surface calcium within enamel and dentine. Wilson and Kent (1972) suggest that the metallic ions present within the setting cement could form salt bridges between the polyacid and negatively charged groups on the enamel surface and more recently, Wilson et al (1983) have demonstrated that phosphate and calcium ions are displaced from synthetic apatite by sodium polyacrylate solution. Displacement occurs in an atomic ratio of 1:0.99 (Ca/P) and they propose that phosphate groups are displaced by carboxyl groups from the polyacid, with the loss of calcium ions to maintain electrical neutrality. This may occur during the initial acidic attack when freshly mixed cement is present on the mineral surface. The setting reaction of the cement and the dissolution of the enamel/dentine surface would result in buffering of the polyacid with a consequent rise in the local pH and reprecipitation of the mineral 'soup' at the cement/tooth interface. The resultant admixture would be a calcium phosphate/polyalkenoate crystalline structure acting as an interface between tooth enamel and the set cement.

Although this inorganic explanation could work within dentine to a lesser degree than within enamel, there is also a large organic component within dentine to consider. McLean and Wilson (1977 a) have suggested that adhesion to this organic component may occur through either hydrogen bonding or metallic ion bridging between the carboxyl groups on the polyacid and the collagen molecules.

Whatever the mechanism of adhesion between glass polyalkenoate cements and enamel and dentine, there are four factors that have been shown to influence the measured bond strength:

1. THE PHYSICAL STRENGTH OF THE MATERIAL

   The physical properties, particularly the tensile strength of a material will have an important bearing upon the maximum measured bond strength. Any factor that adversely affects the physical properties will usually have detrimental affects on the bond strength.

2. THE NATURE OF THE SUBSTRATE

   The bond strength to untreated dentine is considerably less than that to enamel (Table 2.6.). This implies the interaction with apatite is superior to that with collagen. The bond strength to enamel is apparently very similar to that achieved with hydroxyapatite (Walls 1986).

3. SURFACE CONTAMINATION

   Prodger and Symmons (1977) demonstrated a reduced bond strength after salivary contamination of freshly cut dentine. This could be due to a dilution of the cement at the cement/saliva/dentine interface, or interference in any surface interactions by a layer of precipitated salivary proteins.

These would interfere with adequate wetting of the contaminated surface.

4. SURFACE TREATMENT AND 'CLEANSING AGENTS'

The surface of a tooth that has been cut by rotary instruments is not clean as there is always a layer of loosely bound smeared debris at the cut surface. This smear layer may prevent, or modify, the adhesion of the cement to the underlying enamel or dentine. Consequently, various agents which dissolve, disrupt or bind together the smear layer have been tested as topical surface treatments in an attempt to improve adhesion to both enamel and dentine (Table 2.9.). Citric acid was the first agent to be used, not only has it been shown to decrease bond strength (Hood et al 1977), but also to have a deterious effect on the pulp (Cotton and Siegel 1978; Tobias et al 1978). E.D.T.A. chelating solution is contraindicated as a surface treatment due to its excessive opening of dentinal tubules and decalcification of dentine (Powis et al 1982), but Powis et al (1982) did find that conditioners based on high molecular weight, with many functional groups capable of interacting with the substrates but not forming soluble complexes, enhanced adhesion to both enamel and dentine and resulted in an increase of bond strength with time (e.g. 25% polyacrylic acid, 25% tannic acid and 0.9% dodicin). These substances are acidic and may act by dissolving and reprecipitating within the smear layer, binding it firmly to the underlying mineral. Tannic acid and dodicin are capable of also reacting with collagen although mechanisms are unclear.

Beech (1985), Barakat and Powers (1986) and Caples et al (1988) found no improvement in bond strength using polyacrylic acid as a dentine pretreatment. The latter authors also found no improvement with ferric chloride or ferric oxalate as a dentine pretreatment contrary to the findings of Shalabi et al (1981) and Powers et al (1982). Causton and Johnson (1979 a, 1982) used a mineralising solution (I.T.S.) which elevated the shear bond strength of glass polyalkenoate cement to dentine. It is thought that the solution may act by crystallising within the smear layer, binding it more firmly to the underlying enamel/ dentine surface. However, Beech (1985) could not find any worthwhile improvement in bond strength to dentine either with I.T.S. or any of the other advocated pretreatments.

The wide variation in bond strength between glass polyalkenoate cements and dentine with or without surface treatments are a reflection of the difficulties of bond strength testing (Beech 1985). These variations are compounded when using a natural tissue which may be subject to variation in structure between teeth and between persons and which may be affected by post-mortem change (Causton and Johnson 1979 b).

The resistance to dye penetration after thermocycling is used as an in-vitro investigation of marginal gap formation. Fayyad and Shortall (1987) and Kanca (1987) have shown that the adhesion of glass polyalkenoate to dentine pretreated with polyacrylic acid is superior to that of composite resin to dentine pretreated with bonding agent, and Leirskar and Erickson (1986), without using any polyacrylic acid pretreatment have shown the same advantage. Perkins et al (1988) have demonstrated, using thermocycling, that pretreatment of dentine with

polyacrylic acid prior to placing a glass polyalkenoate base decreases but does not eliminate marginal leakage at the cement-dentinal junction.

TABLE 2.9.

VARIATION IN THE MEASURED BOND STRENGTH OF GLASS POLYALKENOATE CEMENTS TO ENAMEL AND DENTINE (MPa)

Surface Treatment	1 E	1 D	2 E	2 D	3 E	3 D	4 E	4 D	5 E	5 D	6 E	6 D	7 E	7 D	8 E	8 D	9 E	9 D	10 E	10 D	11a E	11a D	11a E
None		6.81 s	3.6 t	1.8 t				2.45 s		0.78 s		2.15 t		4.0 s	4.5 t	2.4 t	3.18 t	3.13 t	4.5 t	2.2 t	3.2 t	4.1 t	4.1 t
Citric Acid		4.16 s	3.2 t	1.7 t	4.05 t	2.92 t		4.33 s		3.53 s		1.92 t				1.6 t	5.57 t	3.67 t					
Ferric Chloride												4.71 t					4.50 t	5.38 t			4.5 t	3.1 t	3.2 t
Ferric Oxalate																					5.2 t	5.4 t	2.7 t
EDTA												2.94 t					5.25 t	2.09 t					
Hydrogen Peroxide					2.56 t	1.46 t												3.26 t					
Polyacrylic Acid																	7.14 t	6.79 t		2.7 t	4.6 t	2.9 t	3.9 t
Tannic Acid																	7.02 t	6.32 t		3.1 t			
Surface-active solution with fluoride																	7.52 t	6.59 t					
Dodicin																	6.33 t	6.33 t					
Phosphoric Acid					2.89 t					2.15 s		1.86 t											
I.T.S.														6.0 s						3.3 t			
Hypochlorite																3.0 t							

E, Bond strength to enamel; D, bond strength to dentine; t, bond strength measured in tension; s, bond strength measured in shear.
1, Hood et al, 1977; 2, Prodger and Symmons, 1977; 3, Hotz et al, 1977; 4, Nation et al, 1980; 5, Yedid and Chan, 1980; 6, Shalabai et al, 1981; 7, Causton and Johnson, 1982; 8, Negm et al; 9, Powis et al, 1982; 10, Beech et al, 1985; 11a, b, Barakat and Powers, 1986.

2.4.4. THE BOND PRODUCED BETWEEN ETCHED GLASS POLYALKENOATE CEMENT AND COMPOSITE RESIN

The concept of bonding composite resin to etched glass polyalkenoate cement was apparently first demonstrated at a course presented in 1976 by J.W. McLean and R.W. Phillips. However, it was not until 1985 that it was widely advocated as an acceptable technique for restorative purposes (McLean et al 1985). The procedure now termed the 'sandwich technique' makes optimal use of the adhesive properties and biocompatibility of the glass polyalkenoate cement and the superior mechanical properties and desirable surface and aesthetic appearance of the composite resin.

The success of the sandwich technique depends on achieving a reasonable bond strength between the etched glass polyalkenoate cement and the composite resin and its bonding agent (unfilled resin). The matrix of hardened glass polyalkenoate cement dissolves in acid resulting in a rough and porous surface. During bonding, the unfilled intermediate resin layer penetrates in to the etched porosities creating mechanically retentive tags. Rougher etch patterns can be produced by using phosphoric acid in preference to citric acid (Causton et al 1986), increasing the concentration of the phosphoric acid (Pairman et al 1987), increasing the duration of the etch with phosporic acid (Smith 1986) or by increasing the duration of the washing time after etching (Hinoura et al 1987 a). However, a bond can be obtained without prior acid etching of the glass polyalkenoate (McLean et al 1985). This has been attributed to the voids normally present on the unetched surface which lead to an increased surface area of cement and also produce physically retentive 'holes' into which unfilled resin flows.

The presence of and the wettability of the unfilled resin layer plays a significant part in the development of the union between composite resin and glass polyalkenoate cement. Unfilled resins with low viscosity and low contact angles produce superior bonds to filled resins with higher contact angles (Mount 1987 a, b; Hinoura et al 1987b), and if unfilled resins are used which require mixing, they should be used immediately as prolonged standing results in an unacceptable contact angle (Mount 1987 b). Utilisation of the acid etch technique should not be used without the unfilled resin layer as this will lead to a poorer bond between the glass polyalkenoate cement and the composite resin (Causton et al 1986, Godoy and Malone 1986). However, Hassan and Nathanson (1987) report that a higher shear bond strength between glass polyalkenoate - composite resin can be achieved by using a dentine bonding agent as opposed to an enamel bonding agent. This is an interesting finding and probably occurs due to better adaptation of the dentine bonding agent to the cement surface, resulting in improved mechanical retention.

The time after commencement of mixing of the glass polyalkenoate before it is acid etched has a bearing on the resultant bond strength between the cement and composite resin (Norling and Duke 1985, Causton et al 1986, Wexler and Beech 1986, Chin and Tyas 1987). If the cement is not set, the application of acid etching solution will result in loss of both matrix and glass particles, produce a weaker cement when it does set and result in poorer mechanical retention of resin tags. The composition of different glass polyalkenoate cements will mean that the recommended times before etching will differ. Manufacturers instructions should be followed

closely but the clinical temptation will always be to hasten an operative procedure and this is a potential problem area with the sandwich technique.

The duration of acid etching necessary to produce an adequate bond has been the subject of recent debate. When the technique was in its infancy, 60 seconds was the usual time employed and there are still authors who advocate this (Hassan and Nathanson 1987). However, many authors now regard 30 seconds as adequate (Hinoura et al 1987b) and some even recommend 15 seconds (Smith and Soderholm 1987). The manufacturers of Ketac Bond now recommend that their product is etched for only 30 seconds (ESPE Update 1987).

Quantitative test values of the bond produced between etched glass polyalkenoate cement and composite resin range from:

(a) in tension: 0.9 - 6.1 MPa (Wexler and Beech 1986, Chin and Tyas 1987, Hinoura et al 1987);

(b) in shear: 1.49 - 10.3 MPa (Norling and Duke 1985, Sneed and Looper 1985, Smith and Soderholm 1987, Garcia-Godoy et al 1988); and

(c) in 3 point flexural testing: 7.8 - 12.4 MPa (MacLean et al 1985).

Despite differences in the bond strength values between different cements and between different authors for the same cements, the bonds tested failed in a predominantly cohesive manner within the glass polyalkenoate cement. In other words, when a composite resin is bonded to an etched glass polyalkenoate cement, the resultant bond is stronger than the cohesive strength of the glass polyalkenoate.

The implications of this information are considerable. Powis et al (1982) reported that the glass polyalkenoate bond to dentine is

between 3.1 - 6.8 MPa and Chin and Tyas 1987 gave values of 4.47 - 5.5 MPa. Therefore, a composite resin bonded to an etched glass polyalkenoate base should provide an improved retentive form for the overall restoration.

Additions of metal powders or fibres to glass polyalkenoate cements can improve strength. Seed and Wilson (1980) found that metal fibres were best for increasing flexural strength, and Simmons (1983) suggests mixing amalgam alloy powders into cements. He subsequently developed this system clinically under the name 'Miracle Mix'. Unfortunately, the simple additions of either metal powders of fibres did not improve abrasion resistance and may even reduce it compared with regular glass polyalkenoate cement (Moore and Swartz 1985). The solution to the problem of improving abrasion resistance was suggested by McLean and Gasser (1985 a, b) who sintered the metal and glass particles together at high temperatures effectively eradicating the weak metal/polyacrylate matrix interface. A number of metal powders were tried including silver-tin, silver, gold, palladium and titanium, but clinical experiments (McLean and Gasser 1985 a) showed gold and silver to be the most suitable. The new sintered metal glass composites were called Cermets and when ground to a fine powder they retained their properties due to the metal remaining firmly bonded in the glass. Although cermet-polyalkenoate cements have improved abrasion resistance when compared to regular polyalkenoates, and also higher flexural strength, their strength is still insufficient to replace amalgam alloys.

There is little published data on the bond produced between etched glass cermets and composite resin, but Thornton et al (1986)

suggested that the addition of silver to glass polyalkenoate cement resulted in a poorer bond tested in tension while Chin and Tyas (1987) found the opposite when comparing for Ketac Silver-composite and Ketac Bond-composite, also tested in tension.

Recent discussions on the bond between glass polyalkenoate cements and composite resin have centred around the question: to etch or not to etch? Many authors report quantitative test values of the bond produced between unetched cement to be significantly less than etched values (McLean et al 1985; Norling and Duke 1985; Hinoura et al 1987a; Smith and Soderholm 1987; Joynt et al 1987; Nara and Dogon 1987; Draheim et al 1987; Garcia-Godoy et al 1988), and adhesive failure on testing is more common. However, Sheth et al (1988), have reported that the tensile bond strength of resin to some unetched glass polyalkenoate surfaces may be comparable to etched surfaces. In their experiments, they used a dentine bonding agent, as opposed to an intermediate unfilled resin, between the cement and the composite resin. Smith and Soderholm (1987) reported that washing only of the cement for 30 seconds produced a bond of superior quality to the unetched and unwashed cement, but one that was still inferior to the etched and washed specimens. It is possible that a longer wash would achieve a comparable effect to acid etching and has been investigated in work reported in this thesis.

The resistance to dye penetration after thermocycling of the etched bond has been reported. Gordon et al (1985) and Kanca (1987) found no dye penetration while Fayad and Shortall (1987) reported the converse. Dye penetration tests simply indicate the presence of a marginal gap and do not predict clinical consequences, but if dye penetration is occurring at the interface of the etched bond then it

may be a weak link in the clinical situation.

2.5. ACID TREATMENT OF ENAMEL DISCOLOURATION

2.5.1. INTRODUCTION

Endemic dental fluorosis was first described in 1916 (Black and McKay 1916), but it was 15 years later that other investigators discovered the causative agent (Smith et al 1931). The brown and white tooth stain of fluorosis has a tremendous psychological impact on the patient. It is as disfiguring as many birthmarks, facial scars or developmental anomalies and many patients complain that friends, acquaintances and families have associated the stained teeth with smoking or poor oral hygiene. In the adolescent peer, teasing can be very unsympathetic. Not surprisingly, a number of treatments have been advocated to reduce or remove this condition.

2.5.2. ACID TREATMENTS

The first recorded use of an acid to remove fluorosis stains was by Dr. Walter Kane in Colorado Springs in 1916 (McCloskey 1984). After he protected the gingiva with cotton rolls, the six maxillary anterior teeth were rubbed with hydrochloric acid. The flame of an alcohol torch was then applied directly to the acid-drenched area so that the heat would force the acid into the enamel and dentine. Results were apparently aesthetically pleasing and no tooth was lost. Latterly, he abandoned the alcohol torch for a warmed instrument before finally depending on the acid alone to accomplish stain removal. One of Dr. Kane's patients was recently visited and reported by Croll (1987) and she recalled no pain during application of heat by alcohol torch and the excellent results of the treatment were apparent even after 60 years.

Unfortunately, Kane's methods never received widespread exposure or acceptance because he never published his findings and other dental surgeons were wary of using a caustic agent such as hydrochloric acid in patients' mouths. Despite other authors continuing to advocate its use (Raper and Manser 1941, McMurray 1941, Smith and McInnes 1942) most clinicians avoided the use of acids because they feared damage to and destruction of enamel which would render the tooth more susceptible to caries (Younger 1942).

With hydrochloric acid losing favour a hydrogen peroxide-ether mixture with heat application to individual teeth by way of a heated instrument gained popularity (Ames 1937, Younger 1942, Smith and McInnes 1942). However this often required many treatments over a number of weeks and the heat application usually caused significant discomfort that required analgesia.

McInnes (1966) reported the use of a 30% hydrogen peroxide, 36% concentrated hydrochloric acid and anaesthetic ether mixture. This solution was applied with a cotton tip applicator and sodium bicarbonate powder in distilled water was used as a neutralising agent. However, this method had its disadvantage: little pressure could be applied using a cotton tip applicator; the working solution must be mixed immediately before application; the patients seemed to have a great deal of discomfort and the results were only temporary. Slight modifications of the McInnes method using fine sandpaper discs with the bleaching solution (Bailey and Christen 1968, 1970; Colon 1973) and fine sandpaper discs with a bleaching solution containing added sodium hypochlorite solution (Chandrea and Chawla 1975; Murrin and Barkmeier 1982) have been reported and although initial results were favourable, no mention was made of the permanence of results.

McClosky (1984) has recently described a simple and seemingly effective method of eliminating brown fluorosis stain from cosmetically prominent enamel surfaces using 18% hydrochloric acid. The acid is applied either with cotton wrapped over the end of a steel instrument and rubbed onto the labial surfaces or mixed with fine pumice and applied to the labial surfaces in a rubber prophylaxis cup running at less than 2000 r.p.m. This technique, for which a sodium bicarbonate in distilled water paste is ready to neutralise any spill onto tissue, was slightly modified by Croll and Cavanaugh (1986). They advocated a series of 5 second hydrochloric acid-pumice paste applications to be delivered on a wooden stick with an abrading action. Results are very impressive (Croll and Cavanaugh 1986 a, b) and are expected to be permanent (Croll and Cavanaugh 1986 c). The authors recommended that the acid-pumice abrasion procedure should be considered prior to other methods in the treatment of cosmetically prominent enamel colour defects, regardless of their aetiology.

2.6. THE IN VIVO ASSESSMENT OF RESTORATIVE MATERIALS

2.6.1. INTRODUCTION

The in vivo assessment of restorative materials is not an easy task. It is necessary to achieve high degrees of diagnostic accuracy and reproducibility to monitor even subtle changes in the form or shape of a restorative material in vivo, but at the same time, it is just not possible to subject the patient to the stringent measuring techniques that could be used in vitro. Therefore, although direct (in vivo) methods exist, indirect techniques have been developed that utilise dies and models made from impressions recorded in the mouth. However, difficulties of in vivo assessment do not end here because there is also an inevitable difference between individual patients, both in terms of the extent and position of the restoration to be placed, and with regard to patient co-operation.

These factors combine to produce a situation where it is difficult to achieve meaningful results without using large numbers of patients over as long a period as possible.

The in vivo assessment of restorative materials can be broadly divided into two areas:

(a) Prospective clinical trials; and

(b) Retrospective clinical studies.

2.6.2. PROSPECTIVE CLINICAL TRIALS

The clinical trial should be performed with rigidly applied controlled standards of restorative care, patient management, follow up and assessment. Clinical trials give results which relate to the properties of a material when used as decided prior to the trial

The results are gleaned from an analysis of the changes that occur in the restorations under observation.

Methods of assessment can be divided into direct and indirect:

2.6.2.1. DIRECT ASSESSMENT

The U.S.P.H.S. (Ryge) criteria for the clinical evaluation of restorations were developed by Dr. Gunnar Ryge and his associates in the United States Public Health Service (Cvar and Ryge, 1971). The criteria includes evaluation of anatomic form (wear), marginal adaptation, colour match, cavosurface marginal discolouration and caries, and is based on judgements or decisions that are compatible with the typical clinical observations of a dentist. When all the criteria are used, this remains the only assessment system that gives the profession a reasonably complete picture of the clinical performance of a restorative material (Glantz et al 1984). Anatomic form is the category that evaluates clinical wear in the Ryge criteria. Table 2.10 illustrates how this evaluation is performed. These criteria have been criticised for the relatively small number of 'discriminant points' in each ranking scale. Indeed Smales (1983) has demonstrated that there have to be gross differences between treatments for significant results to become apparent using this type of assessment.

Dennison, Powers and Charbeneau (Dennison et al 1980), modified the Ryge criteria by adding an additional division in the category of anatomic form which distinguished between localised loss of restorative material or loss of multiple areas exposing the enamel wall (Table 2.11). This modification does attempt to discriminate within the broad bravo range of Ryge, but remains rather

Table 2.10 US Public Health Service (Ryge) criteria rating system for evaluating posterior composite resin restorations.

Category and rating	Criteria
Colour match	
Alfa	Restoration matches adjacent tooth structure in colour, shade, or translucency.
Bravo	Mismatch in colour, shade, or translucency but within normal range of adjacent tooth structure.
Charlie	Mismatch in colour, shade, or translucency outside of normal range of adjacent tooth structure.
Cavosurface margin discolouration	
Alfa	No discolouration anywhere on the margin between the restoration and the tooth structure.
Bravo	Discolouration present but has not penetrated along the margin in a pulpal direction.
Charlie	Discolouration has penetrated along the margin in a pulpal direction.
Anatomic form	
Alfa	Restoration is continuous with existing anatomic form.
Bravo	Restoration is discontinuous with existing anatomic form, but missing material is not sufficient to expose dentin or base.
Charlie	Sufficient restorative material is missing to expose the dentin or base.
Margin adaptation	
Alfa	No visible evidence of a crevice along the margin into which the explorer will penetrate.
Bravo	Visible evidence of a crevice along the margin into which the explorer will penetrate or "catch".
Charlie	Explorer penetrates into crevice, and dentin or base is exposed.
Delta	Restoration is mobile, fractured, or missing, either in part or in toto.
Secondary caries	
Alfa	No caries at margin of the restoration as evidenced by softness, opacity, or etch at the margin.
Bravo	Evidence of caries at the margin of the restoration.

Supplemental criteria rating system for evaluating interproximal composite resin restorations.

Category and rating	Criteria
Axial contour	
Alfa	The axial contour of the restoration is continuous with the existing tooth form and with normal proximal embrasures.
Bravo	Restoration is slightly under- or overcontoured.
Charlie	Restoration is moderately under- or overcontoured.
Delta	Restoration is unacceptable because of extreme under- or overcontour and associated soft tissue damage.
Interproximal contact	
Alfa	Contact is tight and it is difficult to pass dental floss between the restoration and the adjacent tooth.
Bravo	Contact is light and it is relatively easy to pass dental floss between the restoration and the adjacent tooth.
Charlie	There is no contact between the restoration and the adjacent tooth.
Hotel	Not applicable because of no proximal surfaces involved.

Table 2.11.

Anatomic Form (Dennison et al 1980)

A - Restoration continuous and harmonious with occlusal morphology
B - Loss of restorative material in local area - enamel wall exposed
C - Loss of restorative material in multiple areas - enamel wall exposed
D - Loss of restorative material with dentin or cement base exposed.

insensitive. These authors also used casts to evaluate subjectively the wear. Using modified criteria for anatomic form, they assessed the degree of occlusal morphology lost at specific time intervals (Table 2.12) but, once again, significant discriminating power was not gained by this method.

Mahler and Marantz (1979) have suggested the use of serial photographs of restorations, taken using a standardised technique, and then compared with a series of 11 'control' photographs demonstrating increasing severity of breakdown for a given restoration. The comparative stage can be performed both under standard conditions and 'blind'. Intra-oral stereophotogrammetry has also been described in an attempt to measure material loss in vivo (Eick et al 1984).

Comparisons between the aforementioned Ryge, Dennison and Mahler assessment techniques have revealed that the lack of precision of the U.S.P.H.S. criteria results in difficulty in detecting small variations between materials and changes occurring in the short-term (e.g., 6 months to 2 years). Conversely comparing photographic records with a series of standard pictures gives a greater number of significant differences between materials, but inter and intra-examiner variability is also greater than with the U.S.P.H.S. system. The quantitative data from stereophotogrammetric analysis gave a better correlation with results achieved using the U.S.P.H.S. criteria than with photographic comparisons (Smales 1983, Ryge et al 1983, Eick et al 1983).

A major criticism of the Ryge criteria was that it lacked sensitivity and yielded only qualitative data. Development of indirect methods of evaluation have mainly been stimulated by the desire to obtain more discriminating or quantititative data. This is

Table 2.12

Evaluation of Models (Dennison et al 1980). Criteria for Anatomical Form (Comparison of 18 months to Baseline)

Criteria	Rating
No visible loss of occlusal morphology	1
Generalized loss of material but morphology still evident	2
Complete loss of occlusal morphology	3

important if we wish to measure subtle differences between the wear characteristics of different materials. However, a word of caution from Dr. Ryge, 'statistically significant' differences between materials may not be 'clinically significant'. (Ryge 1983b).

2.6.2.2. INDIRECT ASSESSMENT

The methods described in this section all involve recording an impression of the restored tooth, and then examining the impression on a replica cast from that impression in vitro. Impressions are usually recorded using an addition or condensation cured silicone rubber material and a suitable replica constructed, usually from an epoxy resin material.

Jorgensen and Asmussen (1978) measured the height of the exposed cavity walls on epoxy casts made from silicone impressions. Measurements were made with a stereo-microscope fitted with an ocular measuring scale, allowing readings with an accuracy of 10 - 15μm. 4 points could be measured reproducibly on casts of premolars and 6 on casts of molars. A possible weakness of this method is the limited number of reproducible points that could be measured, and therefore, the lack of a more complete evaluation of the material lost from the entire restoration. The authors also observed the casts with a scanning electron microscope at the linear magnification between 50 and 10,000 times.

Dennison, Powers and Charbeneau (Dennison et al 1980) determined volume loss using a coping impression technique. Stone casts were made from polyether impressions, a metal coping was cast to fit each baseline cast and a silicone impression or wafer was made

of the interspace between casting and model for each subsequent evaluation period. At each time interval, the average weight of the wafers was determined and an average volume loss of material was calculated relative to baseline. Problems encountered with this technique included high technique variables associated with trimming and removing silicone wafers, and the fact that quantitative data obtained from the silicone wafers, did not differentiate among the restorative materials tested, and also gives volume loss - not depth loss.

Urquiola and Charbeneau (1981) modified the method used by Dennison et al (1980) by using an acrylic tray and addition reaction silicone impressions of baseline and subsequent recall casts, and by then weighing the amount of mercury entrapped between the baseline and recall impression. This method had greater precision, but data from all restorations was grouped together when presented, and no comparison was made within patients, and volume loss - not depth loss was the parameter measured.

De Rijk, Conner, Jennings and Wu (1984) took into account the need to have test material and control within the same patient. Restorations in partial dentures of the test and control material in the same tooth were clinically graded by 2 operators using an explorer and a low power (20 x) stereo-microscope. In their results the standard deviations were greater than the means themselves, thus highlighting the difficulty of implying quantitative data from a system based on qualitative assessment.

A profilometer has been used to measure clinical wear by at least 2 investigators (Lutz et al 1979 and Mitchem et al 1982). Lutz used copper dies made from silicone rubber impressions of M.O.D. Class

II composites in lower first molars. Mitchem on the other hand placed Class I composites into cavities contained in nickel chromium cast replications of mandibular first molar denture teeth, and profiled stone replicas from impressions of these. Material wear was measured as an increase in the distance from the deepest point of the profile curve at specific reference points to the reference plane, for both these methods. A criticism of Mitchem's method is that dentures and denture teeth are not always in occlusion, and so this system is somewhat artificial comparied with the Lutz method.

Leinfelder and Goldberg (Goldberg et al 1981; Leinfelder et al 1983) developed a method of comparing casts with 6 standard casts of differing amounts of wear ranging from no observable to severe wear. However, as a discrete quantitative method this system may be only as discriminating as the evaluators can reproduce it (Eick, 1985). This technique also only measures wear at margins.

Occlusal mapping using stereo imaging systems with or without computer aided analysis, have been described using both visible light (Williams et al 1983) and from intra-oral stereophotographs (Eick et al 1984). These are used to produce precision contour maps of the replica/impression before and after wear. Any areas of material loss can then be identified and volumetric loss computed providing a suitable reference point is established. Alternatively, Lambrechts et al (1984) and Roulet et al (1983) have suggested precision occlusal mapping using optical measurement systems, again utilising a replica technique, with material loss calculated against a known reference plane. A disadvantage of this latter system is expense and this consideration also applies to the method of occlusal mapping by

profilometry utilising computer graphics and servohydraulics (De Long et al 1985). However, a useful feature of this latter method is that the graphics enable the operator to visualise the wear in relation to the surface anatomy in addition to quantitatively measuring it.

Vrijhof et al (1985) described a technique using a custom made cast silver overlay for each prepared tooth. The overlay is prepared from a base line replica and surface impressions of the original and subsequent by after wear replicas were made using the overlay as a 'special tray' with a low viscosity silicone rubber material. The weight of the resultant impression was used to calculate the volumetric loss of material from the surface of the restoration as a whole.

Recently a photogrammetric method has been described by Chadwick (1988). Replicas of trial restorations borne by partial denture teeth are obtained at four monthly intervals. A mechanical jig is then used to orientate and mount the replicas for photography and a stereopair of each replica is obtained using a camera attached to a stereo microscope. The area of most catastrophic wear is identified on the negative of the most recently obtained replica. This point is then transferred by means of a template to all preceding negatives. Each stereopair is then viewed on a stereo comparator and the depth of wear relative to a fixed reference point is computed. This method claims greater reproducibility and accuracy than previous photogrammetric methods.

The accuracy of all the indirect techniques is dependent upon 2 factors: the dimensional stability of the impression material and die materials used (Kusy and Whitley 1985), and the ability to relocate different replicas of the same tooth to allow measurement from known reference planes. This can only be achieved by preparing visible

reference points in tooth enamel, in areas that are not going to be subject to significant abrasion or erosion, so that they may be clearly identified at a later stage. Such a procedure as this would require ethical approval.

2.6.3. RETROSPECTIVE CLINICAL STUDIES

An alternative approach to the assessment of the durability of a material is to retrospectively monitor its performance over a protracted period of time. Such analyses can be undertaken on the basis of the work of a single practitioner (Hunter 1981), or on that of a large number of individuals (Elderton 1983, Patterson 1984, Walls et al 1985).

This type of long-term follow up study is less discriminating than a carefully controlled clinical trial. The type of amalgam or composite material used by the group studied may not be known, or many different types of material may be used by different practitioners. There will also be marked variation in the standards and criteria of diagnosis (Elderton and Nuttall 1983). As a result, data on the performance of a restoration are related to the restoration type, i.e., a Class I amalgam restoration, or a Class III composite restoration, rather than to the performance of specific materials. Despite these problems, the great advantage of retrospective studies is that they give results which relate to the performance of materials when used under less than ideal conditions.

In summary therefore, what evaluation methods should be used to determine wear in clinical research studies? In short-term studies of less than 2 years in duration, the U.S.P.H.S. system does not

discriminate sufficiently between materials, the amount of wear that does occur is often at the limits of accuracy of more sophisticated methods, and actual results, regardless of method obtained, may not reflect long-term performance. In long-term evaluations of greater than 2 years, the U.S.P.H.S. gives meaningful data on the general clinical behaviour of the material, sophisticated methods could be used to give quantitative confirmation to clinical assessments and overall results are generally meaningful, particularly if followed up to 5 years and beyond. In spite of the number of difficult methods of assessment of wear reported here, the best method for measurement of wear is undecided. Should most importance be attached to maximum depth loss, average depth loss or volume loss?

The clinical trials in this thesis involve a considerable number of patients. It was not feasible to entertain ideas of any indirect method of wear assessment, and therefore only a modified U.S.P.H.S. (Ryge) criteria was used, together with occasional photography.

SUMMARY

Glass polyalkenoate cements and composite resins are tooth coloured restorative materials that have undergone successful laboratory development from their promising but crude precursors to the products that we use today. Each material has specific clinical applications and within their limitations each is capable of replacing tooth tissue to give an appearance that may be indistinguishable from natural tooth.

Glass polyalkenoates have two great advantages over composite resins:

1. They can bond to enamel and dentine (thus retaining the ability of one of their precursors the zinc polycarboxylate cements to undergo physico-chemical adhesion with enamel and dentine); and
2. They are capable of continuously releasing ionic fluoride from the surface of the restoration. This may prevent recurrent decay around the restoration both at the cavity margins and in the depths of the cavity.

The early glass polyalkenoate cements had problems of brittleness, lack of translucency, and lengthy duration of set, but advances in materials science within the last decade have resulted in materials which are now improved in all these areas. Nevertheless, with regard to these three areas, the glass polyalkenoates remain inferior to composite resins.

Composite resins, coupled with the widespread use of acid etching of enamel to achieve micromechanical retention, now occupy a position of previously unparalleled importance in aesthetic dentistry. They are capable of being prepared in a number of different opacities

for specific applications, and a wide variety of filler types are now used ranging from 'macrofillers' to very small 'microfillers'. The variations in filler content give the specific resin pastes their individual characteristics.

Macrofilled materials have high physical strengths, low coefficients of thermal expansion and lower setting contraction. In vivo wear is a problem, especially in posterior cavities, leaving roughened surfaces that are susceptible to plaque accumulation and staining. Microfilled materials have poorer physical strengths, higher coefficients of thermal expansion and higher setting contraction. They are still susceptible to wear, but their surface finish is capable of maintaining a lustre that is more resistant to staining and plaque accumulation. Their use in posterior load bearing cavities results 'initially' in little wear, but this is followed by a rapid breakdown after a longer period, particularly in the occlusal contact area. Hybrid materials consisting of both macro and microfillers were subsequently developed in the hope that they would produce an ideal combination of properties. Worldwide clinical trials of several materials are now ongoing to ascertain their applicability as a posterior restorative material. One such material on trial is 'Occlusin'.

Unfortunately, bonding of composite resins to dentine cannot be achieved in a similar manner to which bonding to enamel is obtained. Despite the introduction of bonding or coupling agents to facilitate a union in this situation, the cervical area of Class II composite resin restorations remains a problem. It has been suggested that a layer of glass polyalkenoate cement at the base of a Class II box between the dentine, cementum or residual thin layer of enamel, and the composite

resin may be a solution. A cement has been formulated (Ketac Bond) for this purpose which is both radiopaque and has optical properties similar to dentine.

Progress in materials development can only be achieved by close correlation of in vivo and in vitro tests results. In vitro test methods may then be identified which are valuable clinical indicators. However, there can never be a laboratory substitute for performance evaluation 'in the field'.

This literature review poses the following hypotheses:

Null hypothesis: "Amalgam and glass polyalkenoate last the same length of time in deciduous teeth."

Null hypothesis: "Amalgam and minimal composite restorations last the same length of time in permanent molar teeth."

Null hypothesis: "The sandwich technique is a solution to cervical gap formation in Class II composite resin restorations."

Hypothesis: "Microfilled composite resin veneers perform better than mastique laminate veneers in the adolescent and young adult patient."

Hypothesis: "A method for removing enamel stains by acid abrasion, first practised 70 years ago, still has a place in the armamentarium of modern dental techniques."

Hypothesis: "Pre-treatment of dentine with polyacrylic acid results in a stronger tensile bond to glass polyalkenoate cement."

Hypothesis: "Etching of glass polyalkenoate cement is required to produce a satisfactory bond with composite resin."

Hypothesis: "The tensile bond strength of the glass cermet cement Ketac Silver to composite resin is superior to that formed between conventional glass polyalkenoate cements and composite resins."

It is hoped that these hypotheses will be answered during the course of this piece of work.

3.

PLAN OF WORK

The investigations undertaken in this study can be divided into 2 major groups. Those undertaken in vivo and those undertaken in vitro.

IN VIVO RESEARCH

Five clinical trials have been performed:

1. To compare a glass polyalkenoate cement (Ketac-Fil) with amalgam (Amalcap) as an all purpose restorative material in the deciduous molar dentition.
   Pairs of restorations were placed in the same patient, using a random design to allocate restorative material within each patient's mouth. The restorations were assessed at regular intervals over a period of up to 5½ years.
2. To compare a minimal composite restoration associated with a fissure sealant (Prismafil and Prismaseal) with an amalgam restoration for the management of early occlusal caries in permanent molars of children and young adults.
   Pairs of restorations were placed in the same patient using a random design to allocate restorative material within each patient's mouth. The restorations were assessed at regular intervals over a period of up to 5½ years.
3. To evaluate the durability and clinical performance of a Class II glass polyalkenoate (Ketac Bond) - composite resin (Occlusin) sandwich restoration in premolars and first permanent molars of adolescent and young adult patients.
   The restorations were assessed at regular intervals over a period of up to 24 months.
4. To determine the durability and clinical performance of a

microfilled composite resin veneering system (Heliocolor) for the management of discoloured, hypoplastic, spaced or rotated anterior teeth in children and young adults.

The composite resin was placed in the buccal surface of the anterior teeth, and the gingival health, the presence of marginal staining and the incidence of material loss were monitored over a period of up to 30 months.

5. To determine the efficiency of the hydrochloric acid - pumice abrasion technique in the removal of stains of superficial enamel aetiology in upper anterior teeth of adolescents and young adults.

The clinical appearance of the teeth and the presence of any post-operative sensitivity were monitored over a period of up to 18 months.

IN VITRO RESEARCH

The in vitro studies can be divided into 3 major areas of inquiry:

1. The investigation of the mechanical, chemical, and biomechanical properties of:

(a) Ketac Bond, a glass polyalkenoate cement recommended for use in the sandwich technique;

(b) other glass polyalkenoate cements (one as yet unmarketed); and

(c) a cermet material.

These investigations include examination of properties particularly relevant to cement usage in the Class II sandwich technique.

2. The investigation of the mechanical properties relevant to the use of the microfilled composite resin (Heliocolor) as an anterior

veneering agent.

3. The investigation of the depth of enamel removed during the hydrochloric acid-pumice abrasion technique.

4.

MATERIAL and METHOD

4.1. IN VIVO STUDIES

4.1.1. GLASS POLYALKENOATE CEMENTS

4.1.1.1. CLINICAL MATERIAL

Patients attending the Department of Child Dental Health for routine restorative care were assessed for inclusion in this trial. Subjects were admitted to the trial if they were under 11 years of age and required at least one pair of restorations in their deciduous molar dentition. Paired cavities were either Class I or Class II in nature and if possible, they were in the same tooth type (i.e. in the first or the second deciduous molars).

Any cavity was suitable for inclusion in the trial, whether it was the result of caries on a previously undamaged site or if it arose as a consequence of recurrent decay or loss of a pre-existing restoration. Site specificity for the 2 restorative materials was allocated using a random permuted block design with a block size of 10. Randomisation was achieved using a pseudo-random number generator. A cavity was deemed as unfit for the trial if, in the clinical judgement of the operator, it could only be satisfactorily restored using a stainless steel crown. Between October 1982, and March 1987, 119 pairs of restorations were placed in 80 patients with an age range of 5 to 11 years, and assessed at regular intervals thereafter. 2 Clinicians were involved in this trial. Clinician 1 (A.W.G.W.) placed 59 pairs of restorations and clinician 2 (R.R.W.) placed 60 pairs.

4.1.1.2. CLINICAL METHOD

Having been assessed as suitable for inclusion in the trial, all patients were treated as follows:

At the first treatment visit, the teeth were isolated with cotton wool rolls and a saliva ejector and a Class I or Class II amalgam cavity was prepared in the allocated tooth. Treatment was performed under local analgesia where required. The cavities were prepared according to the precepts of Andlaw and Rock (1983), with minimal width occlusal keyways and rounded line angles. Cavity preparation was performed with a 541 diamond and a plain cut 6 fluted tungsten carbide bur in a roller bearing air rotor under continuous water cooling, and a plain cut number 6 fluted tungsten carbide bur in a slow handpiece. Caries removal was completed with large round steel burs (Nos. 4, 6 and 8) in a slow handpiece. The initial stages of cavity preparation were usually performed by a student under the direction of a clinician. The clinician then checked the cavity and made any modifications he considered necessary prior to lining. Once the cavity was rendered caries-free, a reinforced zinc-oxide/eugenol (Kalzinol) lining was inserted. A Siqveland matrix band was then placed round the tooth for Class II restorations and wedged interproximally. The cavity was varnished (Copalite) and an encapsulated, conventional, lathe cut, amalgam alloy (Amalcap) was triturated according to the manufacturer's instructions and condensed into the cavity by the author. Packing was performed with a round (Ash instruments No. 153) or oval (Ash instrument No. 151) amalgam plugger as appropriate. The amalgam was condensed until excess was present, then the surface was burnished using a pear-shaped hand

burnisher (Ash instrument Ladmore No. 12) and fresh amalgam was condensed onto the burnished surface before carving the restoration to conform to the anatomical form of the tooth. The surface of the restoration was smoothed with a pledget of cotton wool and the occlusion checked for any premature contacts prior to discharging the patient.

At the second treatment visit a Class I or Class II cavity was prepared to receive a glass polyalkenoate cement restoration. Treatment was again performed under local analgesia where required. Cavity preparation simply comprised removal of any existing restoration and recurrent caries, or removal of sufficient enamel to allow for excavation of any carious dentine (Fig. 4.1.). Cavities were not extended for prevention or into 'self-cleansing' areas. Any grossly undermined enamel was removed either with a slow handpiece or hand instruments and the cavity margins were finished perpendicular to the surrounding enamel. No attempt was made to create retentive undercuts in the prepared cavity. Cavity preparation was performed with the same instruments as described previously, undergraduate students undertook the early stages of cavity preparation, any modifications were performed by the author.

In very deep cavities that were adjudged close to the pulp, a small quantity of quick setting calcium hydroxide cement (Life) was placed in the deepest portion of the cavity to protect the pulp (Fig. 4.2.). A narrow Siqveland matrix band, smeared with a thin layer of petroleum jelly, was adapted to the tooth for Class II restorations. The encapsulated glass polyalkenoate cement (Ketac-Fil) was activated, mixed in a high energy vibrator (Silamat), according to the manufacturer's instructions, and syringed (Fig. 4.3.) directly into

Fig 4.1

The prepared cavity.

Fig 4.2

The cavity isolated and lined with calcium hydroxide.

Fig 4.3

Encapsulated Ketac Fil syringed into the cavity.

Fig 4.4

Occlusal morphology recreated through a 0.5μm.melinex sheet.

Fig 4.5

Restoration coated with polymeric varnish.

Fig 4.6

Final restoration after occlusal adjustment.

Fig 4.1

The prepared cavity.

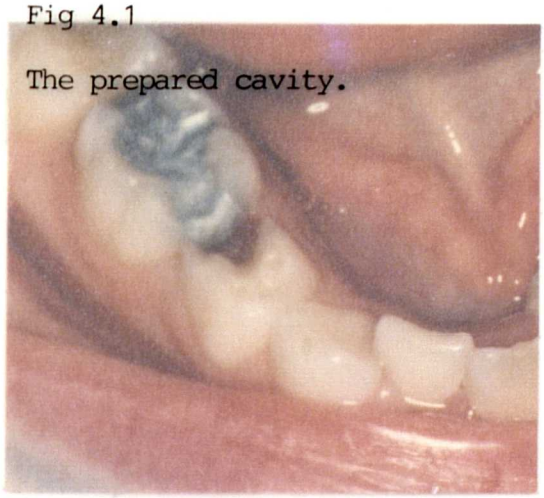


Fig 4.2

The cavity isolated and lined with calcium hydroxide.

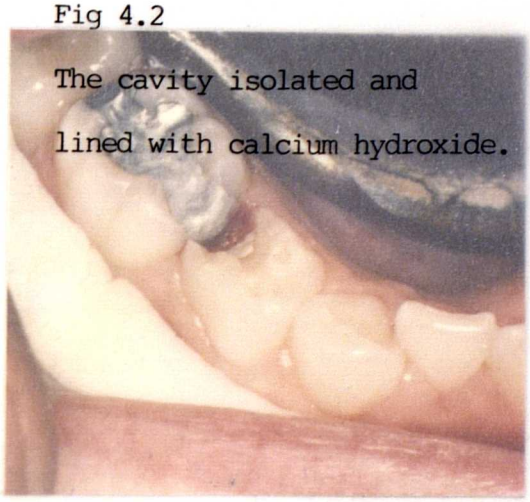


Fig 4.3

Encapsulated Ketac Fil syringed into the cavity.

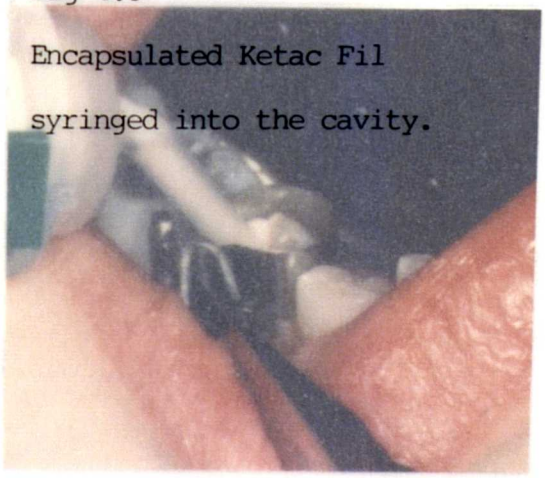


Fig 4.4

Occlusal morphology recreated through a 0.5μm.melinex sheet.

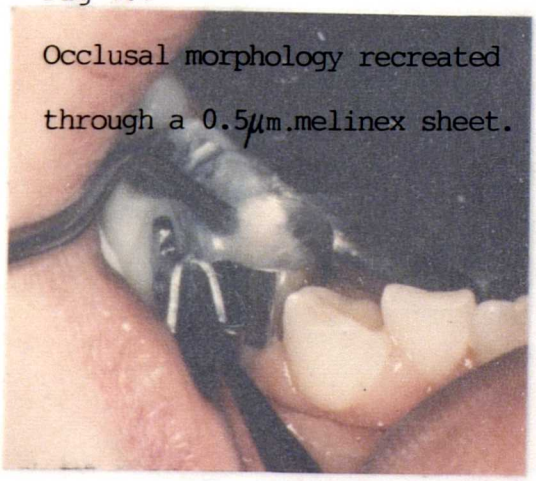


Fig 4.5

Restoration coated with polymeric varnish.

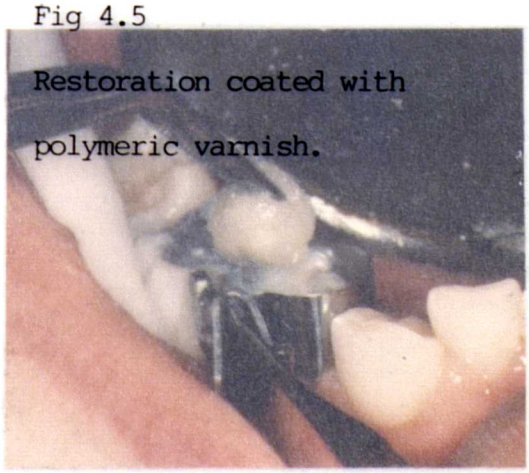
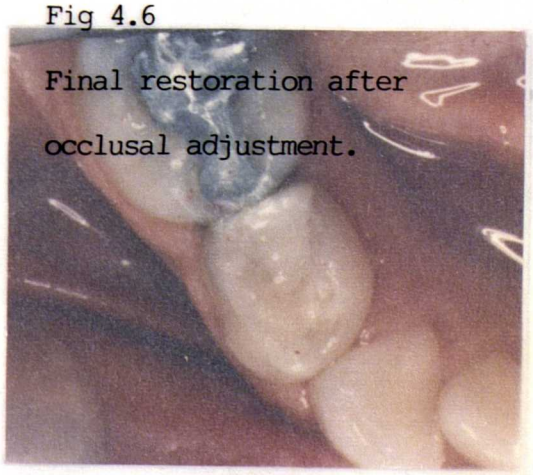
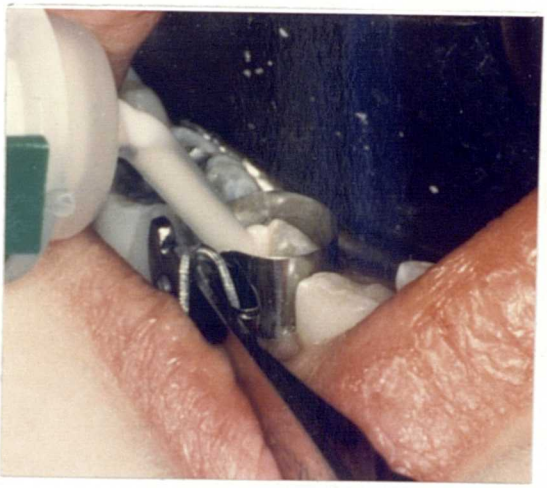
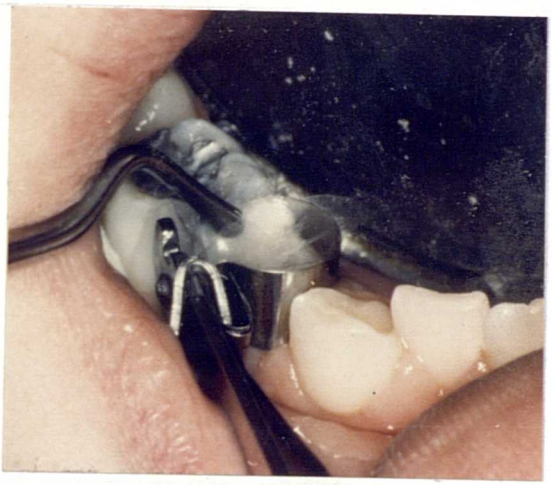


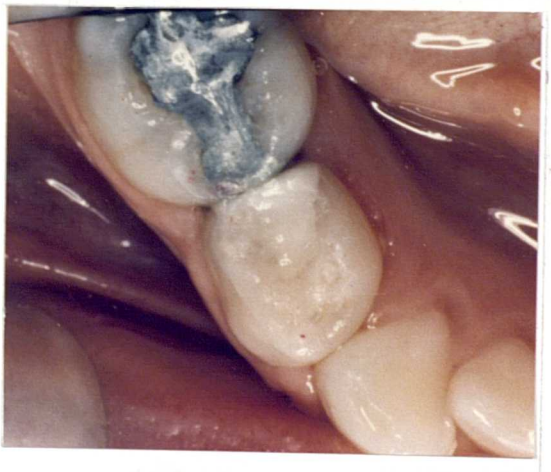
Fig 4.6

Final restoration after occlusal adjustment.









the prepared cavity. Its surface was then covered with a square of 0.5μm Melinex sheeting and the occlusal morphology of the tooth recreated using a plastic instrument through this surface matrix (Fig. 4.4.). The material was allowed to set for 5 minutes (from the time of mixing) and the matrices removed. During matrix removal, the surfaces of the set cement were coated with a polymeric varnish (Fig. 4.5.) to prevent moisture contamination. Any marginal excess was removed and the morphology of the restoration was perfected using sharp hand instruments or a petroleum jelly coated steel bur in slow contra-angle handpiece. The surface was re-coated with varnish after each finishing procedure. The morphology of the restoration was adjusted until it was free from occlusal contacts in centric occlusion and during lateral excursions (Fig. 4.6.).

At the same visit, providing it had been placed more than 7 days previously, the paired amalgam restoration was polished using steel finishing burs in a slow contra-angle handpiece, followed by 3 abrasive slurries on a rubber cup. The abrasive slurries were flours of pumice in water, followed by a proprietary fluoride containing prophylaxis paste, followed by ceric oxide in water. The final lustre was imparted to the surface of the restoration, with a cotton wool pad impregnated with ceric oxide.

The paired restorations were then assessed at baseline and at each subsequent 4 monthly appointment using a modification of the United States Public Health Service scoring criteria (Cvar and Ryge 1971) for anatomical form and marginal integrity and for the presence or absence of recurrent caries (Appendix 1). In addition, the presence or absence of marginal staining was recorded for the glass

polyalkenoate restorations. The outline of the restorations was reproduced on a gridded chart (Fig. 4.7.) and any areas with poor anatomical form, marginal integrity or staining were noted.

Clinician 1 (A.W.G.W.) assessed 58 pairs of restorations for up to 24 months while Clinician 2 (R.R.W.) assessed both these 58 pairs and a further 61 pairs for another 36 months.

Fig 4.7

The graded recording chart used in the glass polyalkenoate clinical study.

Amalgam Vs Glass Polyalkenoate

Study No. ☐☐☐ **Date**

Hospital No.

Name **D O B.**

Type of Restoration ☐ ☐ ☐ ☐

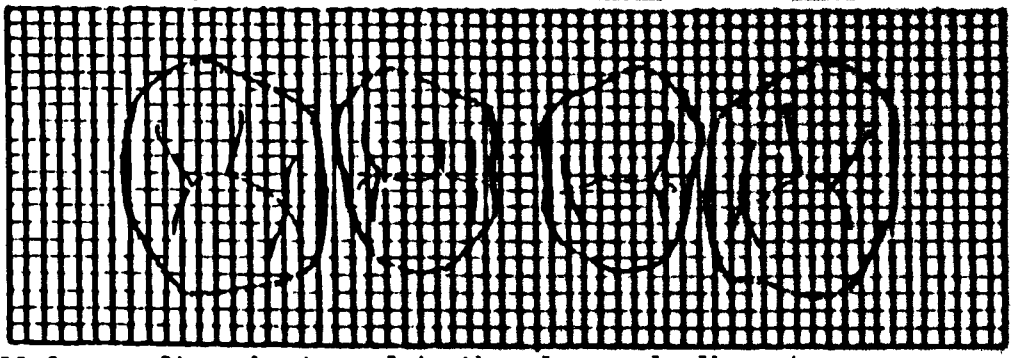
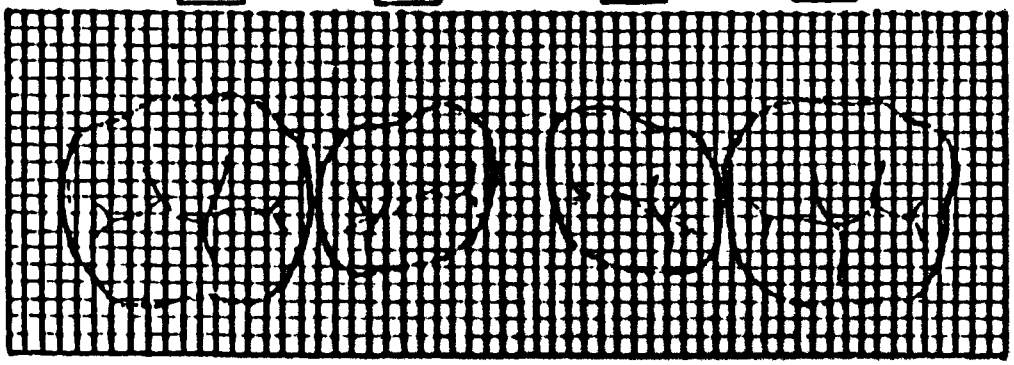


Fig 4.7 The gridded recording chart used in the glass polyalkenoate clinical study.

Amalgam 1 **Glass Polyalkenoate 2**

Type of Restoration ☐ ☐ ☐ ☐



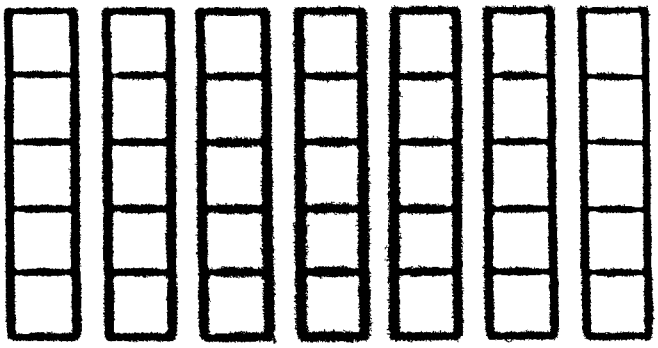
TOOTH

Anatomical form

Marginal Integrity

Caries

Marginal Staining



Amalgam Vs Glass Polyalkenoate

Study No. ☐☐☐

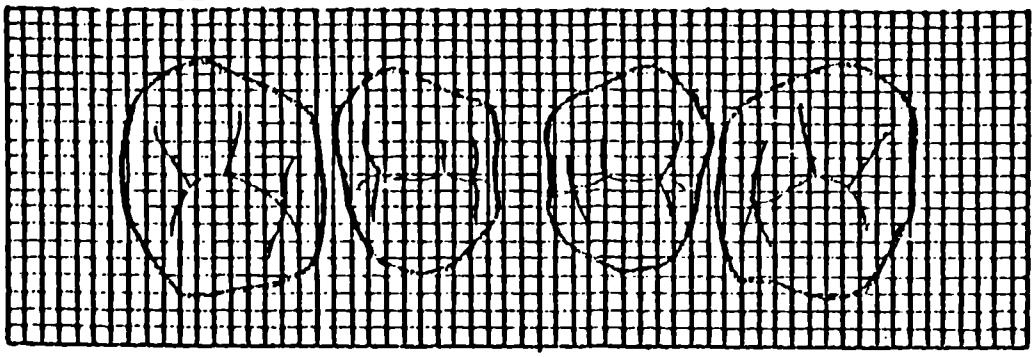
Date

Hospital No.

Name

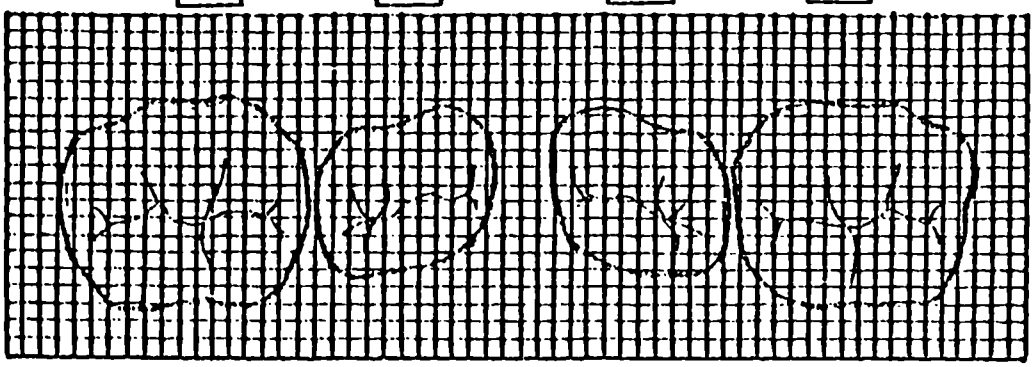
D.O.B.

Type of Restoration ☐ ☐ ☐ ☐



Amalgam 1 Glass Polyalkenoate 2

Type of Restoration ☐ ☐ ☐ ☐



	TOOTH						
Anatomical form	☐	☐	☐	☐	☐	☐	☐
Marginal Integrity	☐	☐	☐	☐	☐	☐	☐
Caries	☐	☐	☐	☐	☐	☐	☐
Marginal Staining	☐	☐	☐	☐	☐	☐	☐

4.1.2. MINIMAL COMPOSITE RESTORATIONS

4.1.2.1. CLINICAL MATERIAL

Patients attending the Department of Child Dental Health at Newcastle Dental Hospital for routine treatment were assessed for inclusion in this trial. Subjects were admitted to the trial if, on clinical and/or radiographic examination, they had 2 small carious lesions or a single small carious lesion and an occlusal amalgam restoration which required replacement in their first or second permanent molar teeth.

A small carious lesion was defined as:

1. Clinically diagnosed fissure caries (diagnosis was made with a sharp dental probe on dry teeth, illuminated with a high intensity mains lighting unit) with no major discontinuity of the overlying enamel.
2. An occlusal cavity which did not extend more than half way through the dentine of the tooth on radiographic examination.

An amalgam restoration was deemed as having failed and needing restoration if:

1. It had fractured, with or without gross loss of restorative material.
2. There was marked marginal breakdown of the restoration.
3. If a diagnosis of recurrent caries beneath the restoration was made from bitewing radiographs. The bitewing radiographs were taken using the bisecting angle technique with a short cone Xray unit. All radiographs were dried and mounted before viewing with adequate, diffused background illumination at the chairside for diagnostic purposes.

Between October 1982, and March 1987, 150 pairs of amalgam/ composite restorations were placed in first and second molars of 103 patients with an age range of 6 to 24 years. These were subsequently assessed at regular intervals.

Site specificity for the restorative procedures was decided using a random permuted block design with a block size of 10. Randomisation was achieved using a pseudo-random number generator. Random allocation was broken if an existing amalgam restoration was assigned to be replaced by a composite restoration. In this case, the composite restoration was placed in the other tooth of the pair and the amalgam was replaced with an amalgam restoration. On no occasion was an amalgam restoration replaced by a composite restoration.

2 Clinicians were involved in this trial. Clinician 1 (A.W.G.W.) placed 85 pairs of restorations and clinician 2 (R.R.W.) placed 65 pairs.

4.1.2.2. CLINICAL METHOD

Once a patient was accepted for the trial he/she underwent the following treatment procedures:

At the first visit, the amalgam control restorations were placed. A local analgesic was administered (2% Lignocaine with 1:80,000 Adrenaline), either by buccal infiltration or inferior alveolar nerve block. The precautions described by Meechan et al (1984) to avoid inadvertent intravascular injection were observed.

The tooth was isolated using cotton wool rolls and a saliva injector. A Black's Class I amalgam cavity (after Andlaw and Rock 1983) was prepared in the tooth assigned to that type of restoration.

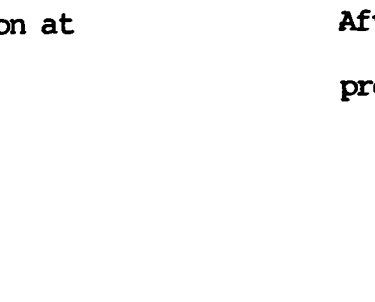
Cavity preparation was performed using the same instruments and techniques as described previously (Section 4.1.1.2.).

Initial cavity preparation was usually performed by a dental student under the guidance of the clinician. The clinician then checked the cavity and performed any modifications to the outline, retention and debridement that he considered necessary, before a reinforced Zinc Oxide/Eugenol (Kalzinol) cement lining was placed as required. The cavity was then varnished (Copalite) and a lathe cut, encapsulated 'conventional' amalgam alloy (Amalcap), which had been triturated according to the manufacturer's instructions, was condensed in place by the author. The restoration was packed, using round and oval amalgam pluggers (Ashe Instruments Nos. 153 and 151) under hand pressure until excess was present. The surface of the restoration was burnished using a pear-shaped hand burnisher (Ashe Instruments Ladmore No. 12) and further fresh amalgam condensed on to the burnished surface. The restoration was then carved to conform to the morphology of the residual tooth surface and to be free from premature occlusal contacts. The surface of the restoration was smoothed with a pledget of dry cotton wool and the patient discharged.

At the second treatment visit, a local analgesic was administered to the second tooth. The tooth was isolated with cotton wool rolls and a saliva ejector (Fig 4.8a) and a cavity was prepared using the same technique as described previously. The extent of the cavity was limited to removal of the amount of enamel required to excavate all carious dentine (Fig 4.8b). No effort was made to extend the cavity along the fissure pattern to achieve 'extension for prevention'. Initial cavity preparation was again performed by a dental

Figs 4.8 a + b

The carious lesion at presentation.



After minimal cavity preparation.

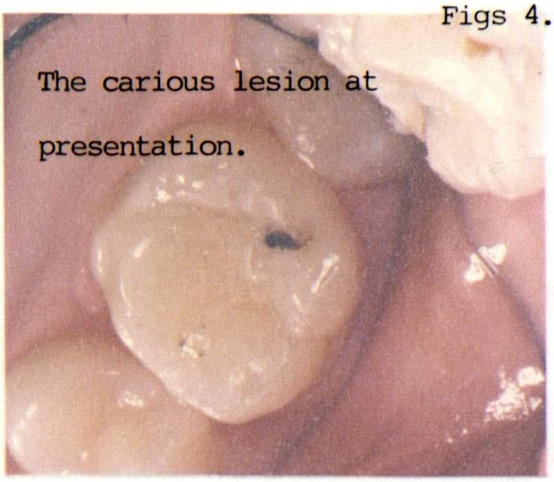
Fig 4.9
Quick setting calcium hydroxide placed over exposed dentine.

Fig 4.10
Prisma-Fil syringed directly into the cavity.

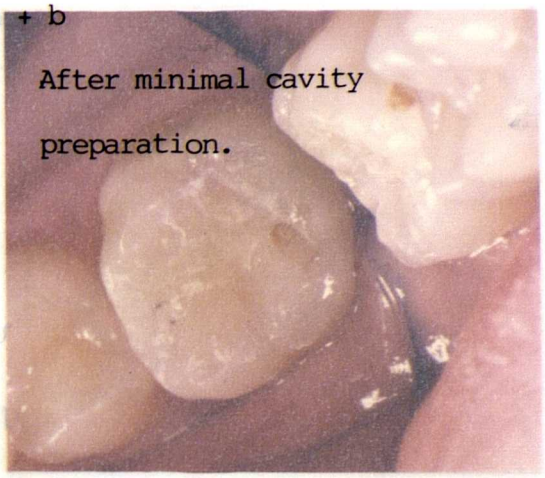
Fig 4.11
Prisma Seal painted over the pit restoration and the remainder of the fissure pattern.

Fig 4.12
The finished minimal composite restoration.

Figs 4.8 a + b



The carious lesion at presentation.



After minimal cavity preparation.

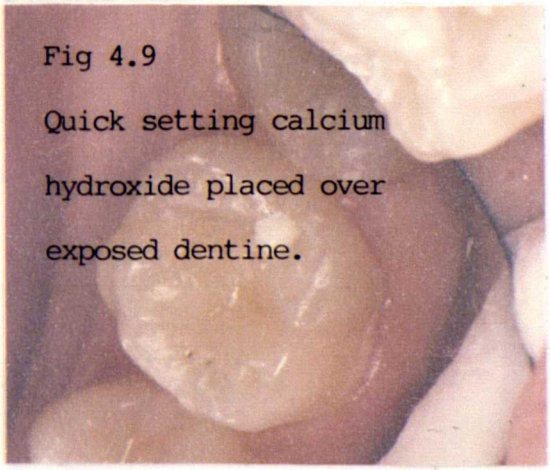


Fig 4.9
Quick setting calcium hydroxide placed over exposed dentine.

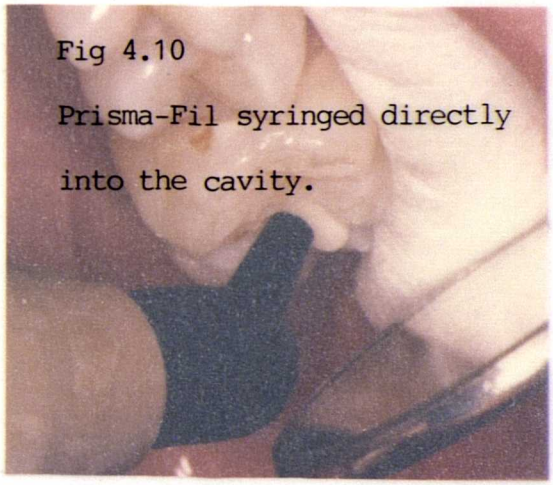


Fig 4.10
Prisma-Fil syringed directly into the cavity.

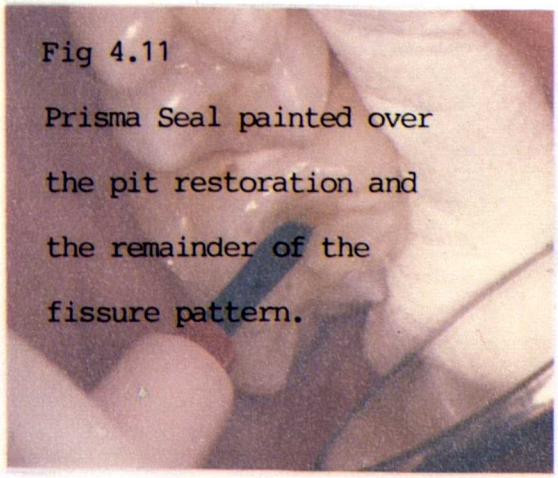
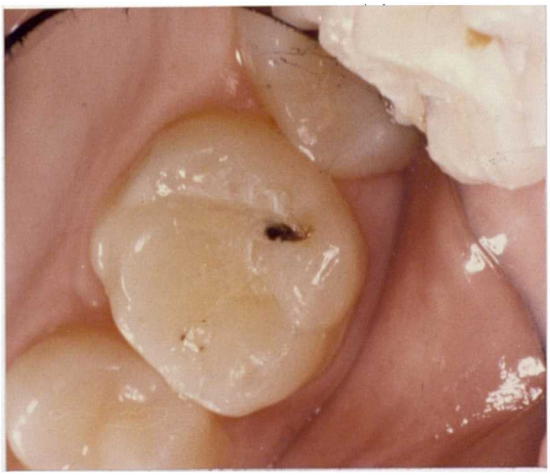
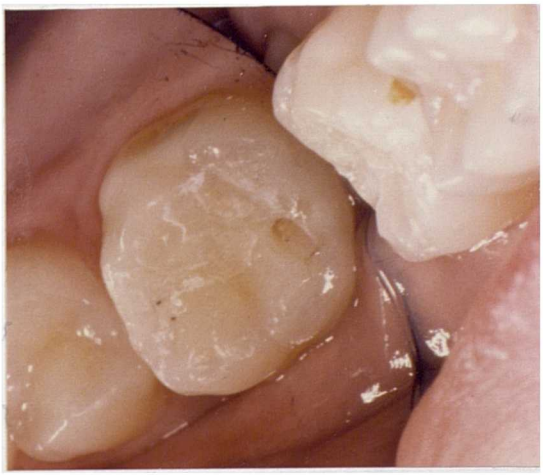
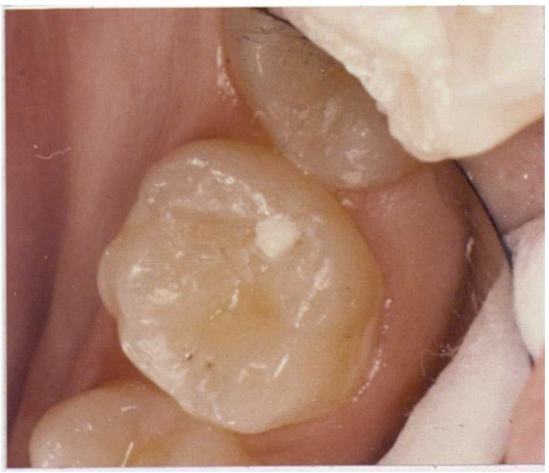


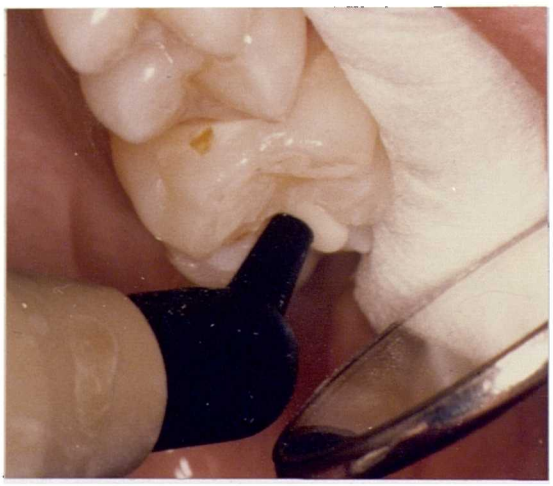
Fig 4.11
Prisma Seal painted over the pit restoration and the remainder of the fissure pattern.

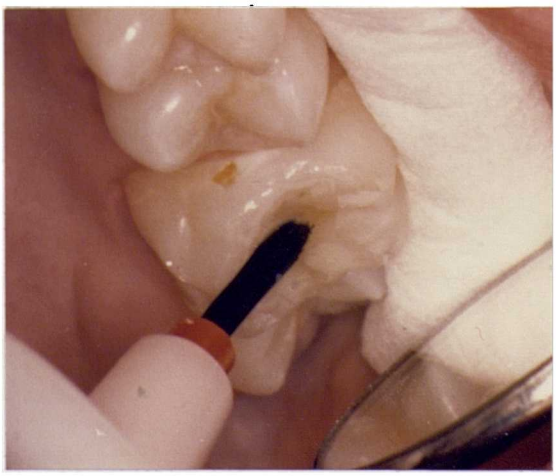
Fig 4.12
The finished minimal composite restoration.

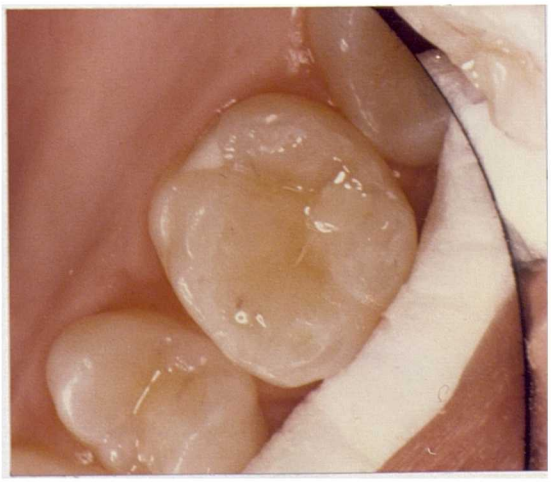












student under the supervision of the author who gave the cavity any necessary 'finishing touches'. A quick setting calcium hydroxide lining (Life) was placed over exposed dentine in the base of the cavity (Fig. 4.9.). The tooth surface was cleaned with a slurry of flours of pumice in water on a bristle brush prior to etching with 37% phosphoric acid on a cotton wool pledget for 60 seconds. The tooth was then washed for 60 seconds and dried with warm oil-free air. If salivary contamination had occurred, then the tooth was re-etched for 15 seconds with acid prior to restoration.

A visible light activated composite resin (Prisma-Fil), supplied in compute form, was syringed directly into the cavity (Fig. 4.10.). The occlusal morphology of the restoration was recreated, using a plastic instrument and a compatible, visible light activated, fissure sealant (Prisma-Seal) material was applied to the whole occlusal surface including the composite material (Fig. 4.11.). The combined restoration was then polymerised with a minimum of 40 seconds of incident light from the manufacturer's recommended polymerisation light - Prisma-Light (Fig. 4.12.).

The occlusion was checked to ensure that there were no premature contacts.

At the same visit, providing it was more than 7 days after its placement, the amalgam restoration was polished using the same techniques as described previously (Section 4.1.1.2.).

The methods for this trial were performed as above unless:

1. The pair of cavities comprised a virgin tooth and a failed amalgam restoration, in which case randomisation was ignored and an amalgam restoration was always replaced by an amalgam restoration. The pre-existing restoration was carefully

removed, along with any recurrent caries and the cavities were modified according to the principles outlined by Elderton (1977), prior to restoration as before.

2. An extensive carious lesion was found, where there was a danger of exposing the pulpal tissue. In this case, a quick setting calcium hydroxide cement (Life) and reinforced zinc-oxide eugenol (Kalzinol) dressing was placed in the tooth for 3 months, prior to a definitive restoration.

3. If the pulp of the tooth was exposed, then a pulp capping procedure, with a quick setting calcium hydroxide cement (Life) was performed prior to restoration.

4. If a cavity in a tooth scheduled for a preventive filling extended to involve more than two thirds of the fissure pattern, it was deemed unsuitable for a composite restoration. The tooth was withdrawn from the trial and, unless there was another suitable cavity in the same patient's mouth, the patient was also withdrawn.

The pairs of restorations were assessed at baseline (after placement of the composite/fissure sealant and polishing the amalgam restoration) and at each subsequent 6 monthly review appointment. The amalgam restorations were scored using a modification of the United States Public Health Service criteria for anatomical form and marginal integrity. The preventive fillings were assessed according to a set of criteria developed for this study, unless the surface wear was sufficiently great to produce loss of marginal integrity or anatomical form; in which case, the same criteria were used as for assessing glass polyalkenoate restorations placed in the deciduous

dentition. The scores for each restoration and any areas of loss of anatomical form, marginal integrity or fissure sealant were noted on gridded form (Fig. 4.13.a.b.). All scoring criteria are given in Appendix 1.

Clincian 1 (A.W.G.W.) assessed 72 pairs of restorations for up to 24 months while Clinician 2 (R.R.W.) assessed both these 72 pairs and a further 78 pairs for another 36 months.

Fig 4.13a

The gridded recording chart used in the minimal composite clinical study - upper arch.

Amalgam vs. Composite

Study No. ☐☐☐ **D.O.B.**

Name **Hosp. No.**

Assessment of Composite Restoration in ☐ ☐

Method of Restoration ☐ ☐ ☐ ☐

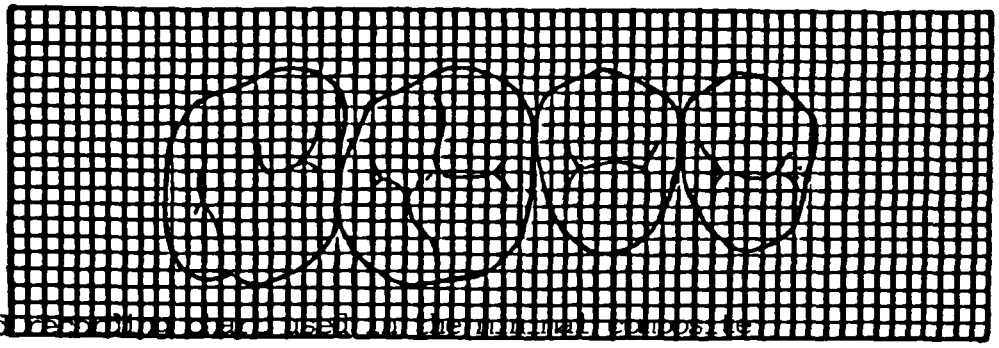
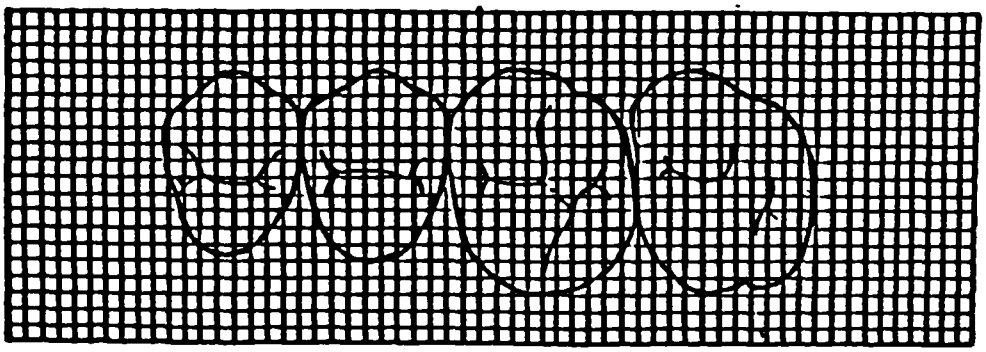


Fig 4.13a

The gridded [illegible] used in the Amalgam vs. Composite clinical study - upper arch.

Amalgam 1 **Composite Resin 2**

Method of Restoration ☐ ☐ ☐ ☐



Assessment of Amalgam Restoration in ☐

1. **Anatomical form** ☐
2. **Marginal integrity** ☐
3. **Caries** ☐

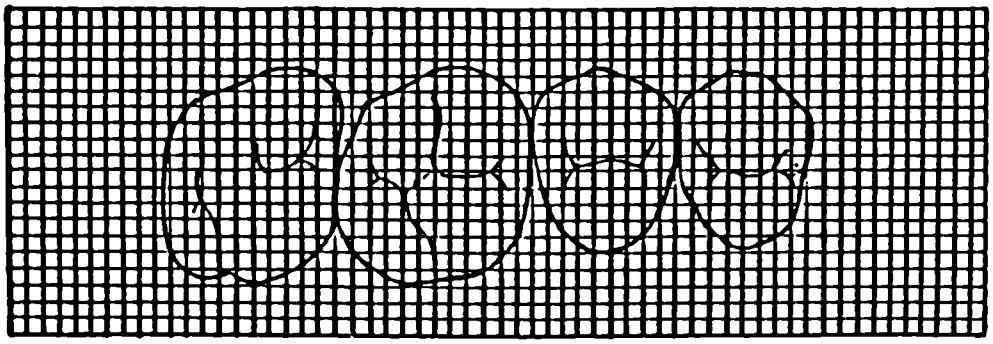
Amalgam vs. Composite

Study No. ☐☐☐ D.O.B.

Name Hosp. No.

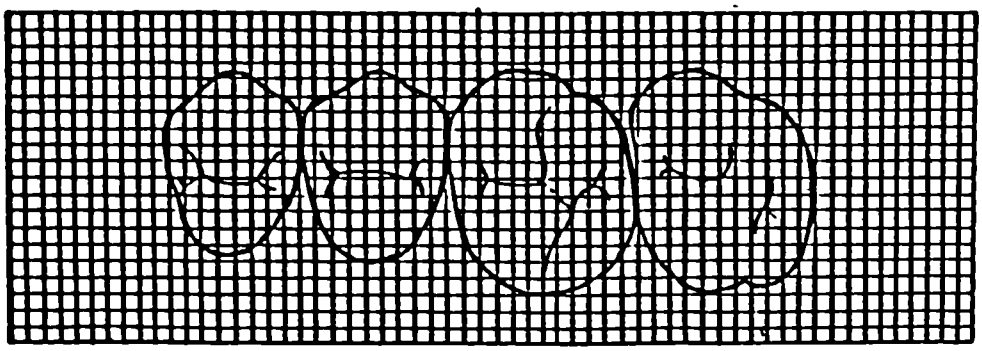
Assessment of Composite Restoration in ☐ ☐

Method of Restoration ☐ ☐ ☐ ☐



Amalgam 1 Composite Resin 2

Method of Restoration ☐ ☐ ☐ ☐



Assessment of Amalgam Restoration in ☐

1. Anatomical form ☐
2. Marginal integrity ☐
3. Caries ☐

Fig 4.13b

The gridded recording chart used in the minimal composite clinical study - lower arch.

Amalgam Vs. Composite

Study No. ☐☐☐ D.O.B.

Date.

Name Hosp. No.

Assessment of Composite Restoration in ☐ ☐

Method of Restoration ☐ ☐ ☐ ☐

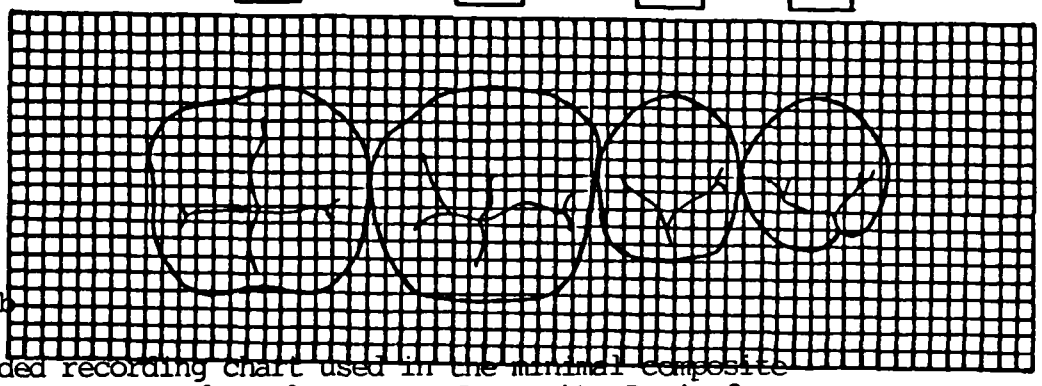
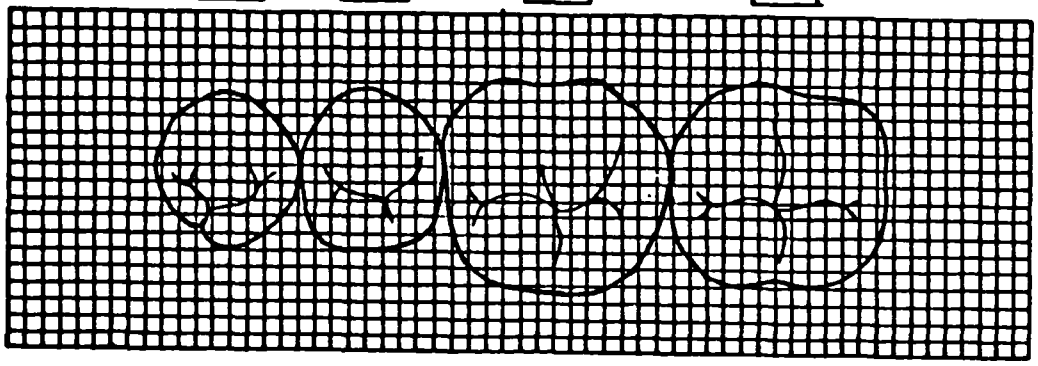


Fig 4.13b The gridded recording chart used in the minimal composite clinical study - lower arch.

Amalgam 1 Composite Resin 2

Method of Restoration ☐ ☐ ☐ ☐



Assessment of Amalgam Restoration in ☐

1. Anatomical form ☐
2. Marginal integrity ☐
3. Caries ☐

Amalgam Vs. Composite

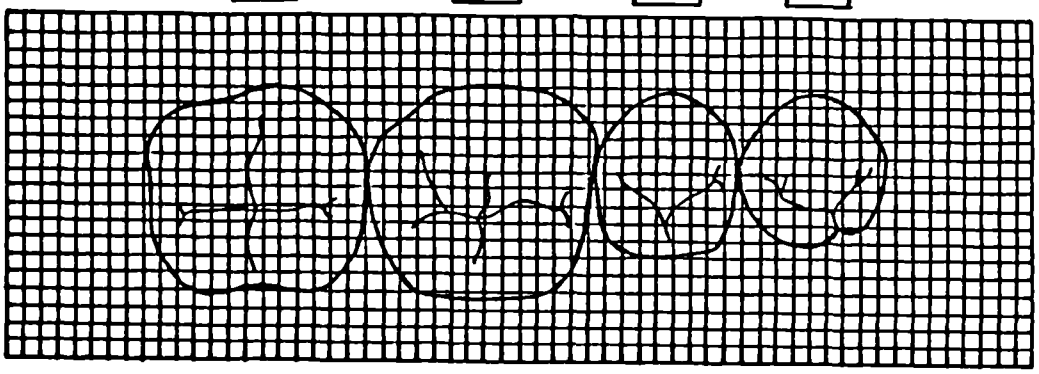
Study No. ☐☐☐ D.O.B.

Date.

Name Hosp. No.

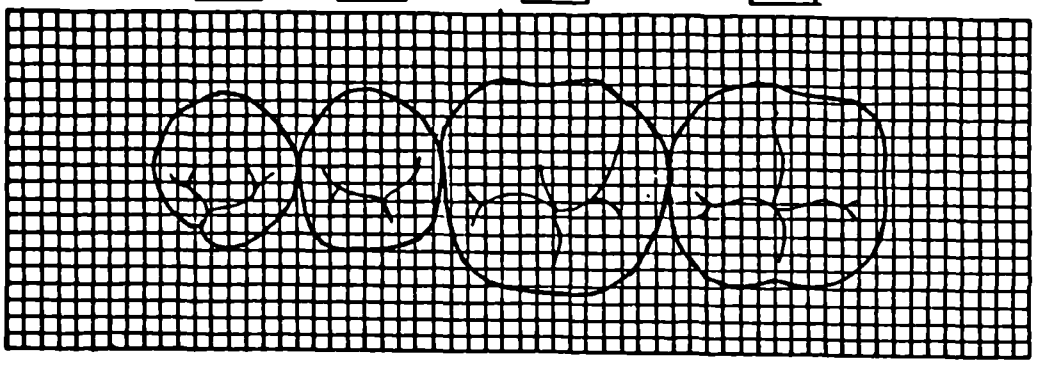
Assessment of Composite Restoration in ☐ ☐

Method of Restoration ☐ ☐ ☐ ☐



Amalgam 1 Composite Resin 2

Method of Restoration ☐ ☐ ☐ ☐



Assessment of Amalgam Restoration in ☐

1. Anatomical form ☐
2. Marginal integrity ☐
3. Caries ☐

4.1.3. GLASS POLYALKENOATE CEMENT - COMPOSITE RESIN SANDWICH TECHNIQUE

4.1.3.1. CLINICAL MATERIAL

Patients attending the Department of Child Dental Health for routine restorative care were assessed for inclusion in this trial. Subjects were admitted to the trial if they had a carious permanent premolar or molar which required a Class II cavity design for restorative purposes. Any cavity was suitable for inclusion in the trial, whether it was the result of caries on a previously undamaged site or if it arose as a consequence of recurrent decay or loss of a pre-existing restoration.

Between March 1986, and July 1987, a total of 49 restorations were placed in 23 patients with an age range of 9 - 26 years. These were subsequently assessed at regular intervals. 1 Clinician (R.R.W.) placed all the restorations.

4.1.3.2. CLINICAL METHOD

A rubber dam was placed prior to cavity preparation which was completed following Black's principles of cavity design for Class II amalgam restorations.

A Tofflemire matrix holder with a very thin Polydent clear matrix band was placed around the tooth and wedged interproximally (Fig. 4.14.). A lining of fast setting calcium hydroxide cement was then placed in deep cavities prior to placement of the glass polyalkenoate cement. Ketac Bond, a non encapsulated glass polyalkenoate cement was then mixed according to manufacturer's instructions and run into the cavity with the aid of a thymozin probe to a depth of 1 - 2 mm. to line

Fig 4.14

The lower left second premolar after cavity preparation.

Fig 4.15

Ketac Bond covering the base of the cavity, the axial wall, and the base of the approximal box out to the approximal surface.

Fig 4.16

Ketac Bond and the enamel margins etched with phosphoric acid gel for 60 secs.

Fig 4.17

Unfilled resin (enamel bond) painted over the cement surface and cavity margins.

Fig 4.18

Incremental packing of composite resin.

Fig 4.19

The completed restoration.

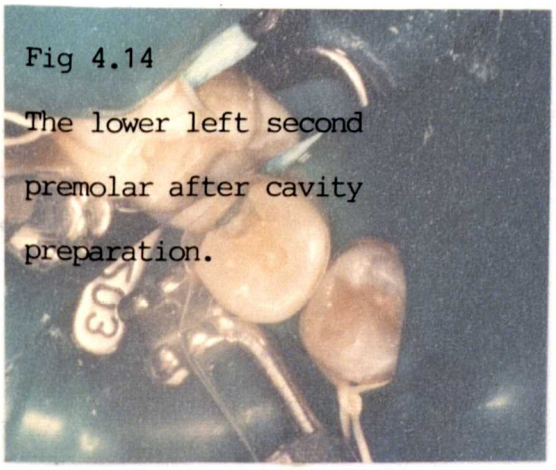


Fig 4.14
The lower left second premolar after cavity preparation.

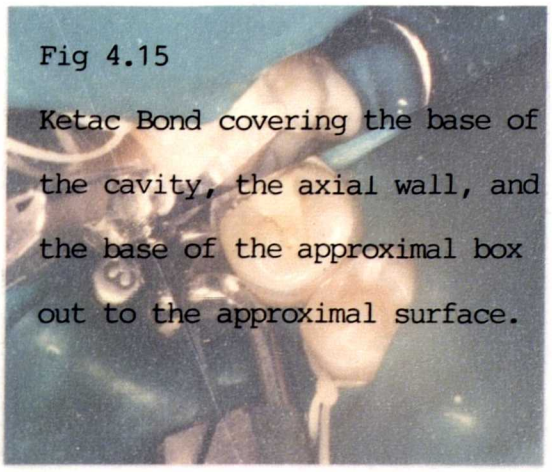


Fig 4.15
Ketac Bond covering the base of the cavity, the axial wall, and the base of the approximal box out to the approximal surface.

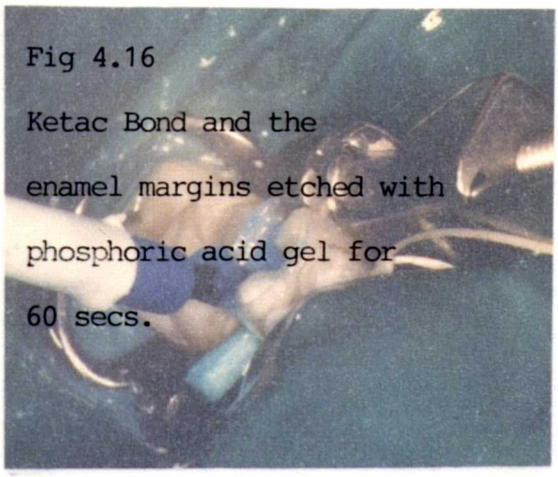


Fig 4.16
Ketac Bond and the enamel margins etched with phosphoric acid gel for 60 secs.

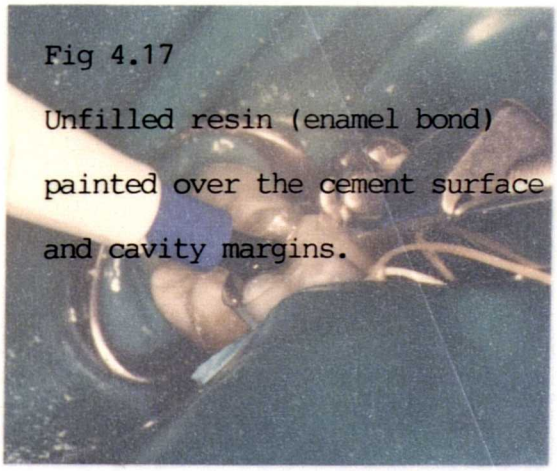


Fig 4.17
Unfilled resin (enamel bond) painted over the cement surface and cavity margins.

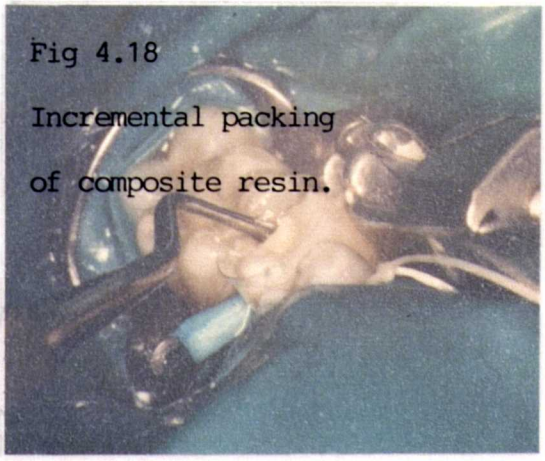


Fig 4.18
Incremental packing of composite resin.

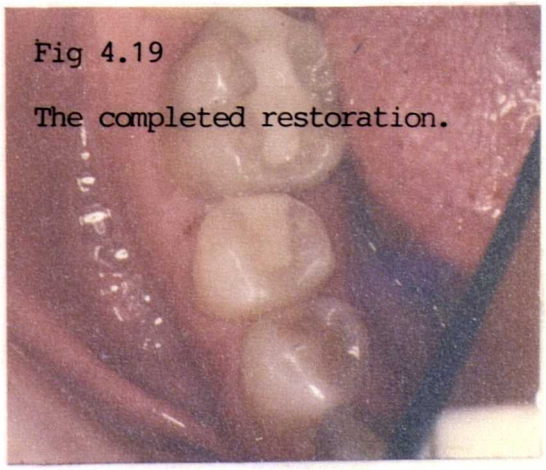


Fig 4.19
The completed restoration.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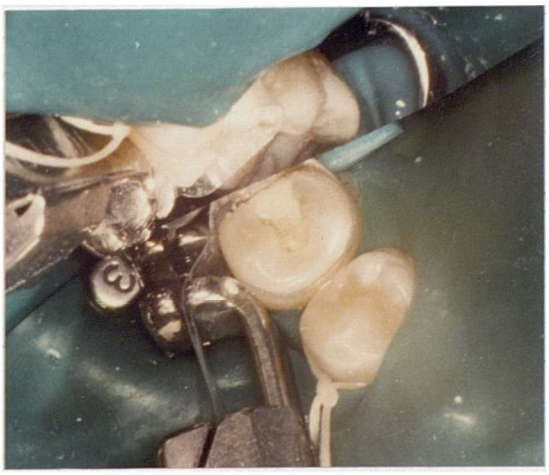
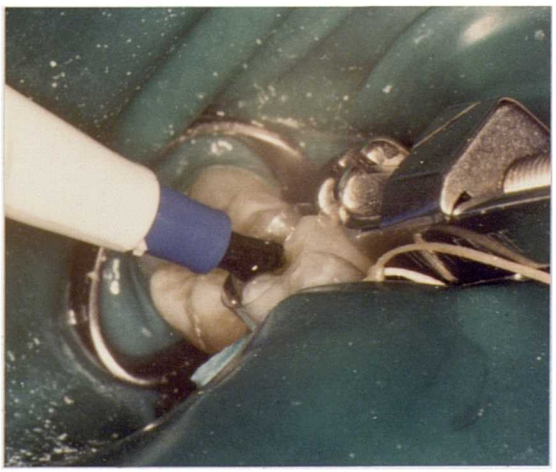
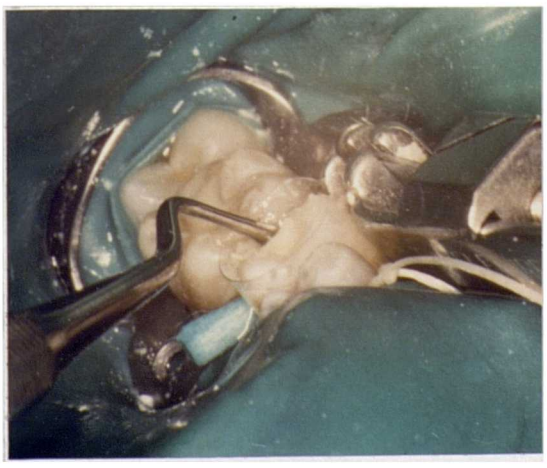
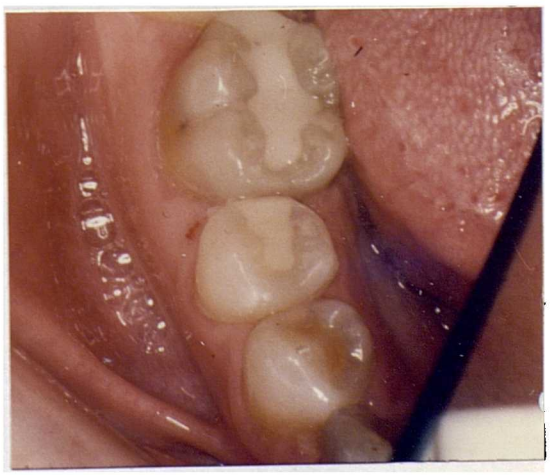








the base of the cavity, the axial wall, and the base of the approximal box out to the approximal surfaces (Fig. 4.15.). After 4 minutes, any excess glass polyalkenoate cement was removed with a sharp excavator and the surface of the cement and the enamel margins etched with phosphoric acid etchant gel for 60 seconds (Fig. 4.16.), then washed for a further 60 seconds before being dried with oil-free air. A thin layer of enamel bond was then painted over the entire cavity and cement surface and cavity margins (Fig. 4.17.) and light cured with a Luxor light for 15 seconds. Occlusin (Pot - Universal shade) was then packed incrementally into the cavity with an amalgam burnisher dipped in enamel bond to prevent the Occlusin sticking to the instrument (Fig. 4.18.). An incremental packing and curing method was employed so that no more than 2 mm. of Occlusin was light cured at any one time. During packing a pre-cured ball of Occlusin was packed into the approximal box to help to establish a contact point with the next tooth (Wander and Paul 1986). To minimise finishing by rotary instruments as much pre-shaping and forming was done before curing with burnishers of different shapes lightly dipped in bonding agent, and occlusal height and contour was facilitated by placing 'Occlustrip' (Polydent) or 'cling film' over the occlusal surface and asking patients to close and perform occlusal excursions. After light curing, the restorations were finished with slow and fast running diamond burs, soflex discs, and finally a green polishing stone (Vivadent). A final glaze was achieved by light curing a thin layer of bonding agent to the surface of the restoration (Fig. 4.19.).

After placement of the restoration, 3 assessments were made:

1. The size of the cavity was classified under the following scoring system:

OCCLUSAL

(1) Cavity extends up the cuspal incline less than 1/4 of the distance from the depth of the fissure to cusp tip.

(2) Cavity extends between 1/4 - 1/3 up the cuspal incline.

(3) Cavity extends greater than 1/3 of way up cuspal incline.

APPROXIMAL

(1) Cavity just clearing contact point areas and into embrasures.

(2) Cavity well into embrasure areas.

(3) Cavity extending onto the buccal and palatal/lingual walls.

DEPTH OF BOX

(1) Above cemento - enamel junction.

(2) At cemento - enamel junction.

(3) Below cemento - enamel junction.

2. A post-operative bitewing radiograph was taken.

3. A clinical photograph was taken.

The restorations were assessed at baseline (1 month post-placement) and at each subsequent 6 monthly review appointment by one clinician (R.R.W.). The restorations were scored using a modification of the United States Public Health Service criteria for posterior composite restorations (Appendix 1). Bitewing radiographs and clinical photographs were taken annually or more frequently if the need arose. The scores for each restoration were recorded (Fig. 4.20.) and any areas of loss of anatomical form, marginal adaption, etc., were noted on a gridded chart (Fig. 4.21.).

Fig 4.20

The clinical assessment chart used in the sandwich restoration study.

LAMINATE RESTORATIONS (SANDWICH TECHNIQUE)

KETAC BOND AND OCCLUSIN IN CLASS II CAVITIES

NAME:

DOB:

HOSPITAL NO: STUDY NO:

DATE OF PLACEMENT:

CAVITY SIZE: OCCLUSAL
APPROXIMAL

DEPTH OF BOX:

DATE										
COLOUR MATCH										
SENSITIVITY										
ANATOMICAL FORM: OCCLUSAL APPROXIMAL										
SURFACE ROUGHNESS: OCCLUSAL APPROXIMAL										
MARGINAL ADAPTATION OCCLUSAL APPROXIMAL										
CAVO MARGINAL DISCOLOURATION										
RECURRENT CARIES										
RADIOGRAPH-BW-										
CLINICAL PHOTOGRAPH										

Fig 4.20
The clinical assessment chart used in the sandwich restoration

LAMINATE RESTORATIONS (SANDWICH TECHNIQUE)

KETAC BOND AND OCCLUSIN IN CLASS II CAVITIES

NAME:

DOB:

HOSPITAL NO: STUDY NO:

DATE OF PLACEMENT:

CAVITY SIZE: OCCLUSAL ☐
APPROXIMAL ☐

DEPTH OF BOX: ☐

DATE										
COLOUR MATCH										
SENSITIVITY										
ANATOMICAL FORM: OCCLUSAL APPROXIMAL										
SURFACE ROUGHNESS: OCCLUSAL APPROXIMAL										
MARGINAL ADAPTATION OCCLUSAL APPROXIMAL										
CAVO MARGINAL DISCOLOURATION										
RECURRENT CARIES										
RADIOGRAPH-BW-										
CLINICAL PHOTOGRAPH										

Fig 4.21

The gridded recording chart used in the sandwich restoration study.

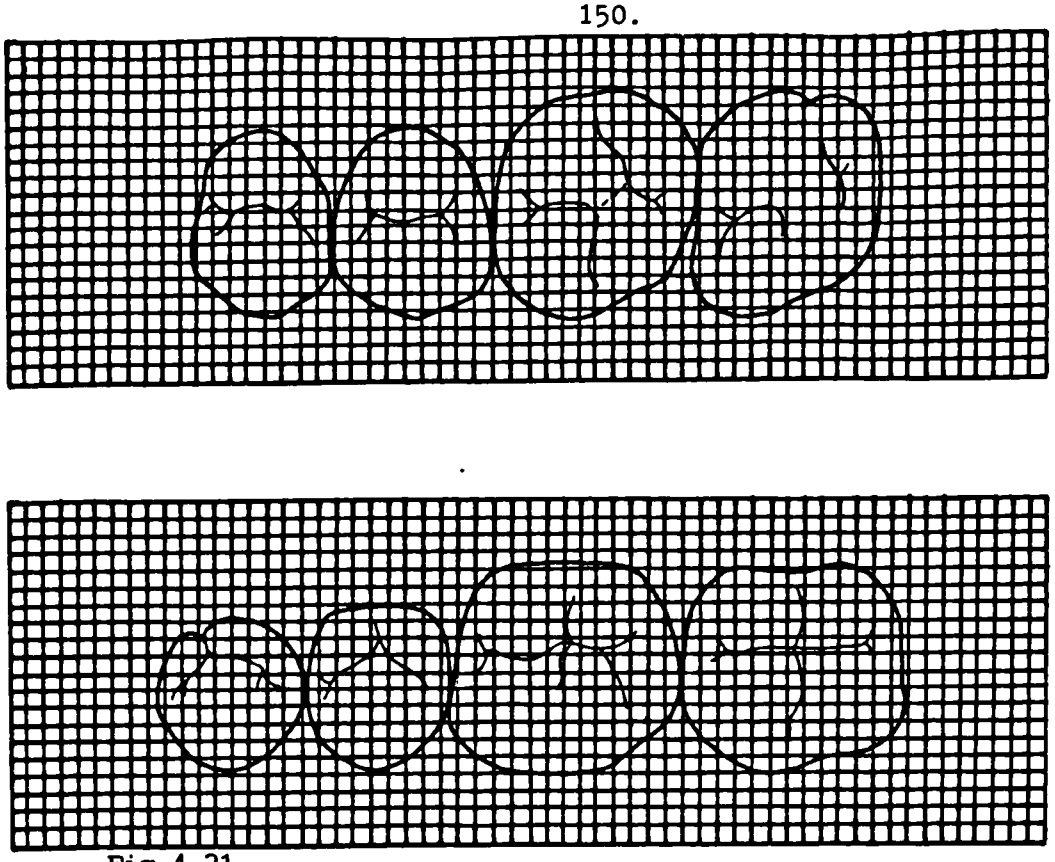
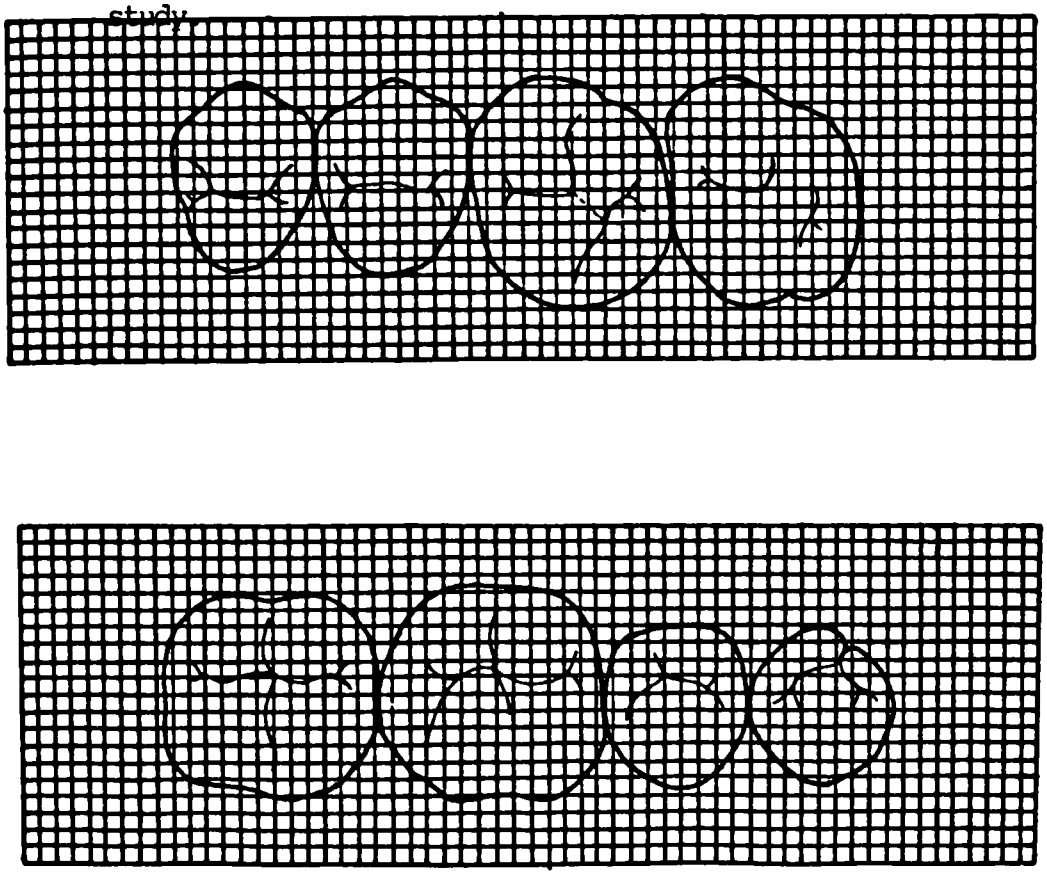
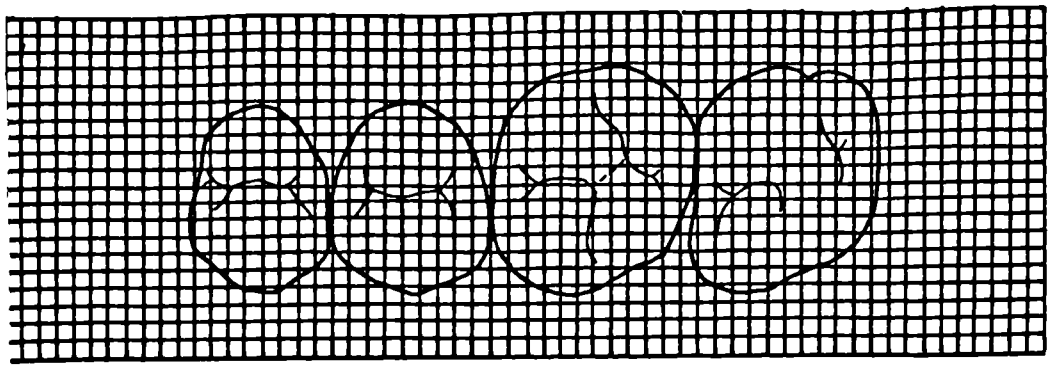
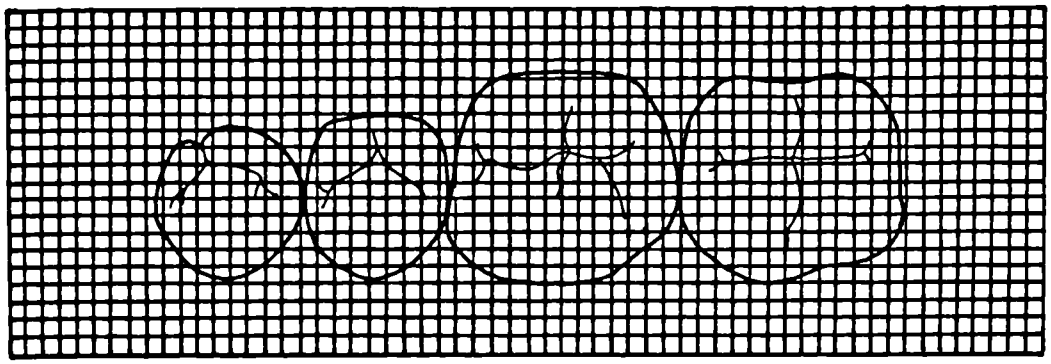


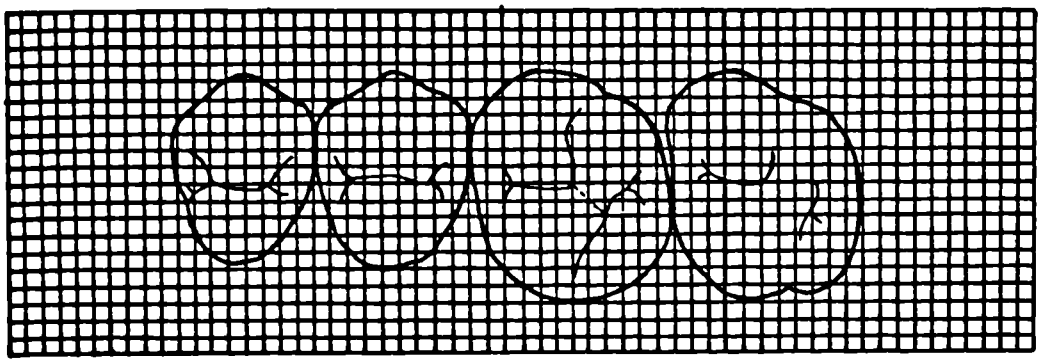
Fig 4.21

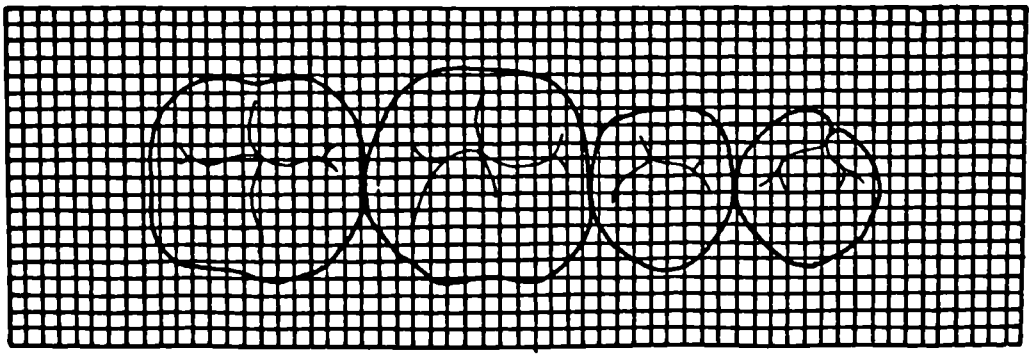
The gridded recording chart used in the sandwich restoration study.











4.1.4. MICROFILLED COMPOSITE RESIN VENEERS

4.1.4.1. CLINICAL MATERIAL

Patients who were referred to the Department of Child Dental Health at Newcastle Dental Hospital for treatment of aesthetic problems concerning their upper anterior teeth were screened for inclusion in this trial. They were provisionally accepted if:

(i) They exhibited intrinsic staining (usually of Tetracycline aetiology), enamel hypoplasia or mottling to a degree that was aesthetically unacceptable to the patient.

(ii) They had suffered loss of tooth tissue as a result of traumatic injury or caries and an old composite restoration was unacceptable.

(iii) They had marked spacing of anterior teeth due either to rotations or hypodontia.

Patients were not included in the trial if they had an Angles Class III type malocclusion with a negative overjet and required treatment to teeth in the upper arch or if they required treatment to teeth solely in the lower arch.

Between November 1984, and March 1987, a total of 66 patients aged 8 - 26 years underwent placement of 287 microfilled composite resin veneers. These patients had all achieved a satisfactory standard of oral hygiene prior to veneer placement. All placement was by 1 clinician (R.R.W.).

4.1.4.2. CLINICAL METHOD

The patients were assessed initially when the nature and extent of any staining/hypoplasia/loss of tooth tissue was recorded

photographically. An assessment was made of the patients' oral hygiene and their gingival health using the Gingival Index (Loe and Sillness 1971) and recorded on a pre-operative form (Fig. 4.22.).

Any patient in whom a Gingival Index of more than 1 was recorded, for any site on the buccal or interproximal surfaces of the teeth to be treated was given extensive oral hygiene instruction. They were instructed in the use of disclosing tablets, a modified Bass short scrub technique of oral hygiene and, if necessary, other methods of interdental cleansing (floss or wood points as appropriate). Patients with a Gingival Index of more than 1 at any anterior site were informed that they could not have veneers placed on their teeth until their oral hygiene had improved.

At the patients' second visit, the oral hygiene and gingival health were checked again and, if they were found to be adequate, the treatment was commenced. Each veneer took approximately 30 minutes to place from tooth preparation to final finishing and only in exceptional circumstances were more than 4 veneers placed at any one visit.

The desired shade for the finished restoration was selected using the manufacturer's biochromatic shade guide under daylight conditions without prior drying of teeth.

All teeth to be veneered underwent buccal enamel reduction of between 0.5 - 1.0 mm. with a tapered diamond bur (Fig. 4.23.). Most commonly, the type of reduction was of 'the feathered incisal edge' type. In a few cases, the 'incisor bevel preparation' was used, and only in rotated or hypodont teeth and those, with appreciable tissue loss, was an overlapped incisal edge preparation used (Fig. 4.24.).

The tooth was isolated with cotton wool rolls and dried. Any

Fig 4.22

The gridded recording chart used in the microfilled composite resin veneer study.

STUDY NO. ☐☐☐ HELIOCOLOR VENEERS

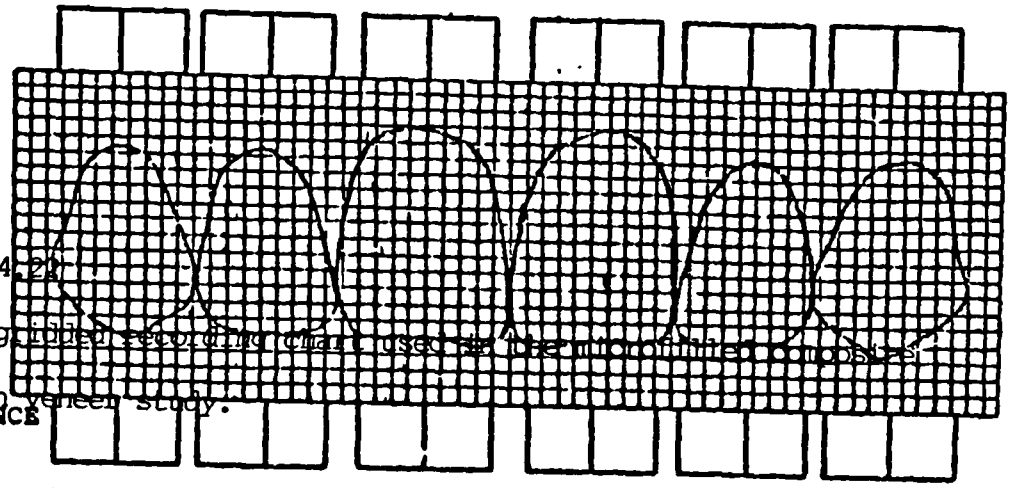
DATE

NAME D.O.B.

NUMBER

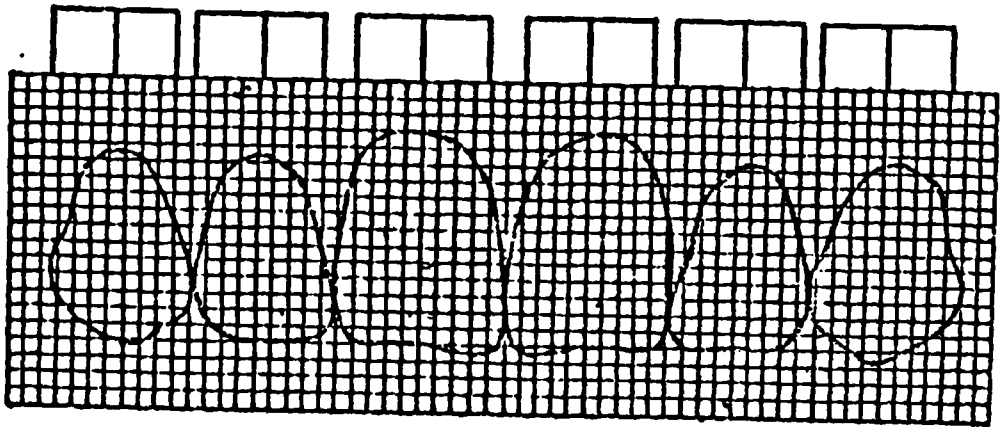
GINGIVAL INDEX ☐☐☐☐☐☐

STAINS ☐☐☐☐☐☐☐☐☐☐☐☐☐☐☐☐☐☐☐☐☐☐☐☐



MONTHS SINCE PLACEMENT ☐☐☐☐☐☐☐☐☐☐☐☐☐☐☐☐☐☐☐☐☐☐☐☐

FRACTURES OR LOSS ☐☐☐☐☐☐☐☐☐☐☐☐☐☐☐☐☐☐☐☐☐☐☐☐



VENEER NO. FOR TOOTH ☐☐☐☐☐☐

Fig 4.28

The gridded recording chart used in the microfilled composite resin veneer study.

STUDY NO. ☐☐☐ HELIOCOLOR VENEERS

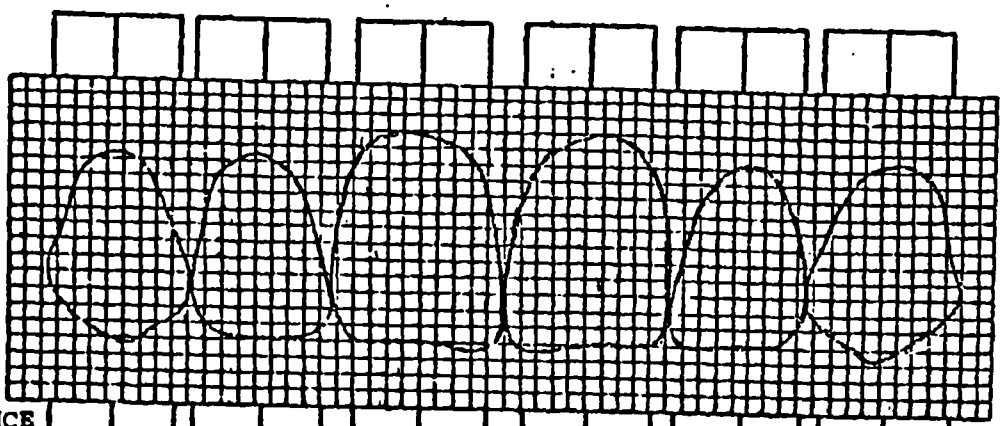
DATE

NAME D.O.B.

NUMBER

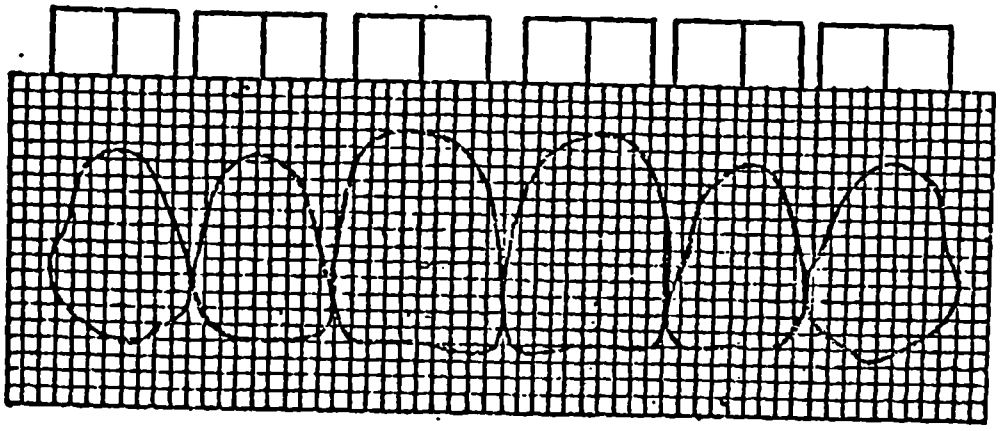
GINGIVAL INDEX ☐☐☐☐☐☐

STAINS



MONTHS SINCE PLACEMENT

FRACTURES OR LOSS



VENEER NO. FOR TOOTH ☐☐☐☐☐☐

Fig 4.23
The prepared tooth after buccal enamel reduction.

Fig 4.25
Contoured matrix strip held by light cured unfilled resin.

Fig 4.26
Severe staining masked by colorant opaquer.

Fig 4.27
A thin layer of heliopaque resin covering gingival, interproximal and on this occasion the buccal surface.

Fig 4.28
Heliosit resin after placement and curing on the buccal surface.

Fig 4.30
The finished restoration.

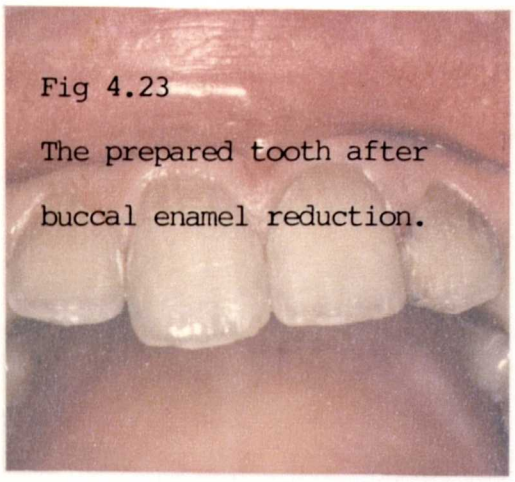


Fig 4.23
The prepared tooth after buccal enamel reduction.

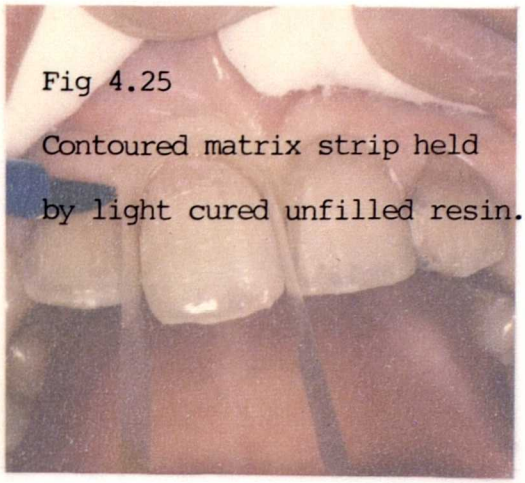


Fig 4.25
Contoured matrix strip held by light cured unfilled resin.

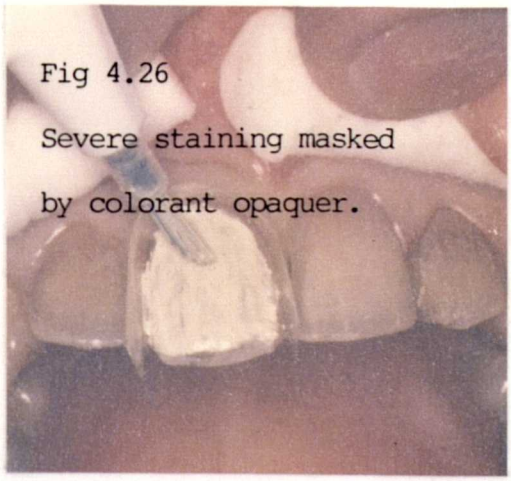


Fig 4.26
Severe staining masked by colorant opaquer.

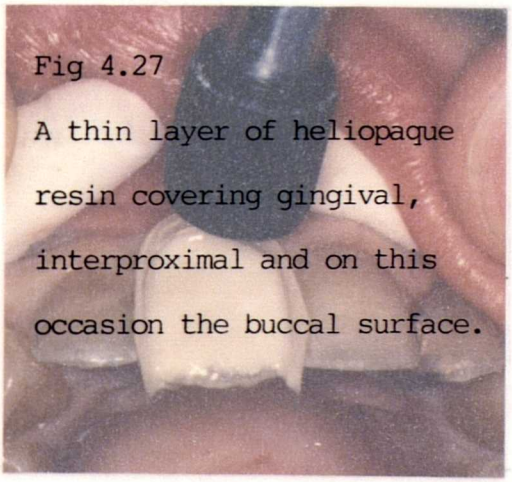


Fig 4.27
A thin layer of heliopaque resin covering gingival, interproximal and on this occasion the buccal surface.

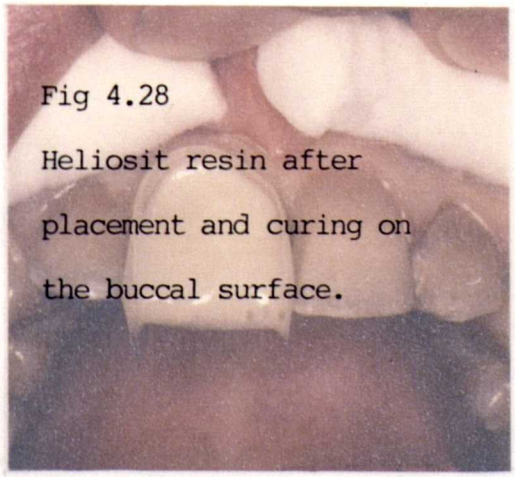


Fig 4.28
Heliosit resin after placement and curing on the buccal surface.

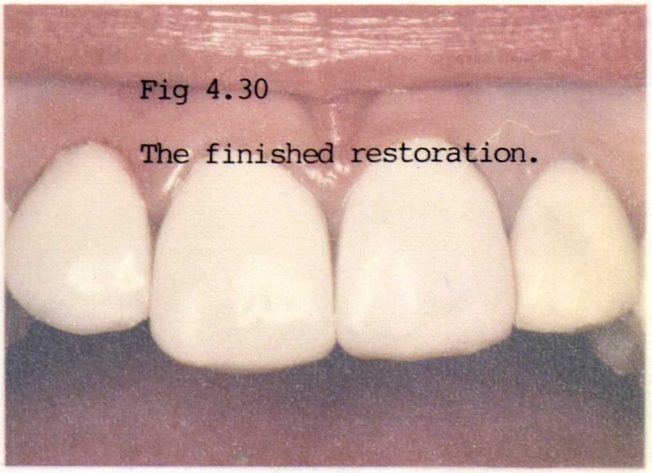
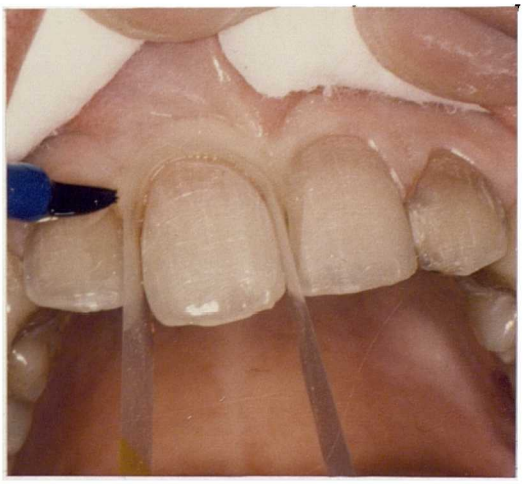
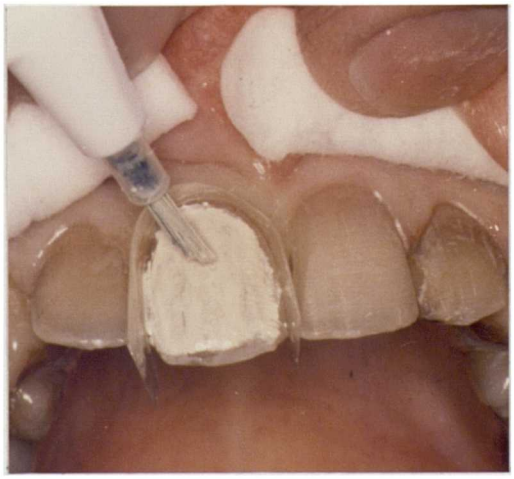
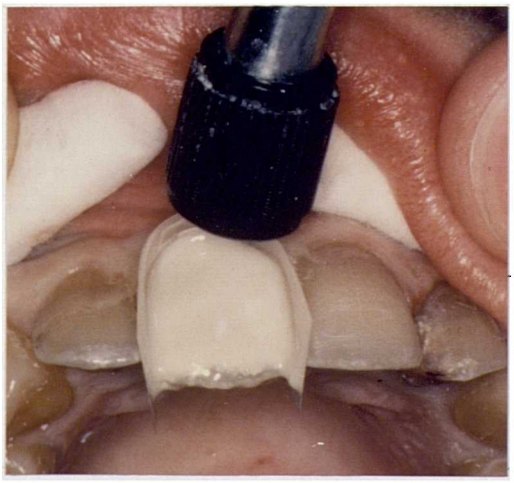
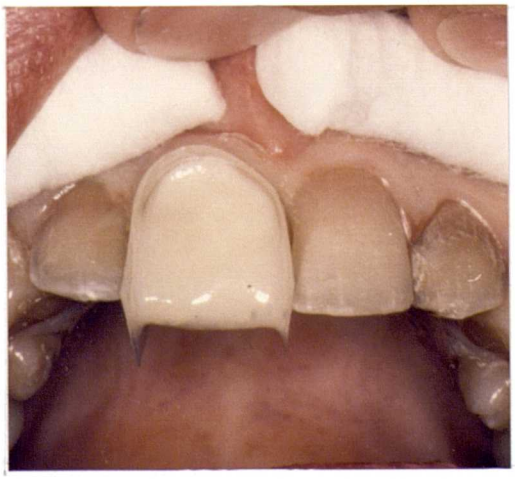


Fig 4.30
The finished restoration.









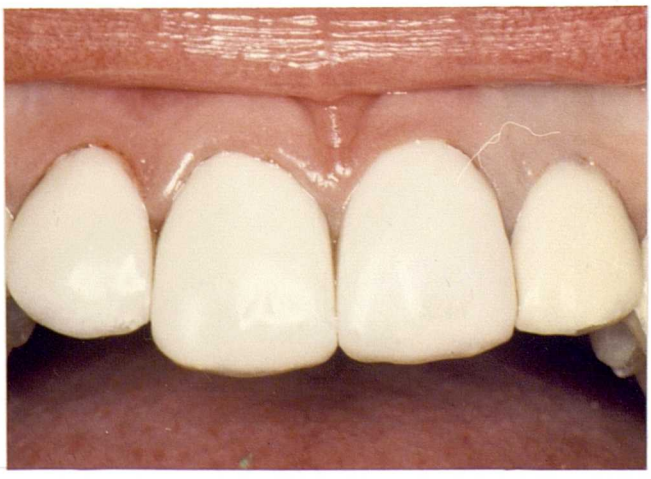
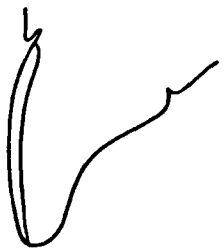


Fig 4.24

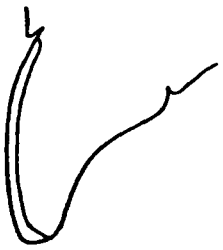
The different types of buccal and incisal coverage used in the microfine composite resin veneer study.

Fig 4.24

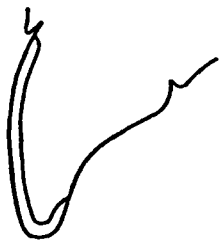
The different types of buccal and incisal coverage used in the microfine composite resin veneer study.



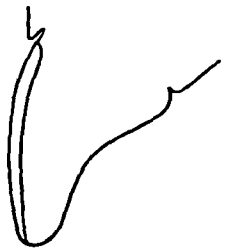
Feathered Incisal Edge



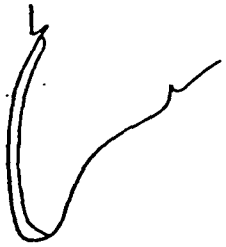
Incisal Bevel Preparation



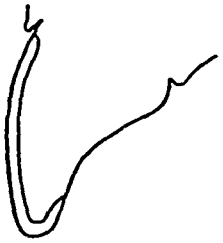
Overlapped Incisal Edge Preparation



Feathered Incisal Edge



Incisal Bevel Preparation



Overlapped Incisal Edge
Preparation

areas of exposed dentine were protected with a quick setting calcium hydroxide cement (Life) and the manufacturer's contoured matrix strip positioned around the gingival margin and interproximal areas. This was held in place by painting some unfilled resin between the non-operational surface of the matrix and the gingival tissue (Fig. 4.25.) and then light curing the resin for 10 seconds with a Heliomat light. The long ends of the matrix were then trimmed with scissors and the tooth etched for 60 seconds using 37% phosphoric acid gel on an applicator brush. The gel was gently agitated during the etching procedure before being washed with water and dried with warm, oil-free air. The quality of the etched surface was checked visually and then a layer of unfilled resin painted thinly onto the whole isolated surface and light cured for 10 seconds. If severe staining was present, a colorant opaquer paint of desired shade was produced by mixing an opaquer tablet with the supplied solvent and the resulting mixture painted onto the tooth surface (Fig. 4.26.) and blown dry. After 30 seconds, another layer of unfilled resin was painted over the opaquer and light cured again for 10 seconds. A layer of heliopaque resin (22% translucency) was placed, 'paddled' and smoothed, with a brush lubricated with unfilled resin, into the gingival and interproximal areas. In those cases that had required opaquer paint to mask heavy staining, a thin layer of heliopaque resin also covered the buccal surface (Fig. 4.27.). The heliopaque resin was then light cured for 60 seconds. Heliosit resin (28% translucency) was then placed on the remainder of the buccal surface and light cured for a further 60 seconds (Fig. 4.28.). Heliotrans resin (38% translucency), when required, was then placed on the incisal third of the buccal surface and light cured for 60 seconds. The relative amounts of heliopaque, heliosit

and heliotrans resins varied according to:

(a) The age of the patient (a younger patient would require less heliopaque resin); and

(b) the necessity for translucent incisal edges.

The different combinations used in this study are shown in Fig. 4.29. After the final light cure, the contoured matrix and unfilled resin holding it were removed and the perimeters of the restoration given a further 60 seconds light cure.

Finishing at the gingival margin was completed with flame diamond finishing and flame Baker-Curzon burs. Interproximal finishing was with 'Soflex' discs and finishing strips and buccal finishing and final characterisation was with 'Soflex' discs and Vivadent green stone. The incisal edge was adjusted with 'Soflex' discs on a rotary mandrel until it had a slight bevel away from the existing incisal edge (if present) in an apical direction (Fig. 4.30.).

The occlusion was checked in protrusive and lateral excursions to ensure that the veneers were not traumatising during function. All patients in the study were instructed in a modified Bass short scrub oral hygiene technique, to ensure adequate cleansing of the gingival crevice. They were then reviewed at 6 monthly intervals by one clinician (R.R.W.), when the following data were recorded, using a similar form to Fig. 4.22.:

(i) The Gingival Index mesially, buccally and distally for each tooth with a veneer in situ.

(ii) Any areas of staining of the restoration, the extent and colour of any stains and their relationship to the veneer.

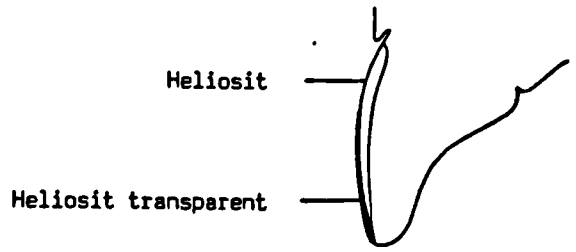
(iii) Any areas on the tooth surface from which the veneers had been

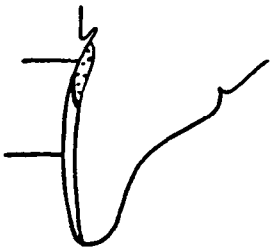
Fig 4.29

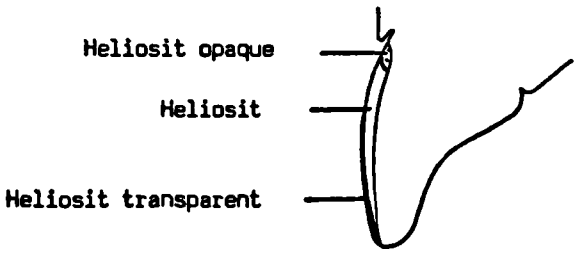
The different combinations of Heliocolor microfine composite resins used in the study.

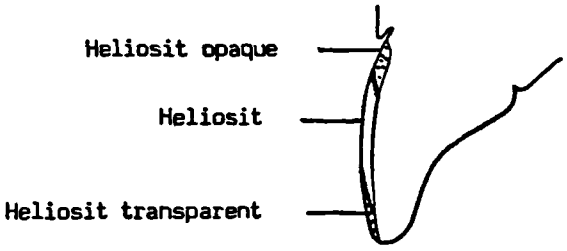
Fig 4.29

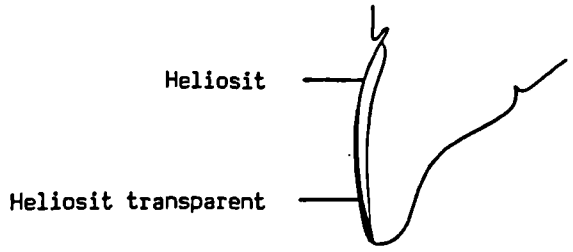
The different combinations of Heliocolor microfine composite resins used in the study.

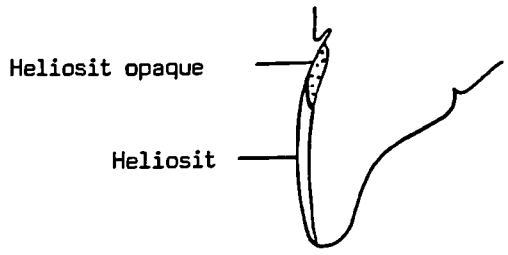


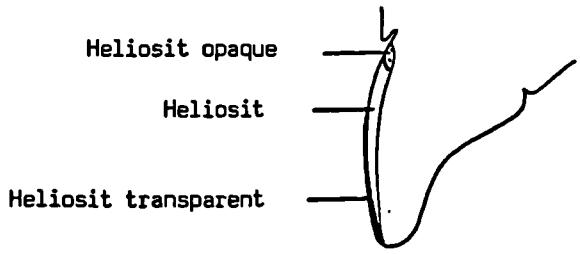


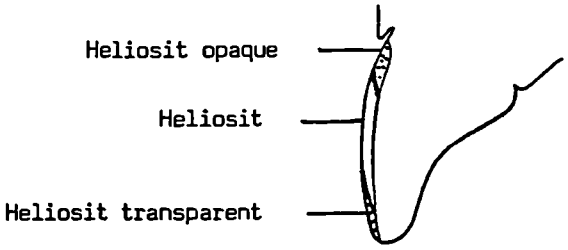





Heliosit
Heliosit transparent


Heliosit opaque
Heliosit


Heliosit opaque
Heliosit
Heliosit transparent


Heliosit opaque
Heliosit
Heliosit transparent

lost.

(iv) The marginal integrity on the mesial, buccal and distal aspects of each restoration was checked using a Briault probe. Any ledges were noted on the assessment form and then refinished using the instruments described above.

Colour transparencies were again taken of the treated teeth using the same film, camera/lens and light source. In the event that a veneer had chipped, but the resultant appearance was acceptable for the patient, the margins of the veneer were smoothed using Soflex discs. If the area of loss was not acceptable, the veneer was either repaired using a combination of the original shades or completely replaced. Any unsightly staining either on the surface of the veneer or marginally was refinished using the instruments described as above. If at any time, the patient was unhappy with the aesthetics of a veneer restoration after repolishing, or at any time in the recall period, then the restoration was replaced. If the patient's oral hygiene deteriorated during the follow-up period, with a build-up of plaque and associated marginal inflammation, then the patient was given further oral hygiene instruction in an attempt to overcome the problems.

4.1.5. CONTROLLED ENAMEL REMOVAL BY THE HYDROCHLORIC ACID-PUMICE ABRASION TECHNIQUE

4.1.5.1. CLINICAL MATERIAL

Patients who were referred to the Department of Child Dental Health at Newcastle Dental Hospital for treatment of aesthetic problems concerning their upper anterior teeth were screened for inclusion in this trial. They were provisionally accepted if:

(i) They exhibited intrinsic staining which the operator considered to be solely within enamel.

(ii) No patient was accepted into the trial if there were any areas of exposed dentine on the teeth concerned or if the oral hygiene was not of a satisfactory standard. The same criteria for oral hygiene were used as in the previous microfine composite resin veneer trial.

4.1.5.2. CLINICAL METHOD

The patients were assessed initially and the nature and extent of any staining was recorded photographically. An attempt was made to identify the cause of staining in each case. Tooth vitality was checked with ethyl chloride or electric pulp tester if the former was negative. Between September 1987, and July 1988, 80 teeth in 30 patients with an age range of 8 - 23 years were treated. 1 Clinician (R.R.W.) carried out all the treatment.

TREATMENT PROCEDURE

The teeth to be treated were cleaned with pumice in a rubber cup (Fig. 4.31.) then isolated by rubber dam (Fig. 4.32.) and the edge

Fig 4.31

Teeth after cleaning with pumice and water.

Fig 4.32

Teeth isolated by rubber dam, with sodium bicarbonate and water paste to protect against accidental spillage of HCl.

Fig 4.33

HCl-pumice rubbed onto tooth for 5 secs.

Fig 4.34

Application of non-acidulated fluoride gel for 3 mins.

Fig 4.35

Final lustre with graded 'soflex' discs.

Fig 4.36

The treated tooth at the end of the procedure.

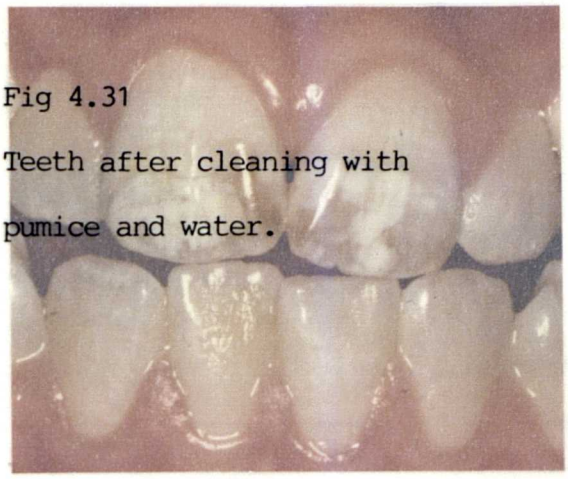


Fig 4.31
Teeth after cleaning with pumice and water.

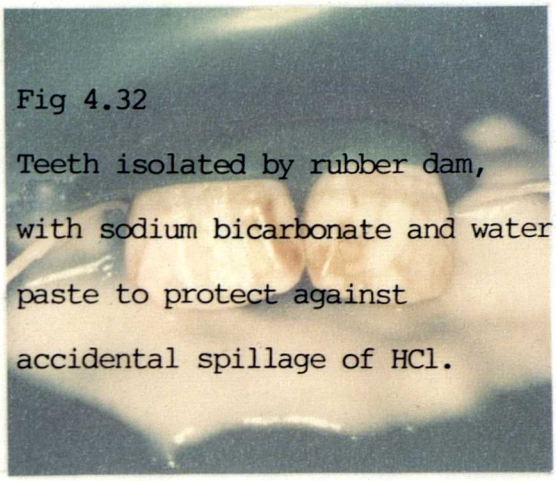


Fig 4.32
Teeth isolated by rubber dam, with sodium bicarbonate and water paste to protect against accidental spillage of HCl.

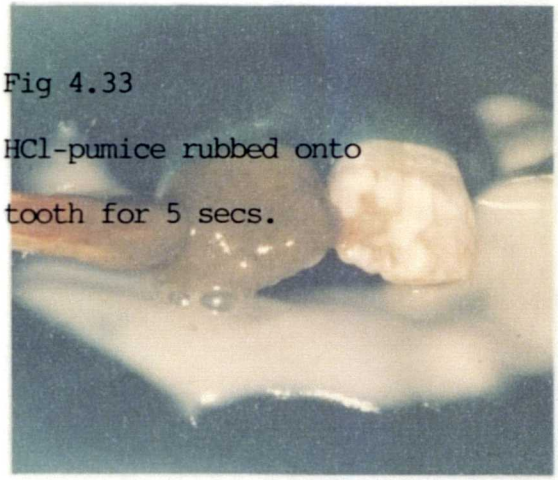


Fig 4.33
HCl-pumice rubbed onto tooth for 5 secs.

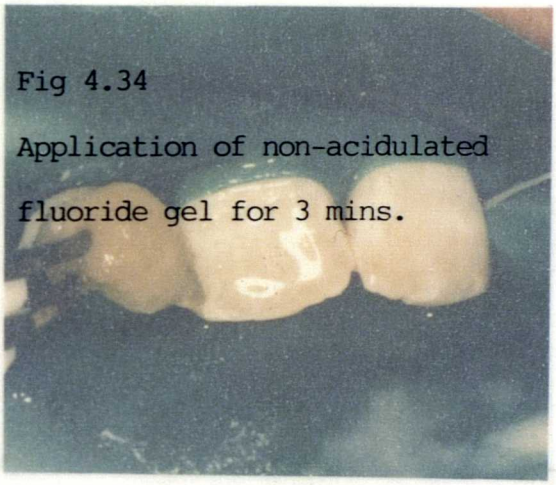


Fig 4.34
Application of non-acidulated fluoride gel for 3 mins.

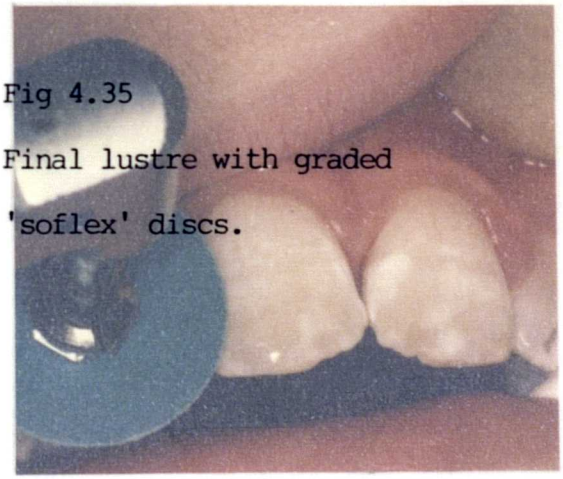


Fig 4.35
Final lustre with graded 'soflex' discs.

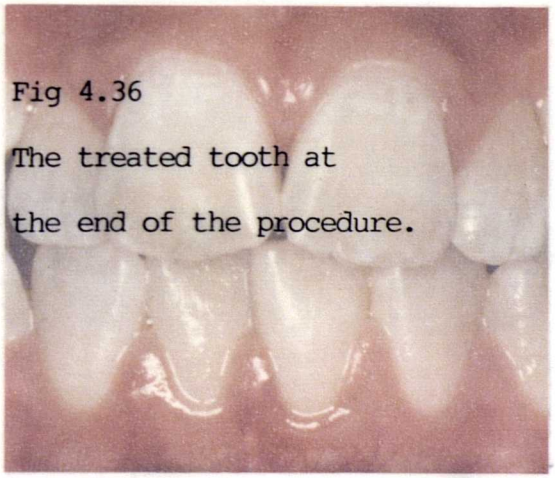
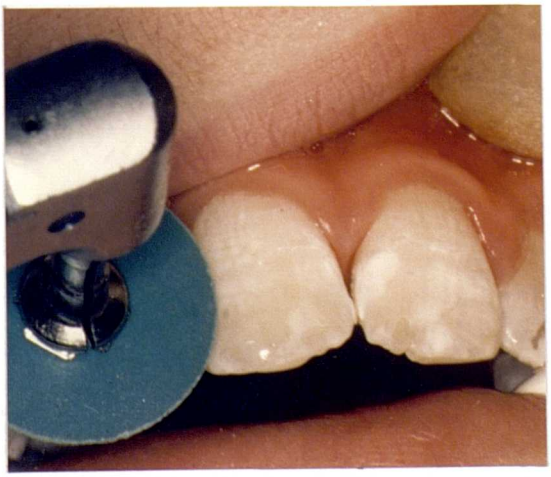
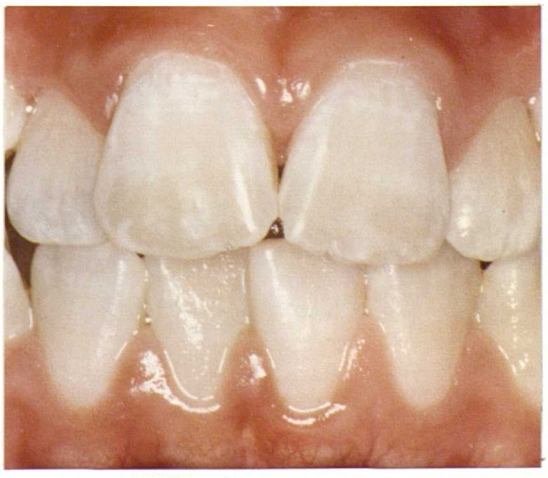


Fig 4.36
The treated tooth at the end of the procedure.





of the dam sealed with Copal water resistant resin varnish. Sodium Bicarbonate and water paste was placed on the rubber dam to protect against inadvertent splashing of the hydrochloric acid. Protective glasses were worn by the patient, operator and nurse and gloves by the operator and nurse. 18% Hydrochloric acid mixed with fine pumice powder into a slurry, was applied to the buccal surface of the tooth on an interdental stick and rubbed over the surface for 5 seconds (Fig. 4.33.). The mixture was then washed off with air-water spray directly into an aspirator tip. The acid pumice application was then repeated a maximum of 10 times for each tooth. If no improvement had been achieved at the end of this time, it was deemed that success was unlikely and the stain was probably of deeper origin than originally thought. The tooth was washed for 30 seconds with an air-water spray and non-acidulated fluoride gel applied for 3 minutes (Fig. 4.34.). The next tooth to be treated then underwent the same sequence. The rubber dam was removed and the teeth polished for 1 minute with fluoridated prophylaxis paste before being given a final lustre with graded 'Soflex' discs (Fig. 4.35.).

Colour transparencies were immediately taken of the treated teeth using the same film, camera/lens and light source (Fig. 4.36.). Any peroperature discomfort or sensitivity was noted and the patients' reaction to the result recorded. The patients were reviewed at 6 monthly intervals by one clinician (R.R.W.), and the following data was recorded:

(i) Any postoperative pain.

(ii) Any postoperative sensitivity to hot, cold or sweet liquids or foods.

(iii) Tooth vitality to:

(a) ethyl chloride;

(b) electric pulp tester.

(iv) Recurrence of stain.

(v) Photographic record.

(vi) Patient satisfaction.

4.2. IN VITRO STUDIES

A series of in vitro studies were performed using four glass polyalkenoate cements, one glass cermet cement, one composite resin and a slurry of hydrochloric acid-pumice. The investigations were designed to:

(i) Investigate and give an understanding of the chemical, mechanical and biomechanical properties of the glass polyalkenoate and cermet cements which are of particular relevance to their use in the Class II sandwich technique.

(ii) Investigate and give an understanding of the mechanical properties of a microfine composite resin which are of particular relevance to its use as an anterior veneering agent.

(iii) Measure the depth of enamel removed during the hydrochloric acid-pumice abrasion technique.

4.2.1. LABORATORY METHOD FOR GLASS POLYALKENOATE AND CERMET CEMENTS

MATERIAL PROPERTIES OF THE CEMENTS

The purpose of this section of the laboratory work was to investigate those properties that were deemed to be of particular relevance to the cements usage in the Class II sandwich technique, remembering that the cement would form the inferior part of the finished approximal cavity wall.

The following properties were investigated:

(i) Chemical - Erosion resistance

(ii) Mechanical - Diametral compressive tensile strength

(iii) Biomechanical - Thermal analysis

- Bond strength determination - to dentine
  - to composite resin
- Morphology of etched surfaces by scanning Electron Microscopy (S.E.M.)

4.2.1.1. CHEMICAL PROPERTIES

One of the main factors which determine the durability of a material used in the mouth is its chemical stability. Materials should not dissolve, erode or corrode, nor should they leach important constituents into oral fluids as this results in degradation of the cement.

EROSION RESISTANCE

INTRODUCTION

The solubility of a material is simply a measurement of the extent to which it will dissolve in a given fluid, for example, water or saliva. Erosion, on the other hand, is a process which combines the chemical process of dissolution with a mild mechanical action. Hence it is possible to envisage a situation in which the surface layer of a material becomes weakened and undermined by dissolution and then becomes totally detached by mild abrasion. These properties are particularly important for all restorative materials since a high solubility or poor resistance to erosion will severely limit the effective lifetime of the restoration.

When assessing the solubility or erosion rate of materials it is important to consider the vast range of conditions which may exist in the mouth. The pH of oral fluids may vary from pH 4 to pH 8.5 representing a range from mildly acidic to mildly alkaline. Highly acidic soft drinks and the use of chalk-containing toothpastes extend this range from the lower end of pH 2 to pH 11. It is possible for a material to be stable at near neutral pH values, but to erode rapidly at extremes of either acidity or alkalinity. This partially explains

why some materials perform adequately with some patients, but not with others (McCabe 1985).

Standard tests of solubility often involve the storage of disc specimens of materials in water for a period of time, the result being quoted as the percentage weight loss of the disc. A novel method developed by Walls et al (1985) measures the quantity of material lost at a single exposed surface after specimens have been subjected to a gentle washing procedure during the erosion period.

MATERIAL AND METHOD

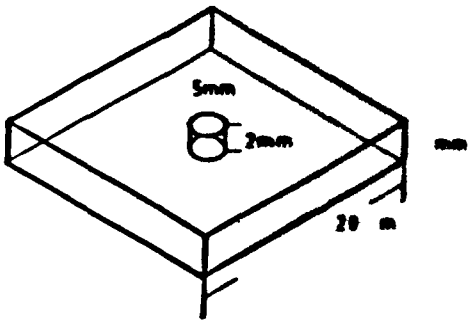
The specimen holders comprised a square of perspex (20 mm. x 20 mm. x 5 mm.) with a hole (5 mm. diameter x 2 mm. deep) bored in the centre of the square (Fig. 4.37.). Erosion cycling was performed using a tissue processing unit (Histokinette) . Beakers of eroding solution (sodium lactate/lactic acid at pH 4.0) and distilled water pH 7 were placed alternately on the table of the tissue processor and a specimen suspended from each arm. The central spindle of the tissue processor is raised mechanically at 90 second intervals to remove the specimens from their eroding baths. It then rotates through 30 degress, before lowering the specimens into the next bath. This action takes a further 60 seconds, thus allowing 24 complete cycles/hour. Specimens under test received equal numbers of eroding and washing treatments. The loss of material during erosion was measured by recording the surface profile of the specimen holder and cement using a profilometer (Surfometer) (Fig. 4.38a.). Two profiles were recorded for each specimen, every attempt being made to ensure that the profile tracks were perpendicular to each other and across the maximum diameter of the cement specimen. Prior to the erosion cycling each specimen was half coated

Fig 4.37

Perspex specimen holder for erosion testing and depth of etch determination.

Fig 4.37

Perspex specimen holder for erosion testing and depth of etch determination.



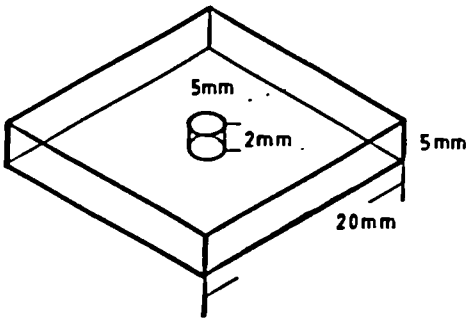

5mm
2mm
5mm
20mm

Fig 4.38a + b

The surface profile method for determining the quantity of material lost after erosion.

a. The surface profile being recorded.

b. A facsimile of the surface profile. A and B are the shoulders of the specimen holder.

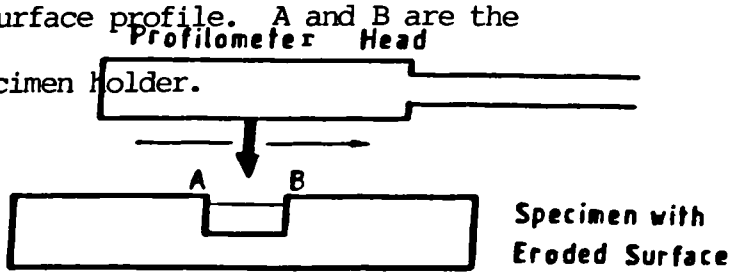
Fig 4.38a + b

The surface profile method for determining the quantity of material lost after erosion.

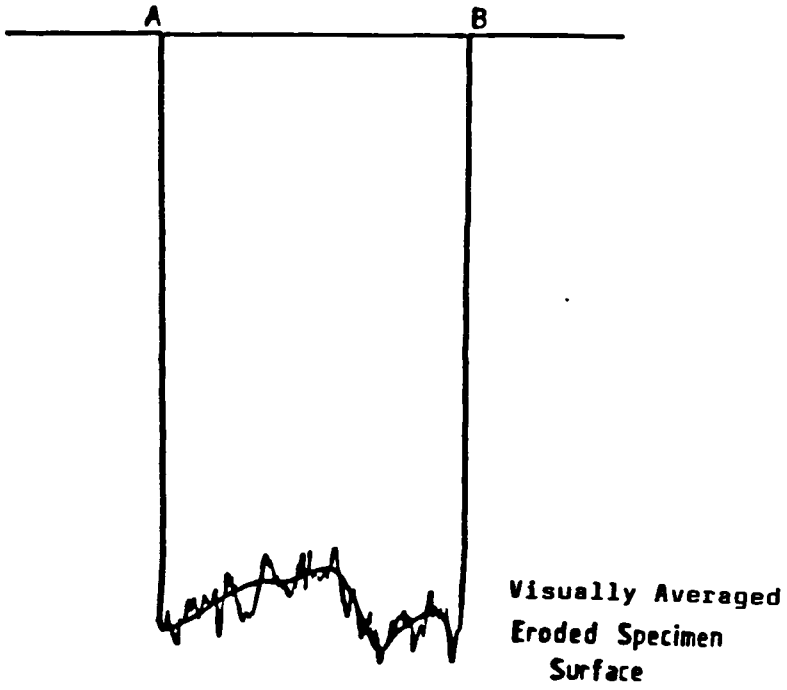
a. The surface profile being recorded.

b. A facsimile of the surface profile. A and B are the shoulders of the specimen holder.

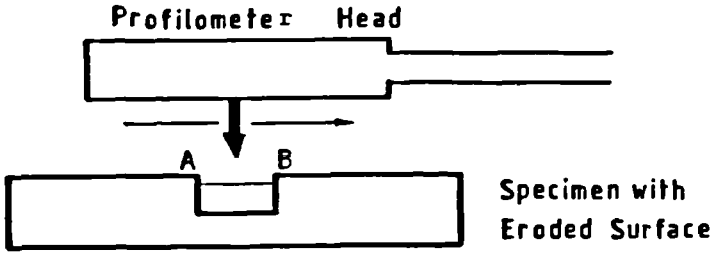
a



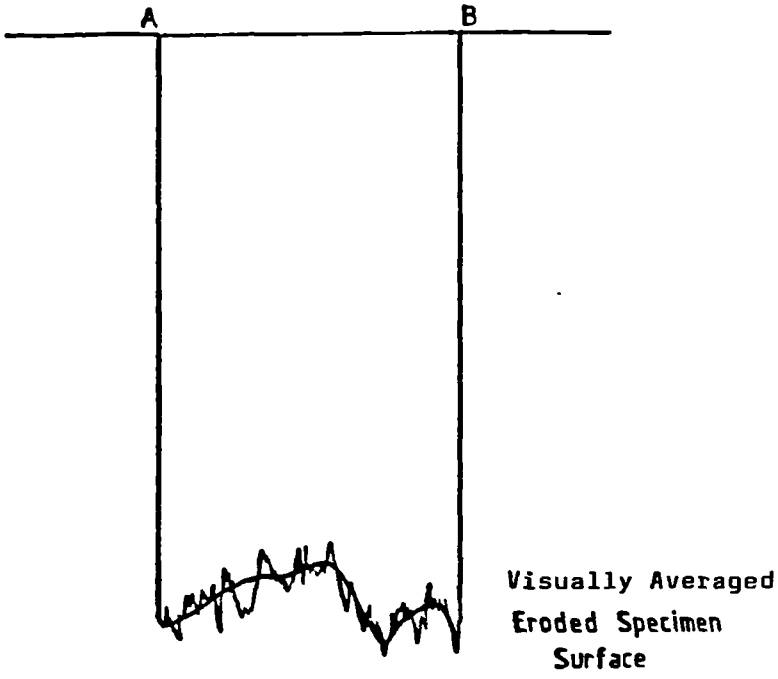
b



a


Profilometer Head
A
B
Specimen with
Eroded Surface

b


A
B
Visually Averaged
Eroded Specimen
Surface

with varnish and this was subsequently removed with a scalpel blade before profiling. The shoulders of the specimen holder can be regarded as fixed datum points, and the area of the profile was determined by joining the two shoulders, visually averaging the irregular base of the eroded specimen trace (Fig. 4.38b.) and then tracing this area on a magnetic digitising tablet with associated micro computer analysis. Average depth loss was obtained by dividing area by distance between the shoulders.

Factors which may influence the erosion of cements were investigated using this method.

(a) Erosion as a function of cement age and type

A total of 60 specimens were prepared for each of the polyalkenate cements Ketac-Fil, Ketac-Bond, Chelon and Coltene 018804B, and the cermet Ketac Silver. The capsules of Ketac-Fil and Ketac-Silver were activated and mixed for 10 seconds in a Silamat high energy vibrator prior to being syringed directly into the specimen holders and covered with a cellulose acetate matrix strip. The hand mixed specimens, Ketac-Bond, Chelon and Coltene 018804B were mixed on a glass slab in accordance with the manufacturer's powder: liquid ratio (by weight) recommendations (KB 3.4:1, Chelon 6.7:1, Coltene 6.9:1). The mixed cement was run into the specimen holder with the mixing spatula and then covered with a matrix. Specimen preparation was carried out at 22 +/- 2°C and 50 +/- 5% relative humidity. The specimens were then placed in an oven at 37°C and 100 per cent relative humidity under 1 kilogramme load. Specimens for cycling at 15 minutes and 1 hour from mixing were taken directly from the oven and lapped until flat using 800 grit carborundum paper on a rotary pregrinder

(Metaserv) with continuous water irrigation. Half of each specimen was then covered with one coat of water resistant varnish prior to commencing an 18 hour cycling process. Specimens for cycling at 24 hour, 7 days and 28 days were removed from the oven at 1 hour, covered with two layers of water resistant varnish and stored in distilled water at 37°C until required, at which time they were lapped as described previously and half covered with one layer of varnish prior to cycling.

(b) Erosion as a function of varying powder:liquid ratios of cement

A total of 60 specimens were prepared for each powder:liquid ratio of the non encapsulated glass polyalkenoate cements Ketac Bond and Chelon. Powder:liquid ratios (by weight) for the cements were as follows:

Ketac Bond	4.26:1, 3.83:1, 2.97:1, 2.55:1
Chelon	8.38:1, 7.54:1, 5.86:1, 5.02:1.

The powder content was weighed accurately and the liquid content obtained from the glass 'dropper' bottle supplied.

A total of 720 specimens were prepared for the erosion resistance investigations.

4.2.1.2. MECHANICAL PROPERTIES

Most applications of materials in dentistry have a minimum mechanical property requirement. For example, certain materials should be sufficiently strong to withstand biting forces without fracture while others should be rigid enough to maintain their shape under load. Before considering the laboratory test undertaken in this category and later on the relevance of the data obtained, it is necessary to define and appreciate 'stress' and 'strain'.

(a) STRESS: When an external force is applied to a body or specimen of material under test, an internal force, equal in magnitude, but opposite in direction is set up in the body. A stress resisting a compressive force is referred to as a compressive stress and that resisting a tensile force a tensile stress. For simple compression or tension the stress is given by the expression: Stress = F/A where F is the applied force and A the cross-sectional area.

(b) STRAIN: The application of an external force to a body or test specimen results in a change in dimension of that body. For example, when a tensile force is applied the body undergoes an extension, the magnitude of which depends on the applied force and the properties of the material. The numerical value of strain is given by the expression:

$$\text{Strain} = \frac{\text{Change in length}}{\text{Original length}}$$

Thus strain, which has no physical dimensions can be seen as a measure of the fractional change in length caused by an applied

force. The extent to which the strain is recovered is a function of the elastic properties of the materials.

(c) STRESS-STRAIN RELATIONSHIP: Stress and strain are not independent unrelated properties, but may be seen as an example of cause and effect. The application of an external force, producing a stress within a material, results in a change in dimension or strain within the body. The relationship between stress and strain is often used to characterise the mechanical properties of materials, and the slope of the straight-line portion of the stress-strain graph gives a measure of the modulus of elasticity (Youngs) defined as: $\frac{\text{Stress}}{\text{Strain}}$

This modulus of elasticity has the units of stress and, despite the name, it gives an indication of the rigidity of a material and not its elasticity.

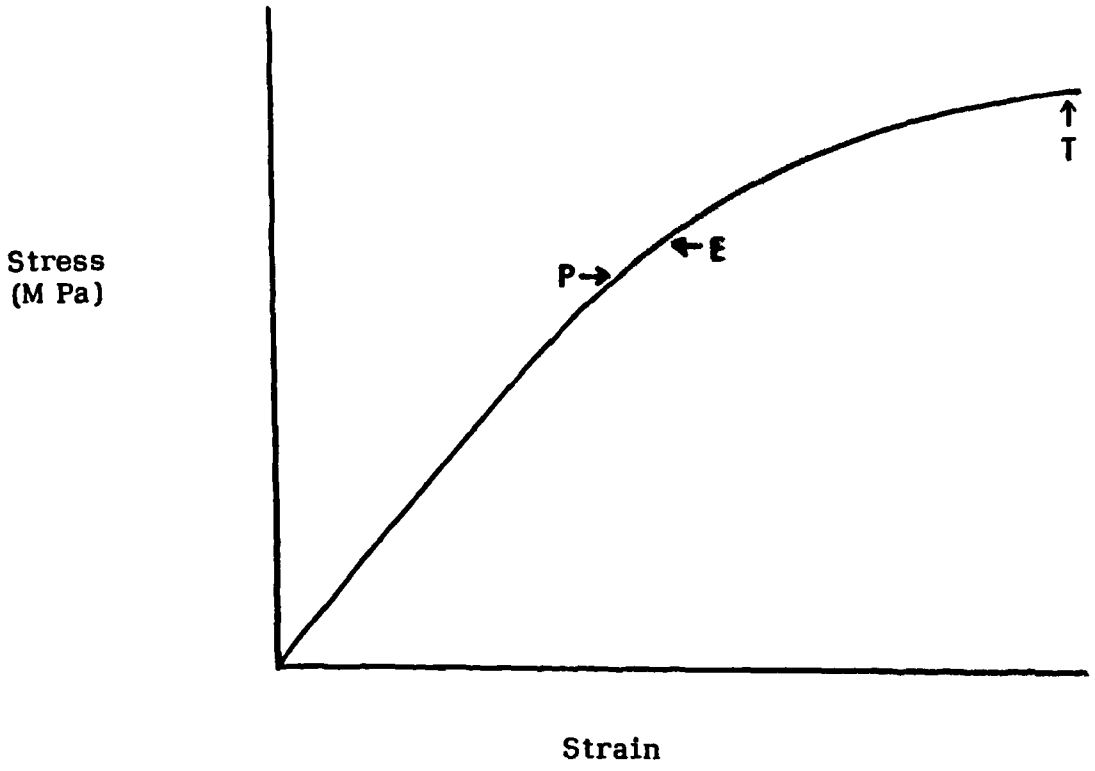
For the simplest type of tensile or compression test, the graph displayed on the pen recorder of a testing machine would be like Fig. 4.39. There is a linear relationship between stress and strain up to the point P. Further increases in stress cause proportionally greater increases in strain until the material fractures at point T. The stress corresponding to point T is the fracture stress. In a tensile test this gives a value of tensile strength, whilst in a compression test, a value of compressive strength is obtained. The value of stress which corresponds to the limit of proportionality P is the proportional limit and point E is the elastic limit which corresponds to the stress beyond which strains are not fully recoverable.

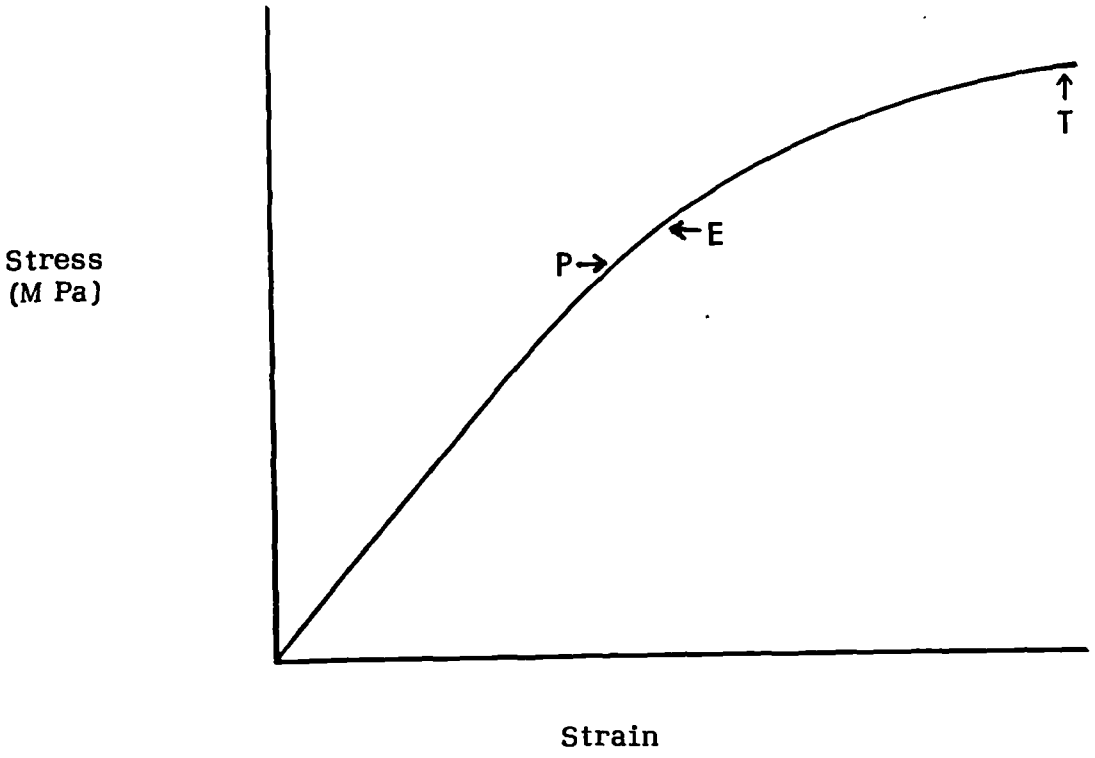
Fig 4.39

Typical stress-strain graph obtained from a simple compressive or tensile test.

Fig 4.39

Typical stress-strain graph obtained from a simple compressive or tensile test.




Stress
(M Pa)
P
E
T
Strain

DIAMETRAL COMPRESSIVE TENSILE STRESS

INTRODUCTION

When a cylinder of a brittle material is compressed across a diameter as shown in Fig. 4.40., a tensile stress is set up in the specimen, the value of the stress being given by:

Stress = $\frac{2F}{TT\ DT}$ at the axis of the cylinder, where F is applied force, D the diameter of the cylinder and T the length of the cylinder. This is the diametral compressive tensile test and is commonly used when conventional tensile testing is difficult to carry out due to the brittle nature of the test material.

MATERIAL AND METHOD

The diametral compressive strength of glass polyalkenoate and a glass cermet cement was determined using an Instron universal testing machine. Specimens (4 mm. diameter x 6 mm. long) were prepared using a PTFE mould with stainless steel plunger and spacing washer (Fig. 4.41.). Freshly mixed material, prepared according to the manufacturers instructions, was placed in the mould and the exposed surface covered with a Melinex matrix under a perspex square and 1 Kg. weight. After a specific time at room temperature the specimens were unpacked, coated with proprietary varnish and stored in distilled water at 37°C for 7 days. After 7 days, the varnish was peeled off, the diameter and length of specimen measured accurately with a micrometer and the specimens laid lengthways on the centre of a 50 Kg. load cell on the Instron testing machine. Diametral compressive tensile stress testing was carried out at a cross head speed of 1 mm. per minute.

Fig 4.40

Diametral compression test for a brittle material.

Fig 4.41

Three part mould used to prepare glass polyalkenoate specimens.

Fig 4.40

Diametral compression test for a brittle material.

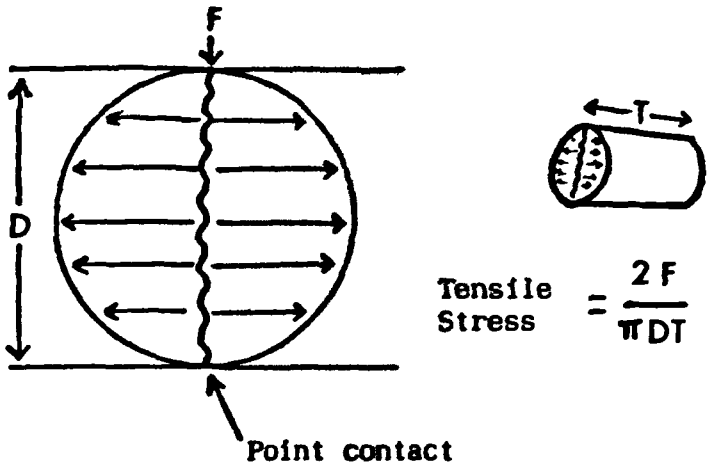
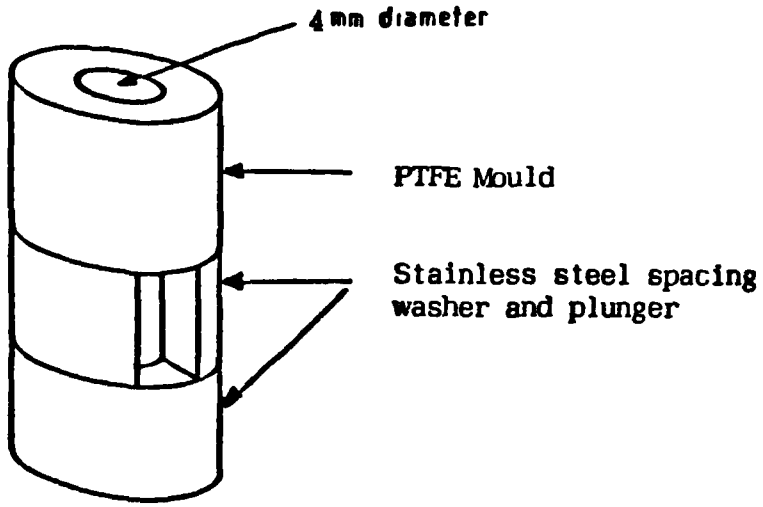
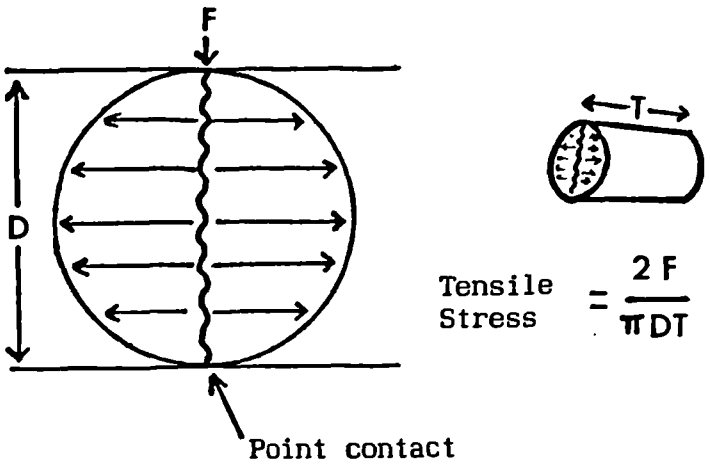
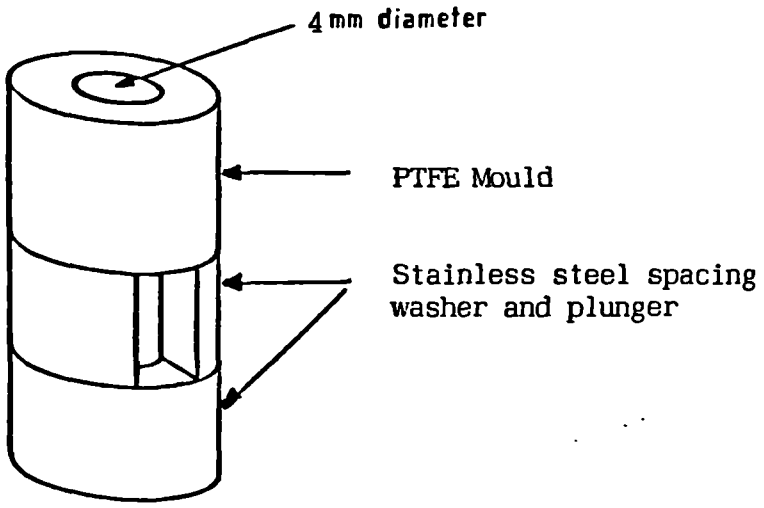


Fig 4.41

Three part mould used to prepare glass polyalkenoate specimens.




F
D
T
Tensile Stress = 2 F / π DT
Point contact


4 mm diameter
PTFE Mould
Stainless steel spacing washer and plunger

Two variables that may effect the mechanical strength of glass polyalkenoate and glass cermet cements were investigated using this method:

(a) The variation in mechanical properties with variation in material composition. 30 Specimens each of Ketac-Bond (unpacked after 4 minutes), Ketac-Fil (unpacked after 8 and 15 minutes), Coltene 018804B (unpacked after 4 minutes) and Ketac-Silver (unpacked after 5 minutes), each mixed to recommended manufacturers instructions (Fil and Silver encapsulated, Ketac-Bond 3.4:1, Coltene 6.9:1, P:L ratios by weight).

(b) The variation in mechanical properties with variation in the powder:liquid ratio of Ketac Bond specimens. Five groups of 30 specimens each were prepared at powder:liquid ratios by weight of 4.26:1, 3.83:1, 3.4:1 (recommended), 2.97:1 and 2.55:1. The glass polyalkenoate cement was unpacked from the proprietary mould 4 minutes after commencing mix, prior to varnishing and storage in distilled water.

A total of 300 specimens were prepared and tested for diametral compressive tensile strength testing.

4.2.1.3. BIOMECHANICAL PROPERTIES

The biomechanical properties of a material are properties which are not related directly to the strength and durability but are of great importance to the clinical success. The **in vitro** investigations of biomechanical properties of the glass polyalkenoate and cermet cements in this study can be broken down into 4 main areas: thermal analysis, bond strength determination, depth of etch determination and morphology of etched surfaces by scanning election microscopy (S.E.M.).

4.2.1.3.1.THERMAL ANALYSIS (REACTION KINETICS)

INTRODUCTION

Most dental materials, set as a result of a chemical reaction which commences as soon as the components of the system are mixed together. There is a finite period of time after mixing during which the material remains 'workable', followed by a second period before the material has fully 'set'. Most chemical reactions involve variation in the temperature of the reacting chemicals. Most reactions are exothermic in nature and the rate and progress of any such chemical reaction can be monitored by recording the temperature of the reacting materials. Wolcott et al (1951) were the first to suggest that monitoring the exotherm of setting reactions may be of clinical value, as the majority of the reaction would have occurred once the peak exotherm had passed. Differential scanning calorimetry (D.S.C.) and differential thermal analysis (D.T.A.) have now substantiated this observation (McCabe and Wilson 1980, Lloyd 1984). The working and setting times of materials can be arbitrarily measured using the plots of heat output/uptake against time. It has been suggested that the

time taken for the D.S.C. trace to first deviate from the baseline at 23°C be regarded as the working time and the time to reach the peak exotherm at 37°C be regarded as the setting time (McCabe and Wilson 1980). However, these studies also indicate that the setting reaction, with associated heat production continues for some time after clinical setting has occurred and indeed this is the case with silver/tin amalgam and to a lesser extent with other materials. Glass polyalkenoate cements are susceptible to moisture contamination during the early stages of their setting reaction with a subsequent deleterious affect upon their physical properties and appearance (McLean and Wilson 1977b, Saito 1978, Phillips and Bishop 1985). Mount and Mackinson (1978) also report that a marked variation in powder:liquid ratio used for a hand mixed glass polyalkenoate cement, may influence the setting reaction of the cement and consequently its susceptibility to aqueous damage.

MATERIAL AND METHOD

Ketac Bond is a glass non encapsulated (encapsulated now recently available) polyalkenoate radio-opaque lining material marketed for use beneath composite resins. The manufacturers instructions recommend that 4 minutes after commencing mix, the cement is acid etched for 60 seconds, washed for 60 seconds and dried prior to bonding to composite resin. With this in mind, it would need to set rapidly to prevent deleterious moisture contamination. Coltene 018804B is a non encapsulated glass polyalkenoate cement not yet available on the commercial market.

The thermodynamics of the setting reaction of Ketac Bond and Coltene 018804B glass polyalkenoate cements were monitored using a differential thermal analysis unit in isothermal mode, firstly at 23°C,

then at 37°C. The unit comprises a reaction chamber with two chrome alumel thermocouples in the base of the chamber. Each thermocouple is attached to a platform on which test material is placed inside two aluminium crucibles (5 mm. diameter x 1.5 mm. deep). The thermocouples record two simultaneous measurements, the temperature of the test sample (freshly mixed) and the temperature difference between the test and reference specimens called the differential curve. The reference specimen used was a preset specimen of the material under test. Temperature variations were recorded using a 2 channel pen recorder giving a characteristic pair of traces (Fig. 4.42.). The upper trace represents the temperature differential between the reference and test thermocouples and the lower trace is the temperature of the sample. The parameters measured were the time taken for the specimen to achieve its peak exotherm, the magnitude of the exotherm, the temperature rise per mg. weight of specimen, the time taken for the specimen to cool to a temperature corresponding to 5% of the peak temperature change, and the area under the differential temperature curve divided by the specimen weight. All specimens were placed onto the test platform 60 seconds after commencement of mix of the cement.

Two variables that may effect the reaction kinetics of glass polyalkenoate cements were investigated:

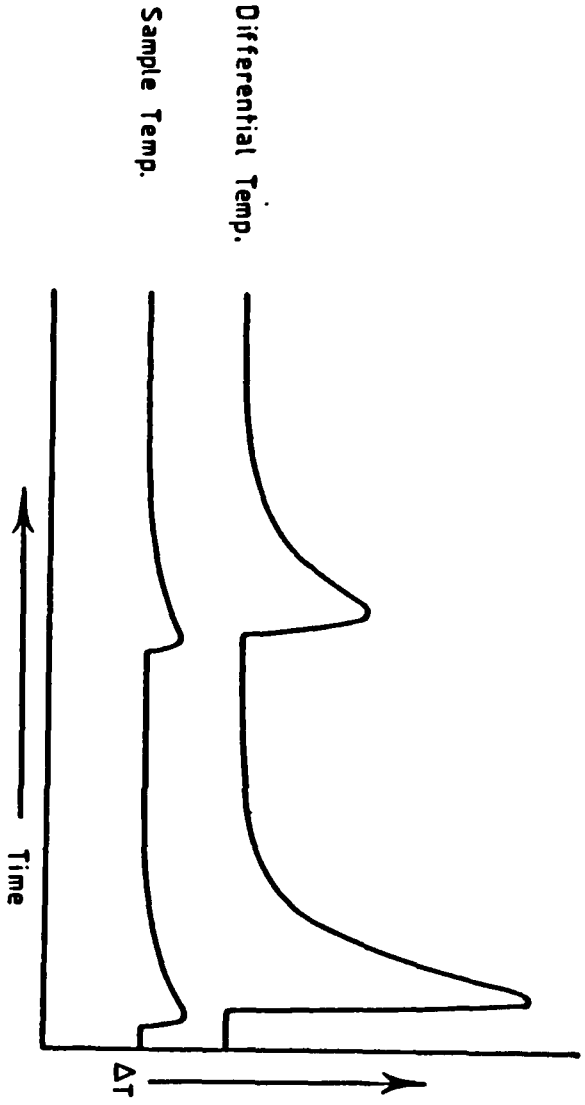
(a) The variation in biomechanical properties with variation in material composition. 3 Specimens each of Ketac Bond and Coltene 018804B at recommended powder:liquid ratios (3.4:1 and 6.9:1) were prepared and tested at 23°C and 37°C. The exothermic reaction was monitored, the setting parameters recorded and all specimens were weighed at the end of the

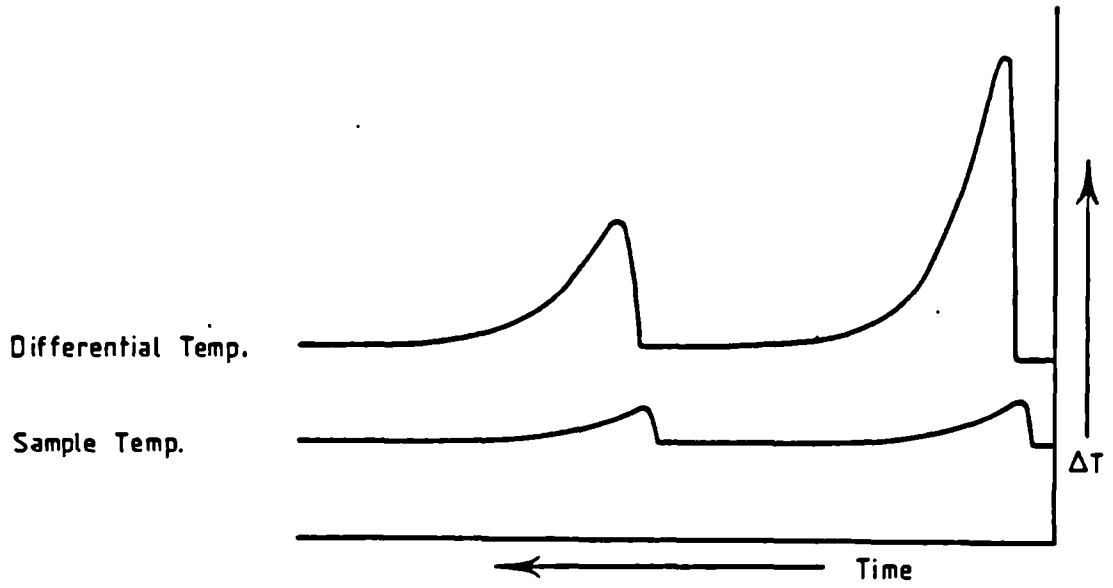
Fig 4.42

Two traces characteristic of those obtained during Differential Thermal Analysis.

Fig 4.42

Two traces characteristic of those obtained during Differential Thermal Analysis.




Differential Temp.
Sample Temp.
ΔT
Time

reaction.

(b) The powder:liquid ratio of Ketac Bond specimens

3 Specimens of each of the following powder:liquid ratios of Ketac Bond were mixed and placed 60 seconds after commencing mixing, into the test aluminium crucible on the sample thermocouple of the D.T.A. unit. Powder:liquid ratios were obtained by accurate weighing 4.26:1, 3.83:1, 3.4:1 (recommended) 2.97:1, 2.55:1. The exothermic reaction was monitored, the setting parameters recorded and the effects of varying the powder: liquid ratio noted. All specimens were weighed at the end of the reaction. 15 Specimens were tested in isothermal mode at 23°C and 15 specimens in isothermal mode at 37°C.

4.2.1.3.2.BOND STRENGTH DETERMINATION

INTRODUCTION

Composite resin restorations even after etching do not adhere to freshly cut dentine in vivo. This drawback becomes extremely relevant when considering restoring a Class II cavity with composite resin. A minimal Class II box will have a good thickness of enamel at its base to which a composite could bond, but a deep box will either have a very thin layer of enamel or be completely within dentine alone, or dentine and cementum. In both these latter situations, marginal leakage will undoubtedly occur and thus jeopardise both the health of the tooth and the efficacy of the restoration. In an effort to produce a bond between dentine and composite resin, coupling agents or dentine bonding agents were introduced, and these fall into 4 categories based on their chemical structure. Results with these have been variable and are discussed elsewhere in this work.

In 1985, another suggestion was reported in a further effort to overcome the problem (McLean et al 1985). This involved combination of the adhesive and biologically bland properties of glass polyalkenoate cement with the better mechanical properties and aesthetic appeal of composite resin. The technique subsequently called 'the sandwich technique' involves using the glass polyalkenoate cement to replace dentine and then when it has set the surface of the glass polyalkenoate cement and the enamel cavity margins are acid etched before being bonded to composite resin.

Bond strength determinations were carried out in the laboratory for both interfaces of the sandwich:

(a) Glass Polyalkenoate-Dentine; and

(b) Glass Polyalkenoate-Composite Resin.

(a) GLASS POLYALKENOATE-DENTINE

MATERIALS AND METHOD

A series of alignment jigs designed and made at Newcastle Dental School were used to test specimens on an Instron Universal testing machine (Fig. 4.43.). These ensured that the forces placed on the bond were tensile, with minimal shear and torsional load.

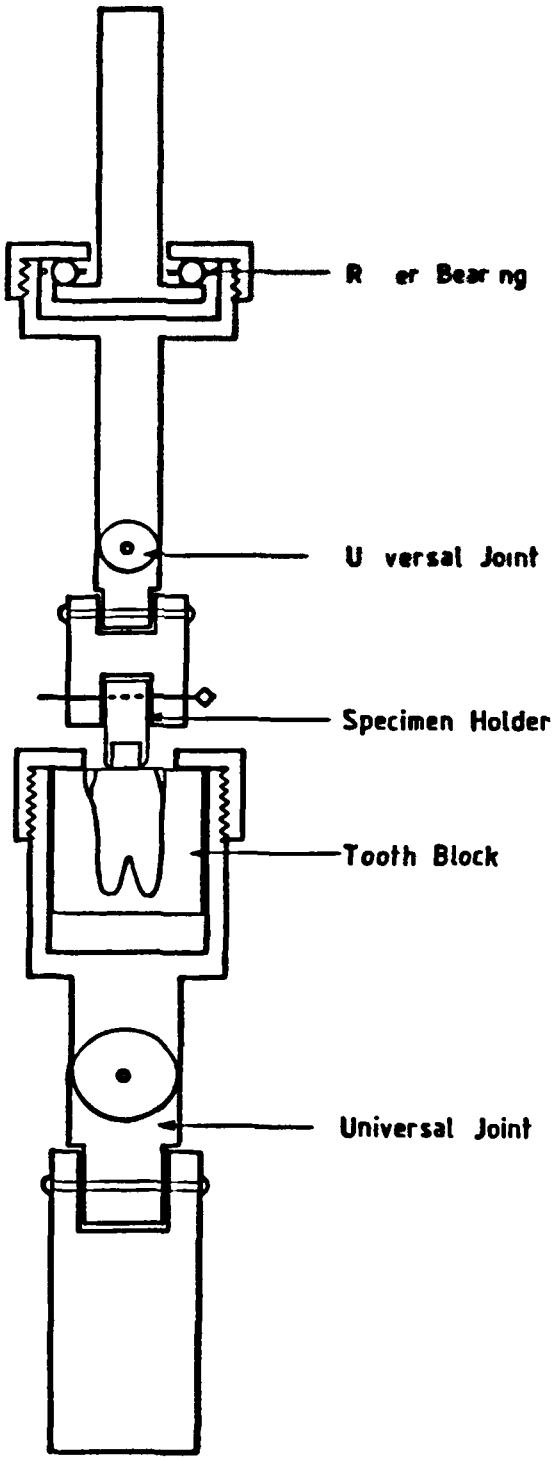
Freshly extracted, non-carious, human third molars were placed in neutral buffered formalin after a bur hole was made into the pulp chamber from the area of root bifurcation. This was to ensure rapid penetration of the fixative into the pulp. The teeth were stored at room temperature (24 +/- 3°C) for 1 month prior to experimental use. Using 180 grit carborundum paper on a rotary pregrinder (Metaserv) with continuous water irrigation the teeth were ground parallel to the occlusal plane until all enamel had been removed and a flat dentine surface produced. Any teeth with visible or occult pulpal exposure were discarded. The teeth were embedded as centrally as possible in a block of autopolymerising polyester resin (Resinous Products Ltd.) with a peak exotherm of 42°C using a proprietary plastic mould. A spring loaded lapping jig was used to allow the upper and lower surfaces of the resin block to be ground flat, perpendicular to the walls of the specimen block (Fig. 4.44.). Initial surfacing was performed with 180 grit carborundum paper on the rotary pregrinder

Fig 4.43

The Tensile Bond strength testing jig for Glass Polyalkenoate-Dentine.

Fig 4.43

The Tensile Bond strength testing jig for Glass Polyalkenoate-Dentine.



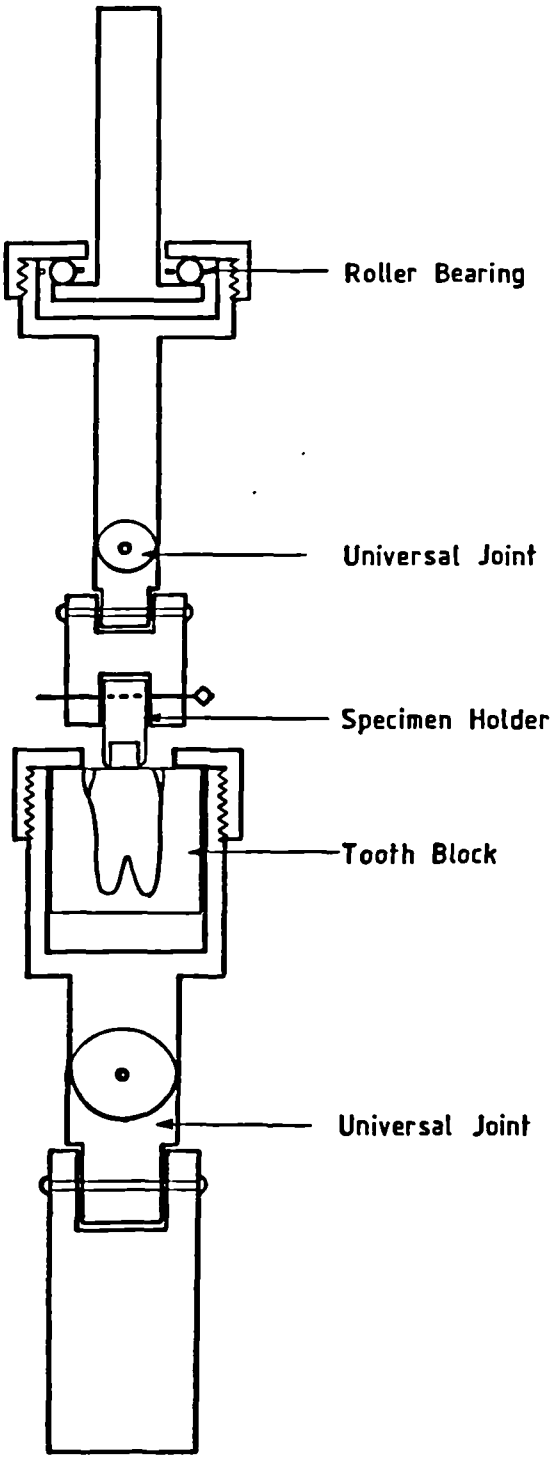

Roller Bearing
Universal Joint
Specimen Holder
Tooth Block
Universal Joint

Fig 4.44

The lapping jig.

Fig 4.45

Stainless steel specimen holder for Bond strength testing.

Fig 4.46

The alignment jig for Tensile Bond strength testing, Glass Polyalkenoate-Dentine.

Fig 4.44

The lapping jig.

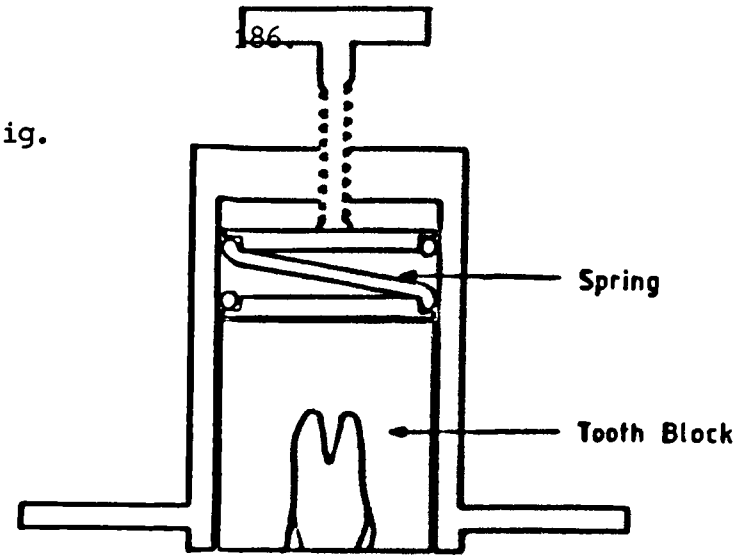


Fig 4.45

Stainless steel specimen holder for Bond strength testing.

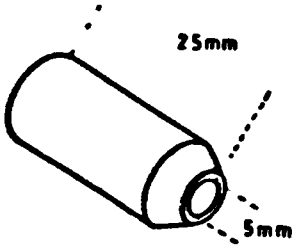
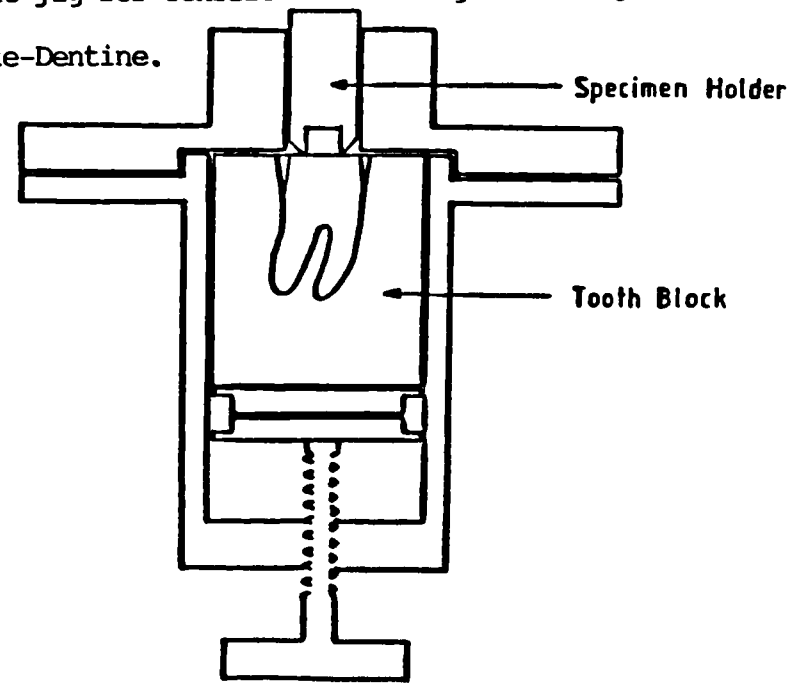
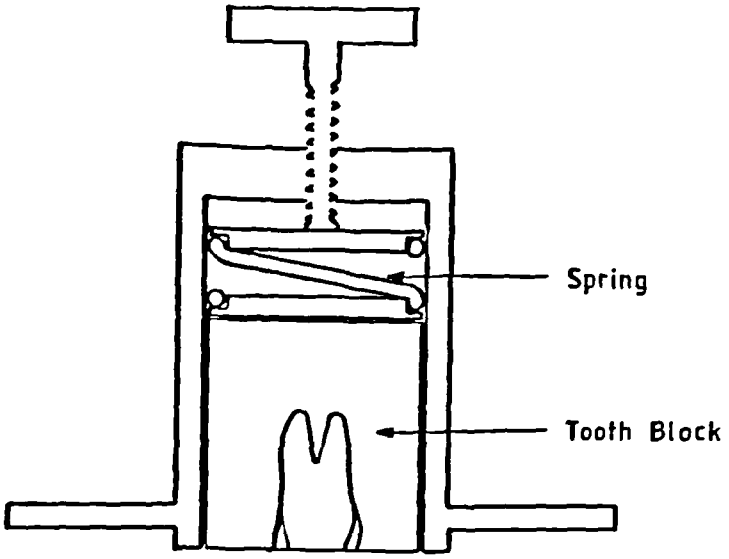
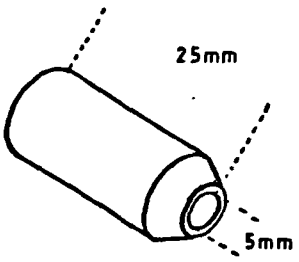


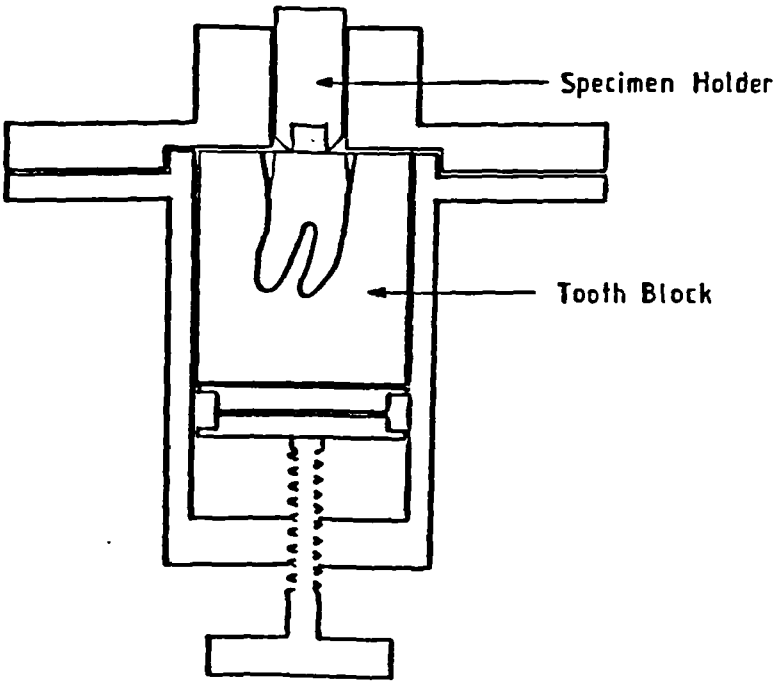
Fig 4.46

The alignment jig for Tensile Bond strength testing, Glass Polyalkenoate-Dentine.




Spring
Tooth Block


25mm
5mm


Specimen Holder
Tooth Block

with continuous water irrigation. The exposed dentine surface (adherend) was then resurfaced using 800 grit carborundum paper.

The specimen holders for the glass polyalkenoate cement (adhesive) comprised a short length of stainless steel bar (9.5 mm. diameter x 25 mm. long) (Fig. 4.45.). A 2 mm. diameter hole was present across the diameter of the bar 2 mm. from one end. At the opposite end the bar was chamfered down to 6 mm. and a hole (5 mm. diameter x 5 mm. deep) was bored up the long axis of the specimen holder. A groove (0.5 mm. deep) was cut into the axial wall of the central hole to provide mechanical retention. The alignment jig (Fig. 4.46.) fitted accurately over the raised shoulder on the lapping jig and had a central sleeve, 9.6 mm. diameter which was perpendicular to the face plate. When in place against the lapping jig, it allowed for accurate central positioning of a specimen holder containing the adhesive, over a polyester block containing the adherend. The alignment was such that the specimen holder was centred on and perpendicular to the surface of the resin block.

The completed specimen was placed in the screw-capped receiver of the bond strength testing assembly on the cross head of the universal testing machine. The cross head was raised until the stainless steel bar passed into the specimen receiver of the upper component of the testing assembly. The 2 units were linked using a 1.5 mm. diameter hard stainless steel pin.

The tensile bond strengths between 3 glass polyalkenoate and one glass cermet cement and dentine (with and without dentine pretreatment with polyacrylic acid) were measured using this system. Pre-treatment with polyacrylic acid (Durelon liquid - ESPE) consisted of painting the adherend with the viscous Duralon liquid for 30

seconds, then washing for 30 seconds before drying. Ketac Fil and Ketac silver (both encapsulated) were syringed into the specimen holder and Ketac Bond and Coltene 018804B spatulated in after mixing at recommended powder:liquid ratio (KB 3.4:1, Coltene 6.9:1). The specimen holder was then bonded to the exposed dentine surface using the alignment jig. The shoulder of the specimen holder was coated with a thin smear of petroleum jelly to prevent adhesion between the glass polyalkenoate material and the specimen holder. The specimen holder was put under a 2Kg. load and stored at 37°C and 100% relative humidity for 5 minutes. The load was removed, the joint coated with proprietory varnish and the specimen stored for a further 10 minutes at 37°C and 100% relative humidity. After this time, the specimen was given a further coat of varnish and stored in distilled water for 1 week at 37°C. 30 specimens for each polyalkenoate were prepared in this way. Tensile bond strength was determined at a cross head speed of 1 mm. per minute. 40 resin tooth blocks were used for this procedure with three bonds being made on each block. Resurfacing with 800 grit carborundum paper followed by storage in distilled water at 37°C for 24 hours occured between each bonding procedure.

(b) **GLASS POLYALKENOATE - COMPOSITE RESIN**

Many factors may potentially affect the quality of the bond between the composite and glass polyalkenoate cement, including the time at which the glass polyalkenoate is etched after commencing the mix, the duration (and type) of the etch, the effect of using different glass polyalkenoate materials and whether or not an intermediate unfilled resin layer is used. These variables have all been

investigated in the following in-vitro study.

MATERIALS AND METHOD

The glass polyalkenoate cements used were Ketac Bond, Ketac Fil Coltene 018804B and the cermet was Ketac Silver. The composite resin was Occlusin (pot, universal shade, I.C.I., England).

Specimen preparation was carried out at 23°C +/- 2°C and 55 +/- 5% relative humidity. The clinical triple syringe was used for all washing and drying procedures.

The glass polyalkenoate was handpacked into a circular undercut cavity (depth 5 mm., surface diameter 8 mm.) in a resin block and the surface made as flush with the block as possible with a plastic instrument. At the predetermined time after mixing, the glass polyalkenoate was etched with a proprietary solution of orthophosphoric acid etchant gel (I.C.I., England), then washed for 60 seconds (manufacturers' recommendation) before being dried. A layer of intermediate unfilled resin was painted on to the etched surface with the clinical applicator brush supplied with Occlusin and this was cured for 20 seconds with a Luxor® light curing unit. The resin block was then placed in an alignment jig and composite resin packed in 2 increments onto the glass ionomer through a hole (6 mm. diameter x 2.5 mm. deep) in a P.T.F.E. insert (Fig. 4.47.). Each increment of approximately 1.25 mm. thick was light cured with a Luxor light for 60 seconds. After removal of the alignment jig and PTFE insert, the resin block with glass ionomer bonded to a composite resin stub was stored in distilled water at 37°C. After 1 week in distilled water at 37°C, the top of the composite was flattened using an 800 grit

Fig 4.47

The alignment jig for packing Composite Resin - Glass Polyalkenoate cement.

Fig 4.48

The alignment jig for Tensile Bond strength testing, Glass Polyalkenoate-Composite Resin.

Fig 4.47

The alignment jig for packing Composite Resin - Glass Polyalkenoate cement.

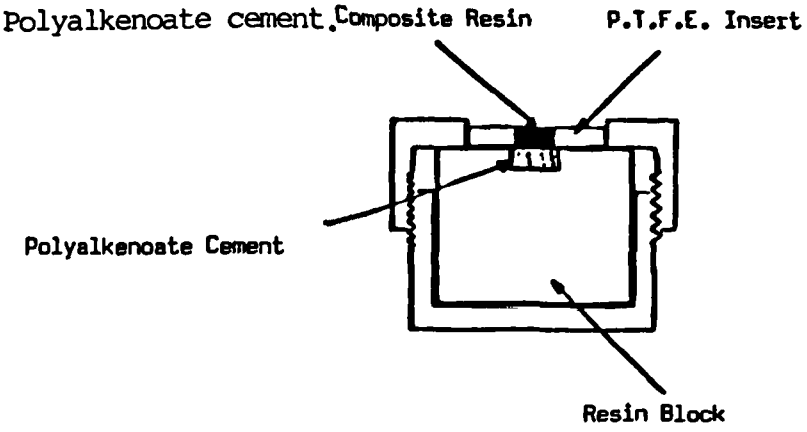
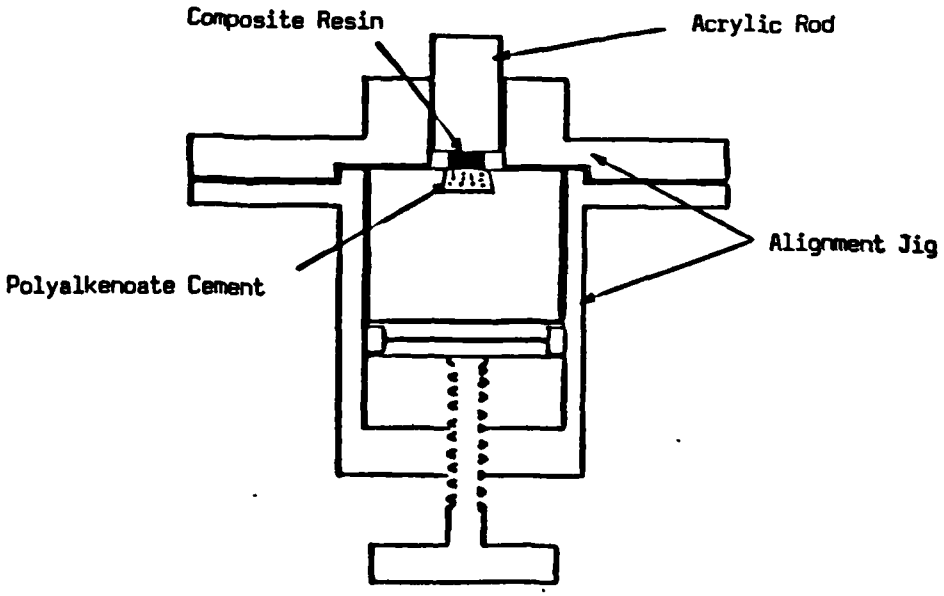
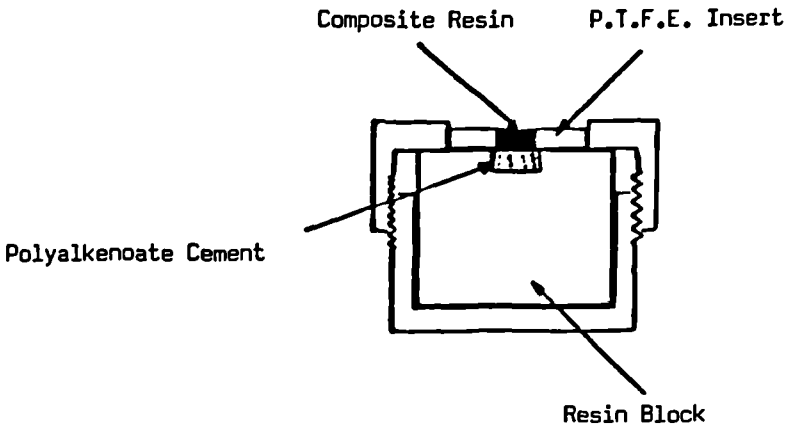
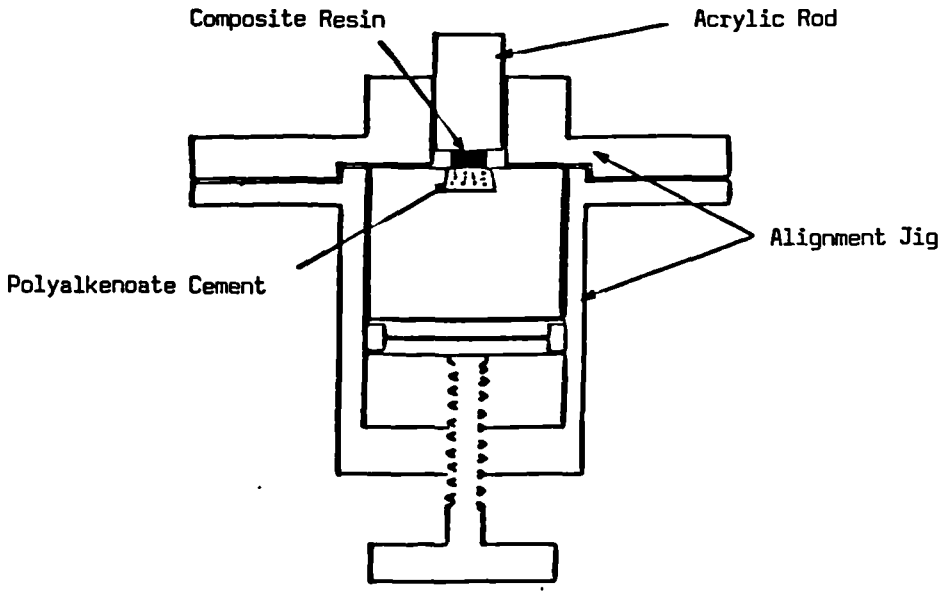


Fig 4.48

The alignment jig for Tensile Bond strength testing, Glass Polyalkenoate-Composite Resin.




Composite Resin
P.T.F.E. Insert
Polyalkenoate Cement
Resin Block


Composite Resin
Acrylic Rod
Alignment Jig
Polyalkenoate Cement

carborundum water cooled disc and bonded to an acrylic rod with cyanacrylate cement using an alignment jig (Fig. 4.48.). This assembly was then mounted on an Instron testing machine using the alignment jig to hold the resin block and acrylic rod in vertical alignment with minimal shear or tortional stress (Fig. 4.49.). Tensile Bond strength (T.B.S.) testing was carried out at a crosshead speed of 1 mm./minute with 30 or 60 specimens for each variable. The following variables were tested:

(i) T.B.S. as a function of material composition.
Ketac-Bond, Ketac-Silver, Ketac-Fil and Coltene were all prepared according to manufacturers recommendations. At specific times after commencement of mix (Ketac Bond and Coltene 4 minutes, Ketac Silver 5 minutes, Ketac Fil 15 minutes) the specimens were etched for 60 seconds, washed for 60 seconds and dried (Table 4.1.).

(ii) T.B.S. for Ketac Bond-Occlusin as a function of the powder: liquid ratio of Ketac Bond. Powder:liquid ratios by accurate weights of 2.55:1, 2.97:1, 3.4:1, 3.83:1, 4.26:1 were employed where 3.4:1 is the manufacturers' recommended one level scoop to one drop of liquid. 4 Minutes after commencement of mix, the specimens were etched with acid for 60 seconds, washed with water for 60 seconds and then dried prior to bonding (Table 4.2.).

(iii) T.B.S. for Ketac Bond - Occlusin as a function of the length of set after commencement of mix prior to etching, the type and duration of etch and the presence of an unfilled intermediate resin layer (Table 4.3.).

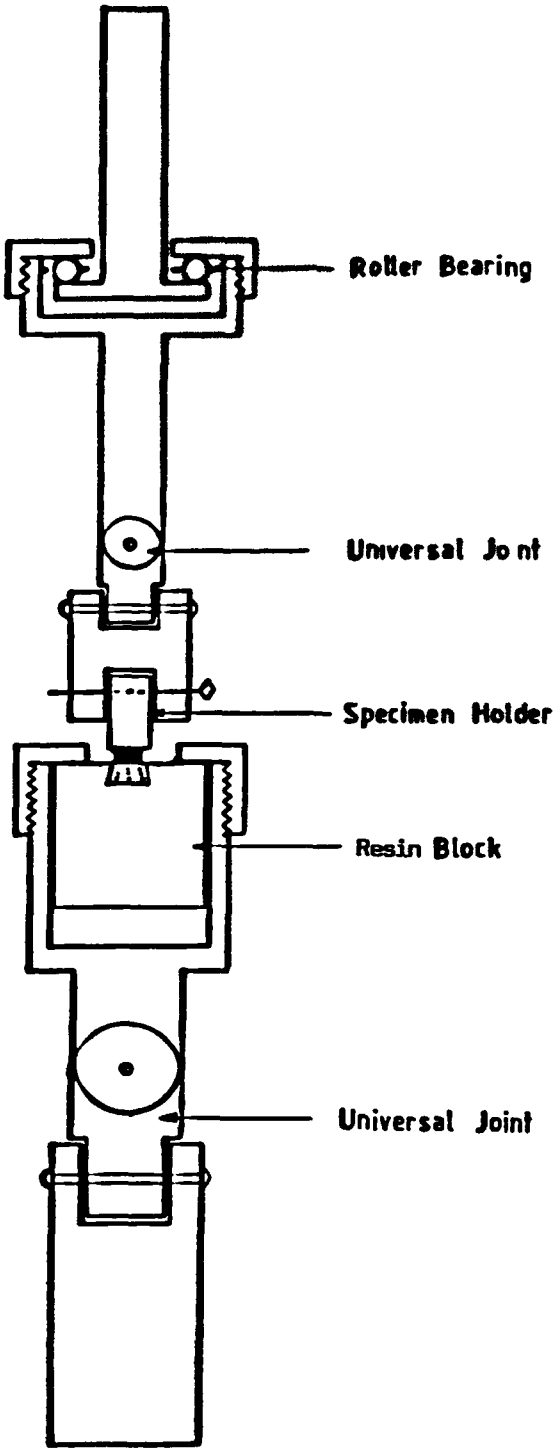
(iv) T.B.S. for Ketac Silver - Occlusin as a function of the length of set prior to etching, the type and duration of etch and of

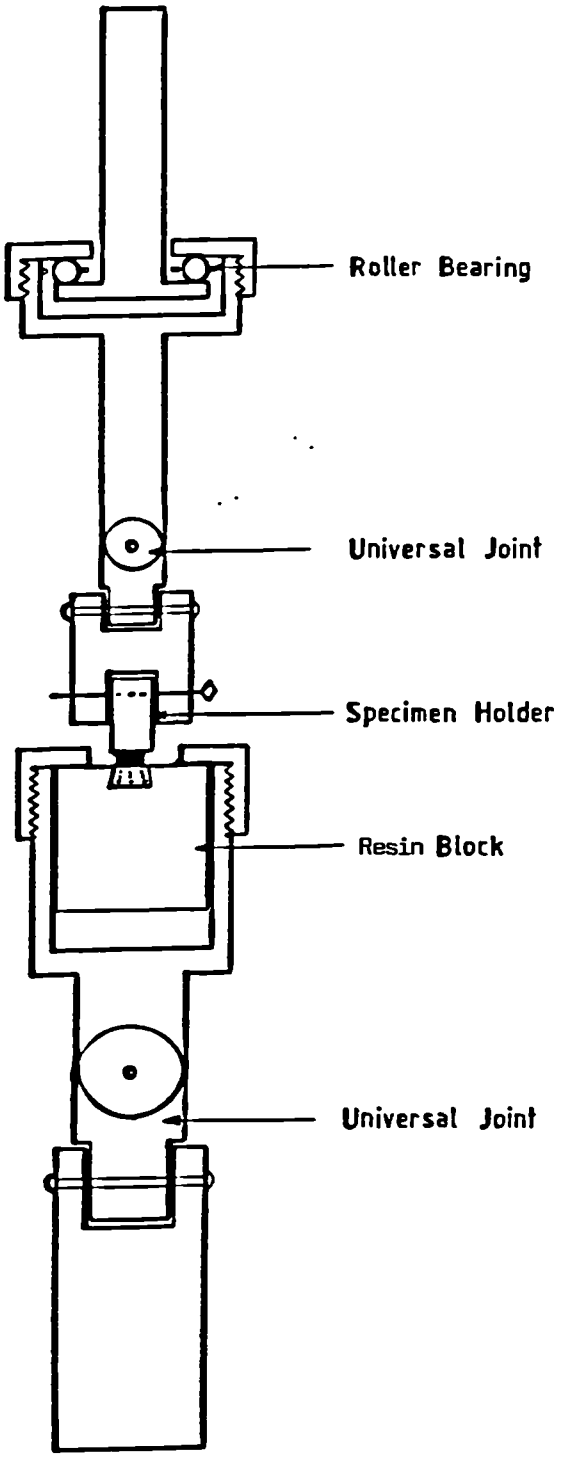
Fig 4.49

The Tensile Bond strength testing jig for Glass Polyalkenoate-Composite Resin.

Fig 4.49

The Tensile Bond strength testing jig for Glass Polyalkenoate-Composite Resin.




Roller Bearing
Universal Joint
Specimen Holder
Resin Block
Universal Joint

mechanical preparation of the cement surface prior to etching (Table 4.4.). The surface of Ketac Silver was smoothed with a No. 5 round bur in conventional handpiece for 5 seconds.

(v) T.B.S. for Ketac Fil - Occlusin as a function of length of set prior to etching (Table 4.5.).

(vi) T.B.S. for Coltene - Occlusin as a function of the type of etch employed. In addition to the specimen already prepared in section (a), a further one was prepared, but on this occasion, omitting the acid etch (Table 4.6.).

A total of 780 specimens were prepared.

TABLE 4.1.

T.B.S. as a function of material composition.

DESCRIPTION OF VARIABLE	CODE USED
Ketac Bond: etch (60 secs.) + wash; after 4 mins.	KB 60 4
Ketac Fil: etch (60 secs.) + wash; after 15 mins.	KF 60 15
Coltene 018804B: etch (60 secs.) + wash; after 4 mins.	Col 60 4
Ketac Silver: etch (60 secs.) + wash; after 5 mins.	KS 60 5
30 specimens tested for each variable All washes for 60 secs.	

TABLE 4.2.

T.B.S. as a function of the powder:liquid ratio of Ketac Bond.

DESCRIPTION OF VARIABLE	CODE USED
Ketac Bond P:L ratio 2.54:1 w/w	KB $\frac{60}{4}$ 2.55
Ketac Bond P:L ratio 2.97:1 w/w	KB $\frac{60}{4}$ 2.97
Ketac Bond P:L ratio 3.4 :1 w/w	KB $\frac{60}{4}$
Ketac Bond P:L ratio 3.83:1 w/w	KB $\frac{60}{4}$ 3.83
Ketac Bond P:L ratio 4.26:1 w/w	KB $\frac{60}{4}$ 4.26
4 minutes after commencement of mix, all specimens were etched with acid (60 seconds), washed (60 seconds) then dried prior to bonding to resin. 30 specimens for each variable were tested.	

TABLE 4.3.

T.B.S. for Ketac Bond - Occlusin as a function of: the length of set after commencement of mix prior to etching, the type and duration of etch: the presence of an unfilled intermediate resin layer.

DESCRIPTION OF VARIABLE	CODE USED
° Ketac Bond etch (60 secs.) + wash; after 3 mins.	KB 60 / 3
° Ketac Bond bonded after 4 mins. no etch or wash	KB new / 4
° Ketac Bond wash only after 4 mins.	KB ne / 4
° Ketac Bond etch (30 secs.) + wash; after 4 mins.	KB 30 / 4
° Ketac Bond etch (60 secs.) + wash; after 4 mins.	KB 60 / 4
° Ketac Bond etch (60 secs.) + wash; after 4 mins. omitting unfilled intermediate resin layer	KB 60 nr / 4
* Ketac Bond wash only after 60 mins.	KB 60 / 60
* Ketac Bond etch (60 secs.) + wash; after 60 mins.	KB ne / 60

° 30 specimens

* 60 specimens. All washes for 60 secs.

TABLE 4.4.

T.B.S. for Ketac Silver - Occlusin as a function of: length of set prior to etching; the type and duration of etch, mechanical preparation of cement prior to etching.

DESCRIPTION OF VARIABLE	CODE USED
• Ketac Silver wash only after 5 mins.	KS ne 5
• Ketac Silver etch (60 secs.) + wash; after 5 mins.	KS 60 5
* Ketac Silver wash only after 60 mins.	KS ne 60
* Ketac Silver etch (60 secs.) + wash; after 60 mins.	KS 60 60
* Ketac Silver etch (60 secs.) + wash; after 60 mins. with mechanical surface prep.	KS 60M 60
• 30 specimens * 60 specimens. All washes for 60 seconds.	

TABLE 4.5.

T.B.S. for Ketac Fil - Occlusin as a function of length of set prior to etching.

DESCRIPTION OF VARIABLE	CODE USED
° Ketac Fil etch (60 secs.) + wash; after 8 mins.	KF 80 8
° Ketac Fil etch (60 secs.) + wash; after 15 mins.	KF 60 15
° 30 specimens * 60 specimens. All washes for 60 seconds.	

TABLE 4.6.

T.B.S. for Coltene - Occlusin as a function of the type of etch employed.

DESCRIPTION OF VARIABLE	CODE USED
Coltene 018804B: wash; after 4 minutes	Col ne 4
Coltene 018804B: etch (60 seconds) and wash after 4 minutes	Col 60 4
30 specimens tested for each variable. All washes for 60 seconds.	

4.2.1.3.3.DEPTH OF ETCH DETERMINATION

INTRODUCTION

Over the last 3 years, there has been a great interest in the bond which can be achieved between both etched and unetched glass polyalkenoate cements and composite resin and the applicability of this bond to various clinical situations in restorative dentistry. The purpose of this investigation was to determine the quantity of cement lost (the depth of etch) during acid etching and washing procedures.

MATERIAL AND METHOD

Specimen holders comprised squares of Perspex (20 mm. x 20 mm. x 5 mm.) with a hole (5 mm. diameter x 2 mm. deep) bored at the centre of each square (Fig. 4.37.).

Glass polyalkenoate specimens were mixed by hand to the manufacturer's recommended powder:liquid ratio under ambient laboratory conditions (23 +/- 2°C and 55 +/- 5% relative humidity) and packed into the cavities in the perspex squares with a plastic instrument. They were covered with a cellulose acetate matrix and allowed to set at room temperature under 1 kilogramme load. The specimens were then lapped for 15 seconds until flat on a rotary pre-grinder (Mataserv) using 800-grit carborundum paper with continuous water irrigation, then subjected to 1 of the 3 experimental variables: washed for 60 seconds then dried; etched for 30 seconds, washed for 60 seconds then dried, etched for 60 seconds, washed for 60 seconds then dried.

The loss of material during the etching and washing was

measured immediately after drying by recording the surface profile of the specimen holder and the cement, using a profilometer (Surfometer). Two profiles, perpendicular to each other and across the maximum diameter of the cement were recorded for each specimen. The base of the surface profile was visually averaged and the area of cement loss between the fixed datum points of the perspex shoulders of the cavity was determined by tracing the area on a high resolution magnetic digitising tablet with associated micro-computer analysis. The average depth loss (μm.) per reading was calculated from this.

3 Variables which may influence the depth of etch or loss of cement were investigated using this method.

(i) The variation in depth of etch with variation in material composition. 12 Specimens each of Ketac Bond and Coltene 018804B were subjected to each of the experimental variables 4 minutes after commencement of mix.

(ii) The variation in depth of etch with earlier etching and washing of the specimen. 12 Specimens of Ketac Bond were subjected to each experimental variable after only 3 minutes from commencement of mix.

(iii) The variation in depth of etch with differing powder:liquid ratio mixes of Ketac Bond: 2.55:, 2.97:1, 3.83:1, 4.26:1.

12 specimens of each P:L ratio were subjected to each of the 3 experimental variables.

A total of 216 specimens were prepared for the depth of etch investigations.

4.2.1.3.4.MORPHOLOGY OF ETCHED SURFACES

INTRODUCTION

The combination of the adhesive and biologically bland properties of glass polyalkenoate cement with the better mechanical properties and aesthtic appeal of composite resin has been mentioned previously. This study will investigate by scanning electron microscopy and certain characteristics of the glass polyalkenoate-composite interface:

(a) the surface of the glass polyalkenoate cement; and

(b) the depth of composite resin tag penetration (previously in contact with the glass polyalkenoate cement) with differing durations of etching.

MATERIALS AND METHOD

STUDY OF ETCHED GLASS POLYALKENOATE SURFACES

The P.T.F.E. insert used in previous tensile bond strength testing (Fig. 4.47) was utilised to prepare specimens. The P.T.F.E. insert was placed on a melinex strip and glass polyalkenoate cement hand packed into the 6 mm. diameter x 2.5 mm. deep hole. A second melinex strip and a glass slab under 1 Kg. weight was placed over the hole to extrude excess cement. After a specific length of time under ambient laboratory conditions (23°C +/- 2°C and 55 +/- 5% relative humidity) the specimen was extruded from the P.T.F.E. insert, held gently between tweezers and subjected to an etching and washing protocol. 37% Phosphoric acid was used for etching and all washing and drying was with a clinical triple syringe. The specimen was then immediately cemented to an alloy S.E.M. mounting spigot with epoxy

resin, vacuum dried for 10 minutes, then sputter coated with gold in order to prevent charge build up. The specimen was now viewed on the S.E.M. (Cambridge - Stereoscan 600). At a working distance of 15" and Kilvoltage of 7.5, each sample was viewed and photographed at 3 magnifications, 200x, 1,000x and 5,000x.

The following variables were investigated with one specimen prepared for each variable:

Ketac Bond: 4 minutes after commencement of mix the specimens were etched for either 15, 30 or 60 seconds prior to washing and drying.

Ketac-Fil: 8 minutes after mix commencement the specimens were etched for either 15, 30 or 60 seconds prior to washing and drying.

Ketac-Silver: 5 minutes after mix commencement the specimens were etched for either 15, 30 or 60 seconds prior to washing and drying.

STUDY OF COMPOSITE RESIN TAG MORPHOLOGY

Modified resin blocks with tapered instead of undercut cavities, contained in the same alignment jig as that used in the tensile bond strength testing of glass polyalkenoate - composite resin, were used to prepare glass polyalkenoate -- composite resin (Occlusin) specimens (Fig. 4.50.). The specimens were prepared in exactly the same manner as those for tensile bond strength testing using an intermediate resin unless specified. After light curing, the Occlusin composite resin surface was lapped flat with an 800 grit carborundum water cooled disc (Metaserv), removed from the resin block

Fig 4.50

Modified glass polyalkenoate-composite resin preparation jig with a tapered non undercut cavity in the resin block.

Fig 4.51

The glass polyalkenoate-composite resin stub prior to immersion in 18% hydrochloric acid for 12 hours.

Fig 4.50

Modified glass polyalkenoate-composite resin preparation jig with a tapered non undercut cavity in the resin block.

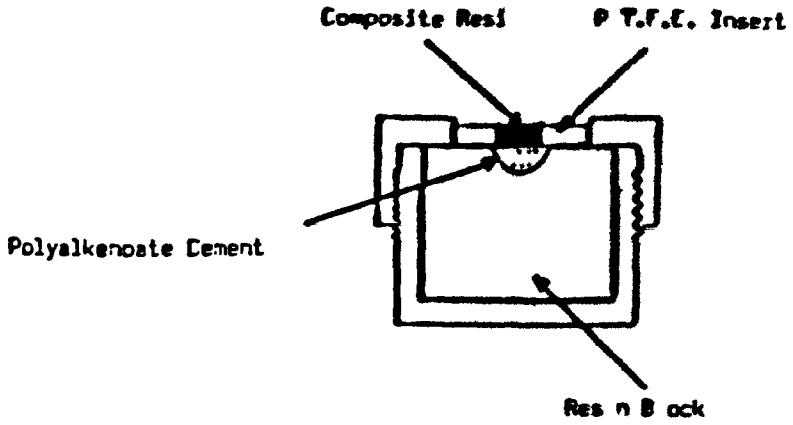
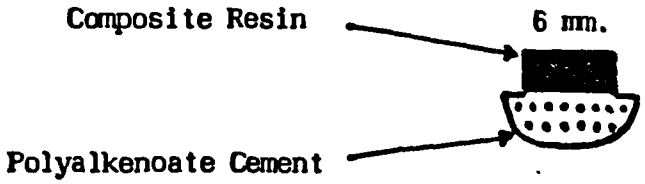
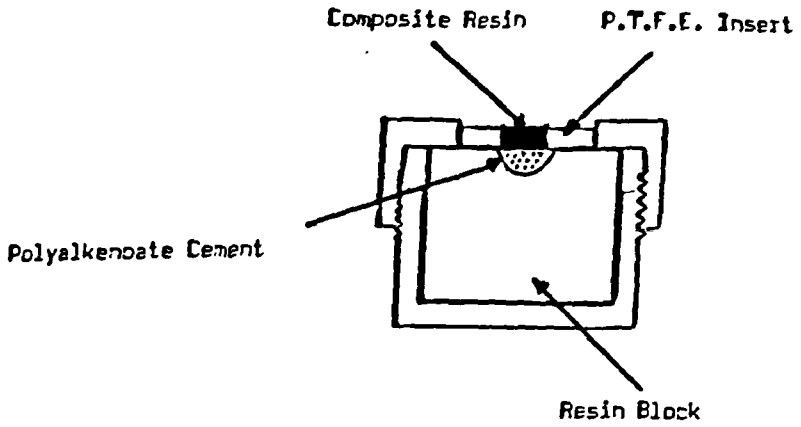
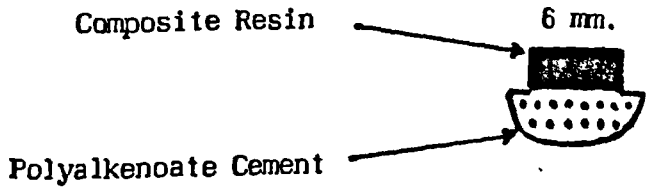


Fig 4.51

The glass polyalkenoate-composite resin stub prior to immersion in 18% hydrochloric acid for 12 hours.




Composite Resin
P.T.F.E. Insert
Polyalkenoate Cement
Resin Block


Composite Resin
6 mm.
Polyalkenoate Cement

and align jig (Fig. 4.51.) and immersed overnight in 18% hydrochloric acid to dissolve away the glass polyalkenoate cement. After 12 hours, the specimen was removed from the acid and placed for 20 minutes in an ultrasonic cleaner to remove any residual traces of glass polyalkenoate. The flat surface of the resin was cemented to an S.E.M. spigot with epoxy resin and placed in a vacuum drier for 10 minutes. The 'working surface' was then sputter coated with gold and the specimens viewed and photographed on S.E.M. under the same conditions as previously.

The following variables were investigated with one specimen prepared for each variable:

Ketac Bond:

(i) 4 minutes after commencement of mix

(a) No etch or wash

(b) Wash 60 seconds only and dry

(c) Etch 15 seconds, wash 60 seconds and dry

(d) Etch 30 seconds, wash 60 seconds and dry

(e) Etch 60 seconds, wash 60 seconds and dry

(f) Etch 60 seconds, wash 60 seconds and dry - no intermediate resin

(ii) 3 minutes after commencement of mix

(a) Etch 60 seconds, wash 60 seconds and dry

(iii) 5 minutes after commencement of mix

(a) Etch 60 seconds, wash 60 seconds and dry

Ketac Fil:

(i) 8 minutes after commencement of mix and

(ii) 15 minutes after commencement of mix, etch 60 seconds, wash 60 seconds and dry.

Ketac Silver:

(i) 5 minutes after commencement of mix

(a) Wash 60 seconds and dry

(b) Etch 60 seconds, wash 60 seconds and dry.

4.2.2. LABORATORY METHOD FOR HELIOCOLOR MICROFILLED COMPOSITE RESIN

4.2.2.1. MECHANICAL PROPERTIES OF HELIOCOLOR

The purpose of this section of the laboratory work was to investigate those properties that were deemed to be of particular relevance to the use of the resins as an anterior veneering agent.

The following mechanical properties were investigated:

1. Fatigue Wear
2. Abrasive Wear
3. Roughness Average
4. Surface Hardness
5. Flexural Strength.

4.2.2.1.1.FATIGUE WEAR

INTRODUCTION

Wear within the oral cavity can occur by one or more of a number of mechanisms, some of which may be of mechanical origin and others chemical. It is likely that 'mechanical wear' can be significantly accelerated by chemical effects.

Many materials which are used as restoratives are subjected to intermittent stresses over a long period of time. Although the stresses encountered may be far too small to cause fracture of a material when measured in a direct tensile, compressive or transverse test it is possible that, over a period of time, failure may occur by a fatigue process. This involves the formation of a microcrack at or just beneath the surface caused either by stress concentration at a surface fault or porosity or due to the shape of the restoration. This crack slowly propagates until fracture occurs which can ultimately

be at quite a low level of stress.

Wear due to intermittent stresses caused by, for example, tooth-restorative contacts where the degree of scratching may be minimal is termed fatigue wear. The fatigue life; the number of stress cycles of given magnitude and frequency required for failure and the 'fatigue' limit the value of the cyclic stress required to cause fracture within a set number of cycles are thought to give a guide to fatigue wear resistance (McCabe 1985).

MATERIAL AND METHOD

The following 2-body abrasion technique (McCabe and Smith 1981) may give a respresentation of the resistance to abrasive wear which also involves a fatigue process. A laboratory flask shaker vibrating at a frequency of 43 HZ was used to vibrate 4 capsules lined with 800 grit silicon carbide abrasive paper. 2 of the capsules contained a test specimen whilst the other 2 contained amalgam (Amalcap). The wear rate is measured as a function of weight loss against time which is converted to volumetric loss against time. The rate of abrasion of all materials is expressed as a 'wear factor' in relation to the rate of wear of an amalgam control (Amalcap). Heliocolor specimens (Heliosit shade 20) and Adaptic specimens were prepared using a split stainless steel mould producing specimens 5 mm. diameter x 6 mm. high (Fig. 4.52.). The mould was assembled and one surface covered with a melinex strip and placed against a glass slab. Heliocolor resin was compressed into the moulds with a stainless steel burnisher and 2 increments of 2 mm. were each light cured for 60 seconds with a Luxor light. The final 2 mm. of resin was then packed and the upper surface of the mould covered with a second layer of matrix and a second glass slab.

Fig 4.52

Split stainless steel mould to give 5mm diameter x 6mm high specimens of Heliocolor.

Fig 4.53

Four part stainless steel mould used to prepare amalgam specimens for abrasion testing.

Fig 4.52

Split stainless steel mould to give 5mm diameter x 6mm high specimens of Heliocolor.

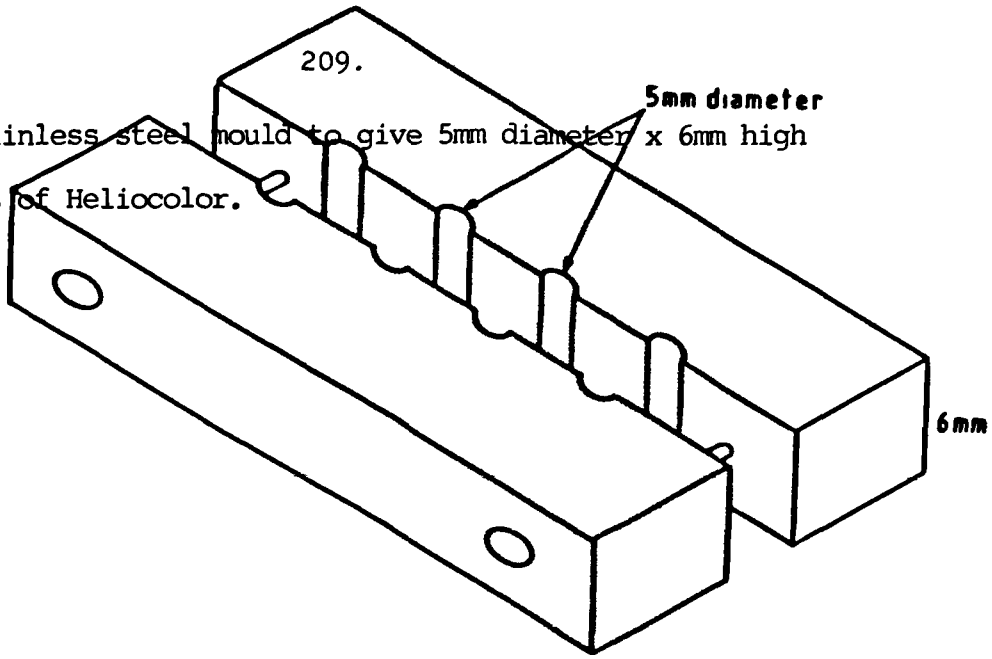
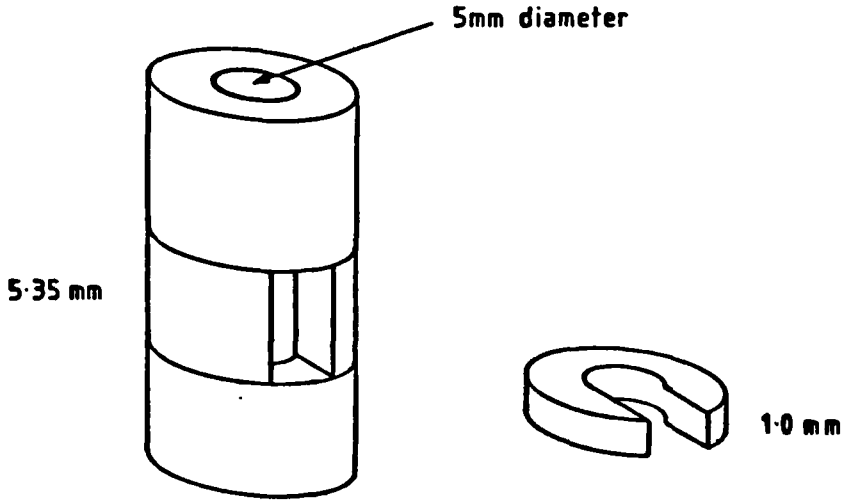
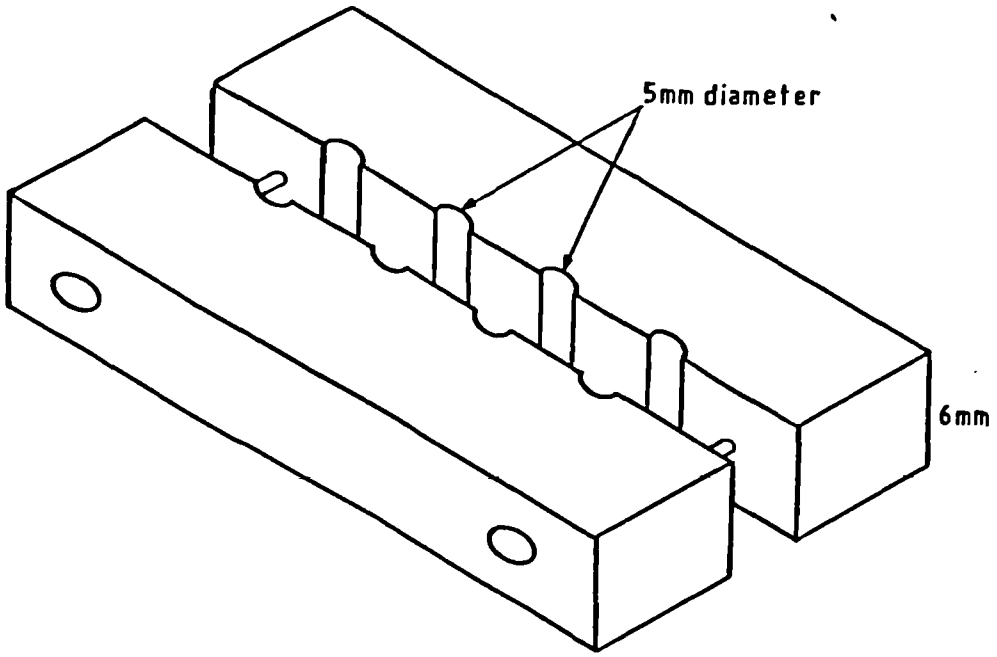
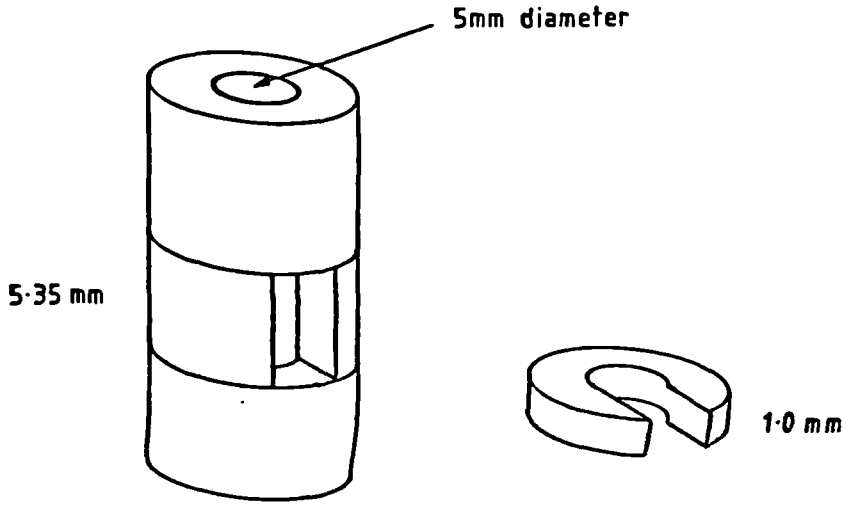


Fig 4.53

Four part stainless steel mould used to prepare amalgam specimens for abrasion testing.




5mm diameter
6mm


5mm diameter
5·35 mm
1·0 mm

Firm pressure was applied for 15 seconds, then the second slab was removed and the last incremental of resin was also light cured for 60 seconds. The amalgam specimens were prepared using a 4 part stainless steel mould (Fig. 4.53.) comprising a base and 5 mm. central hole, and 2 slotted spacing pieces, 1 mm. and 5.35 mm. thickness. The material was activated and triturated according to the manufacturers' instructions and condensed into the mould using an amalgam packer. After 1 minute, the 1 mm. spacer washer was removed and the mercury rich layer of amalgam was carved away. The specimens (5 mm. x 5.35 mm. high) were removed from the mould after 10 minutes by removal of the 5.35 mm. spacer and the application of steady pressure to the piston. 12 Amalgam (Amalcap), 6 Heliocolor (Heliosit shade 20) and 6 Adaptic specimens were prepared and then stored in distilled water at 37°C for 1 week. Each specimen was weighed and placed in a polypropylene capsule (49.75 mm. high x 14.25 mm. diameter) with a square of 800 grit carborundum paper lining the inner surface of the capsule. 2 Capsules containing the test material and 2 containing the control amalgam specimens were placed at diagonally opposite stations of a laboratory flask shaker (Gallenkamp). The shaker was activated for 20 minutes at 43 HZ, the speed of oscillation being continually monitored using an infrared omitter sensor system and a suitable signal counter (Radiospares). At the end of 20 minutes, the capsules were rotated 1 station in a clockwise direction, and a further 20 minute period of shaking was performed. After 80 minutes, during which each capsule had been at every shaker station, the specimens were weighed, a fresh square of abrasive paper inserted into the vial and the whole procedure repeated 3 further times. The total test time was 320 minutes, with

weight measurements at 80, 160, 240 and 320 minutes. The degree of wear was measured as the weight loss of the specimens and was converted to volumetric loss after calculating the density of the material. The gradient of a plot of time versus volume lost (as determined by linear regression analysis) enabled the rate of volume loss to be calculated. This is porportional to the specimen weight (McCabe and Smith 1981) and so the calculated rate was divided by the original specimen weight to give the wear rate of the material. Wear rate of the test material was then expressed as a wear factor relative to Amalgam (McCabe and Smith 1981). The results for Heliocolor (Heliosit) and Adaptic were compared to those for Occlusin (Chadwick 1988) tested under the same conditions in the same laboratory.

4.2.2.1.2.ABRASIVE WEAR

INTRODUCTION

Wear caused by indenting and scratching of the surface of a material by abrasive toothpastes or food is termed abrasive wear and the hardness of a material is often used to give an approximate indication of the resistance to this form of abrasion.

MATERIAL AND METHOD

The 3-body abrasion resistance of a microfilled composite resin (Heliocolor - Heliosit), a hybrid composite resin (Occlusin), a large particule macrofilled two paste chemically activated composite resin (Adaptic) and a lathe cut conventional amalgam alloy (Amalcap) were assessed using a toothbrushing machine which conformed to the design embodied in British Standard B 5136 for dentifrices. The brushes (Boots Medium Nylon) used were of a multitufted design with polyamide

bristles, and had been soaked in distilled water for a minimum of 7 days before use. Each brush was used for one abrasion sequence of 50,000 brush strokes. 1 Type of abrasive slurry was used. British standard dentifrice (BS 5136) diluted at 1 part paste to 2 parts water (by weight). A fresh slurry was made for each 50,000 cycles. The specimen holders comprise blocks of perspex (95 mm. x 42 mm. x 5 mm. deep) with a hole (10 mm. diameter x 2 mm. deep) in the centre (Fig. 4.54.). Composite resin specimens were prepared by packing material into the central cavity, the surface covered with a Melinex matrix and a 2 Kilogramme load applied through a flat glass slab. After 1 minute, the Heliocolor and Occlusin specimens were light cured with a Luxor light for 60 seconds. These specimens together with the chemically activated Adaptic were then conditioned for 20 minutes at 37°C and 100% relative humidity before being stored in distilled water at 37°C. The amalgam specimens were prepared by hand condensation of amalgam alloy into the specimen holder to excess and carving away the excess 5 minutes after mixing. These specimens were also stored in distilled water at 37°C. After 24 hours, all specimens were lapped flat using 800 grit carborundum paper, with continuous water irrigation on a rotary pregrinder (Metaserv) prior to testing. Each specimen was placed in the brushing bath with 50 ml. of abrasive slurry. The specimens were partially masked with heavy duty, self adhesive polyvinychloride (PVC) tape leaving a channel approximately 5 mm. wide across the centre of the specimen. The specimens were then subjected 50,000 brush strokes, and removed from the brushing bath. The PVC tape was removed and the surface profile of the abraded track and perspex shoulders was recorded using a profilometer (Surfometer)

Fig 4.54

Perspex specimen holder for abrasive wear testing.

Fig 4.55

Plastic specimen holder for flexural testing

specimen size 2mm x 2mm x 25mm (width x depth x length)

Fig 4.54

Perspex specimen holder for abrasive wear testing.

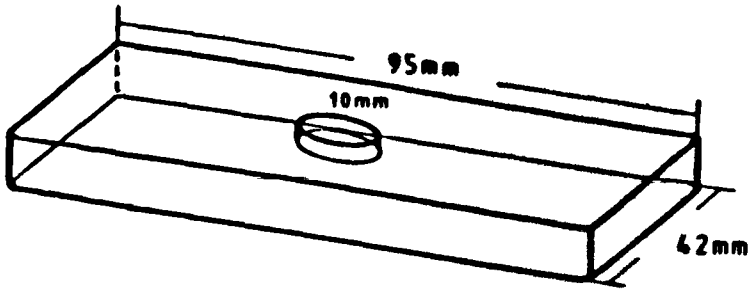
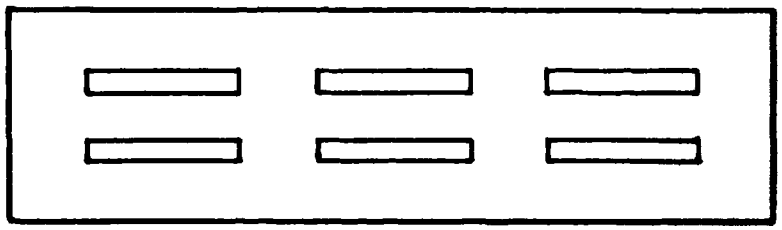
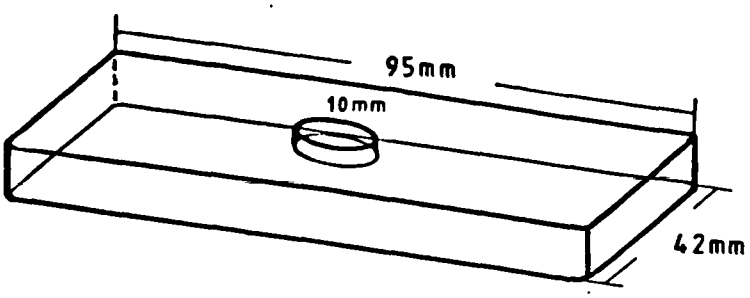


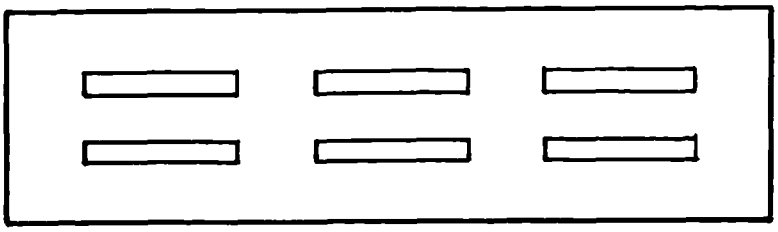
Fig 4.55

Plastic specimen holder for flexural testing

specimen size 2mm x 2mm x 25mm (width x depth x length)




95mm
10mm
42mm



running perpendicular to the brushing stroke. The abraded depth was determined by joining the protected shoulder of the profile trace, visually averaging the irregular base of the profile, and measuring the area of the profile. The area measurement was performed using a high resolution digitising tablet under microprocessor control. The mean depth loss was determined by dividing the area by the width of the abraded track.

2 Specimens of each material were prepared and profiled twice. The depth of the abrasion track in the perspex specimen block alone was also determined as a form of internal control.

4.2.2.1.3.ROUGHNESS AVERAGE

The profilometer was set up as for the profile measurements except that the meter output switch S4 was set to 'Ra' (Roughness Average) and a full scale deflection of 10 μm. was selected. Switch S3 was set to 'LOW' damping which is necessary for fine textured specimens, and the meter indicator was allowed to settle to zero before operating the 'fast' traverse switch. The reading rose to an approximately constant value indicating the Ra value for the surface.

The Ra figure is obtained by processing a continuously integrated signal which is then displayed on the meter. This readout is not necessarily a constant value, but a statistical average over a given length of time.

Each of the 2 specimens of the 3 composite resins and the amalgam in the abrasive wear experiment were profiled 5 times so that a Roughness Average for each material was calculated using 10 readings.

4.2.2.1.4.SURFACE HARDNESS

INTRODUCTION

The value of hardness often referred to as the hardness number depends on the method used for its evaluation. Generally, low values of hardness numbers indicate a soft material and vice versa.

MATERIAL AND METHOD

Heliocolor microfilled composite resin (Heliosit shade 20) was packed into a cavity 10 mm. diameter x 2 mm. deep in a Perspex block and light cured with a Luxor light for 60 seconds. The specimen was lapped with an 800 grit carborundum water cooled disc (Mataserv) and stored in distilled water for 1 hour prior to being mounted on the stage of a Leitz miniload hardness microscope loaded with a 200 g. force. The specimen was brought into the centre of the field by the micrometer spindles and the Vickers hardness testing diamond swung into position by rotating the turret assembly. Depression of the cable release allowed the diamond to slowly descend on the object (approximately 15 seconds). The 200 g. force was applied for 20 seconds prior to raising the indenting unit and rewinding the drive spring.

Indentations were now evaluated at high accuracy in the micrometer eyepiece. The setting scale (the centre scale of the eyepiece) is divided into 25μm. intervals for the 40 x measuring objective. Intermediate values were measured by displacing these divisions against an eyepiece division participating in this movement (scale unit 0.5μm. by interpolation 0.1μm.). The clamping screw was then loosened, the micrometer eyepiece rotated through 90° and the other diagonal of the indentation measured. The mean of those 2 diagonal values of the Vickers indentation together with the test load (value 200g.) was used to read the Hardness Value from tables

included with the Leitz miniload hardness tester. The Hardness Value is obtained from the Vickers formula:

$$HV = \frac{1{,}854 \times P}{d^2}$$

where HV = Vickers Hardness in Kg./mm^2.
P = Measuring force in pond
d = Length of the indentation diagonal in m.

2 Specimens were prepared and each underwent 4 indentations. Results were compared to those for Occlusin (Chadwick 1988) obtained under the same conditions on the same testing machine.

4.2.2.1.5 **FLEXURAL STRENGTH**

INTRODUCTION

An anterior restorative material used to restore incisal edges and cover buccal tooth surface will undergo a degree of 'bending' or 'flexion' during mastication. The bending stress at fracture, often called the flexural strength, is closely related to the tensile strength of the material.

MATERIAL AND METHOD

Specimens of 1 anterior resin [Heliocolor (Vivadent, Lrechtenstein)] was prepared in plastic specimen moulds as illustrated in Fig. 4.55. The exposed end of the specimen mould was covered with a mylar matrix strip layed on a flat glass slab and the resin packed in with a number 151 amalgam packer. Upon completely filling the mould, the upper surface of the composite was covered with a second mylar matrix strip and a glass slab applied on top of this under digital pressure to squeeze out excess material.

The glass slabs were removed and the specimen cured for 1 minute through the matrix strip using a stationary Luxor light. The mould was inverted and the specimen cured for a further minute from the opposite end through the second nylon matrix strip. A uniform exposure was given to all specimens. The matrix strips were removed and any excess material was trimmed away using a sharp scalpel blade prior to ejection of the specimen from the mould. Specimens were stored in distilled water at 37°C for 1 week.

Flexural strength (3 point) was measured by the application of an external force to the midpoint of test beams using an Instron Universal testing machine at a crosshead speed of 1 mm./min. The force (F) at which fracture occured was recorded.

$$\text{Flexural Strength (MPa)} = \frac{3FL}{2bd^2}$$

Where F is the applied force in Newtons, L is the distance between the supports (20 mm.), b is the width of the specimen and d its depth. 30 Specimens for each of the test resins were prepared and tested, and these were compared to results obtained for Occlusin (Chadwick 1988) tested under the same conditions in the same laboratory.

4.2.3. LABORATORY INVESTIGATION INTO THE DEPTH OF ENAMEL REMOVED BY THE HYDROCHLORIC ACID-PUMICE ABRASION TECHNIQUE

Freshly extracted, non carious human third molar teeth were placed in neutral buffered formalin, after a bur hole was made into the pulp chamber from the area of root bifurcation. This was to ensure rapid penetration of the fixative into the pulp. The teeth were stored at room temperature (24 +/- 3°C) for one month prior to experimental use. The least convex approximal enamel surface of the tooth was ground using 180 grit carborundum paper on a rotary pregrinder (Metaserv) with continuous water irrigation until an area of smooth enamel approximately 3 mm. x 3 mm. was achieved. The teeth were now embedded in a block of autopolymerising polyester resin (Resinous Products Limited) with a peak exotherm of 42°C, using a proprietory plastic mould. The prepared enamel surface was positioned so it was parallel to and very close to the inferior surface of the resin block. A spring loaded lapping jig was used to allow the upper and lower surfaces of the resin block to be ground flat perpendicular to the walls of the specimen block, and to expose on the lower surface of the block the prepared enamel surface.

A slurry of 18% hydrochloric acid and fine pumice powder was prepared and a small quantity delivered to the enamel surface on a wooden interdental stick. The slurry was rubbed backwards and forwards in one plane only across the centre of the exposed enamel surface. After 5 seconds, the specimen was washed with distilled water. The procedure was repeated a number of times, depending on the experimental protocol, with the abrasive action always occurring in the same plane.

After the final wash, the surface profile of the enamel

specimen was recorded using a profilometer (Surfometer). One profile was taken across the maximum diammeter of the specimen at right angles to the plane of abrasion. The area of enamel loss was determined by tracing the resultant profile on a high resolution magnetic digitising tablet with associated microcomputer analysis using the Perspex shoulders of the profile as fixed datum points. The average depth loss (μm.) per reading was calculated from this.

The amount of enamel removed relative to the number of acid applications was investigated as follows:

(a) 6 Specimens received 5 x 5 second applications;

(b) 6 specimens received 10 x 5 second applications; and

(c) 6 specimens received 15 x 5 second applications.

A total of 18 specimens were prepared, treated and profiled.

4.3. STATISTICAL ANALYSIS OF RESULTS

A variety of statistical techniques were used to analyse the data depending upon its type and the objectives of the analysis.

4.3.1. IN VIVO STUDIES

GLASS POLYALKENOATE v. AMALGAM RESTORATIONS

Restorations placed in the deciduous dentition will be lost, as the teeth exfoliate naturally, or are extracted for orthodontic reasons. This imposes unusual constraints upon the analytical techniques available, especially when one of a pair of restorations may be lost as a result of natural variation in exfoliation dates, some time before the second. In this situation, it would no longer be practicable to compare scores for the different restorations as it would not be valid to extend the criteria for a tooth that had been shed to a subsequent date.

In view of these problems, it was decided to analyse the data from the clinical trial in the deciduous dentition predominantly using survival analysis. Information about any trends in alteration of the scores for individual restorations, or within a group of restorations was gained by altering the criteria for failure and monitoring the effect of such alterations upon the overall survival pattern. Sequential analysis was also done for this study as it took into account the 'matched pairs', part of the study design.

MINIMAL COMPOSITE v. AMALGAM RESTORATIONS

Survival analysis techniques were the method of choice for analysis of these data. This choice was made because it was not

possible to make direct comparisons of quantitative data since the scoring indices for amalgam and composite restorations were different. In addition, the ability to 'top up' the fissure sealant on the minimal composite restoration had no parallel in the amalgam and consequently direct comparison between the groups would be inappropriate.

GLASS POLYALKENOATE - COMPOSITE RESIN SANDWICH RESTORATIONS

Due to the relatively small number of restorations, the results were presented as the number of restorations scored at each modified USPHS scoring category with time.

MICROFILLED COMPOSITE RESIN VENEERS

Analysis of the discrete variables associated with alterations of the Gingival Index for the patients was performed using a non parametric method (Wilcoxon's matched pairs signed rank test). Survival analysis was used to give an estimate of the probability of a veneer failing at any given time interval after placement.

HYDROCHLORIC ACID PUMICE ABRASION TECHNIQUE

Response to this treatment was not possible by statistical technique and was assessed by clinical colour photographs.

4.3.2. SURVIVAL ANALYSIS

Survival analysis is a powerful statistical technique that was devised in the seventeenth century and is one of the basic tools of vital statistics and actuarial science (Armitage 1971). It can be used to compute the probability of an event occurring at a given

instant in time after a procedure in a longitudinal study of a treatment method. Its use in dentistry has been confined to the retrospective or prospective analysis of large cohorts of data concerning the longevity of amalgam restorations in children and adults (Hunter 1981, Elderton 1983, Patterson 1984, Walls et al 1985, Holland 1985, Walls et al 1988). It has also been used in medicine to monitor both survival and improvement or deterioration in symptoms after an operation or during the testing procedures associated with a new pharmacological product (Peto et al 1976, 1977).

The product limit estimate method of computing cumulative survival curves has been used in this study to analyse the occurrence of loss of anatomical form, or marginal integrity, or failure of a restoration. There are two commonly used statistical tests that can be used to compare survival curves namely; Breslow and Mantel (or Mantel-Cox). The principle behind these tests is the comparison of the hazard at which an individual from each of two or more groups is under at any given time. The two tests have a different bias; Breslow places more weight upon the results obtained during the early stages of the follow up when the numbers in each group are at the highest, and the results are most accurate; Mantel places more emphasis upon the tail areas of the curves, which are the least accurate sections of any survival curve, but may be the most interesting. Use of both test methods can give an indication whether a trend which is visible during the early stages of a prospective trial continues for the whole of the test period, or whether it dissipates with time.

4.3.3. IN VITRO STUDIES

The variation in the values achieved in vitro can often be assumed to correspond to the normal distribution, consequently the students' t-test and one and two way analysis of variance (ANOVA) were used extensively in comparison of results. However, in the analysis of tensile bond strength testing results the Weibull analysis was used (Weibull 1951).

4.3.4. THE WEIBULL ANALYSIS

It is normal practice in materials science when measuring mechanical properties such as strength to make a series of measurements on a number of apparently identical specimens. Typically, the results show considerable variation, particularly when the fracture process is of a brittle nature. The most widely used method for reporting the result from such tests is to give the number of tests performed, the mean strength and the standard deviation. The use of a normal distribution, on which mean and standard deviation calculations are based assumes that the mean value is the 'true value' and that random variations around this true value are due to variations in test method, specimen preparation etc. This method of analysis is perfectly acceptable for some types of work, but in materials science, the true value of strength of a material may be evisaged as the strength of a perfect, flaw-free specimen and that variations from this are due to surface or integral defects introduced during preparation (McCabe and Carrick 1986). Low strength test results could be explained by assuming specimen faults and high values by assuming they are approaching the 'true strength' of the material.

In certain circumstances, for example when setting safety limits, it is important to know the probability of a material or component having a low value of fracture stress. It may be necessary for a material to behave such that there is less than a 1 in 10^x chance of it having a fracture stress of less than a pre-determined value.

Weibull (1951) described a distribution which is capable of dealing with this situation. The Weibull equation, which relates the probability (Pf) of failure to stress (σ) is:

$$Pf = 1 - \exp\left\{-\left(\frac{\sigma - \sigma_u}{\sigma_0}\right)^m\right\}$$

where σ_u, σ_0 and m are constants. The constant σ_u is the lowest level of stress at which Pf approaches zero. It is customary to assume $\sigma_u = 0$. The constant σ_0 is difficult to visualise and is normally referred to as a normalising parameter. The constant m is termed 'the Weibull Modulus' and has important practical implications. A high value of m indicates a close grouping of fracture stress values whilst a low value indicates a wide distribution with a long tail at low stress levels.

The way in which the Weibull distribution is used depends upon the application. Some evaluations involve testing actual sample components, others involve testing of geometrically symmetrical specimens, produced for ease of testing, which may represent considerable scaling up or down from the normal material use.

Many dental materials perform well in most cases, but occasionally fail for no apparent reason. The Weibull analysis offers a means of being able to predict the dependability of a material. Simple calculations allow the prediction of failure probability at any selected level of stress or vice versa. Objections

have been raised against the Weibull distribution function on the grounds that is has no theoretical basis. Weibull countered this argument by stating that the same can be said of most statistical treatments, and that the value of the Weibull function lies in its ability to accurately fit experimental data and predict performance. In fact Weibull originally suggested that the distribution may have a range of uses in medical science and biology as well as materials science.

5.

RESULTS

5.1. IN VIVO STUDIES

5.1.1. GLASS POLYALKENOATE CEMENTS

Eighty eight patients were provisionally accepted as being suitable for inclusion in the clinical trial. However, stainless steel crowns were required on 1 or more teeth in 2 patients, a further 2 patients completed only 1 restoration in the pair, and 8 patients having complete placement of both restorations failed to return for review appointments.

A total of 76 patients returned for follow up appointments between October, 1982 and July 1988 (Table 5.1.). This group of 76 patients received 119 pairs of amalgam and glass polyalkenoate cement restorations. Clinician 1 (A.W.G.W.) placed 54 pairs and clinican 2 (R.R.W.) placed 65 pairs. The ages of the patients at the time of treatment and the distribution of the restorations are fiven in Figs. 5.1., 5.2. and Table 5.2. There was no significant differences between the number of Class II restorations of a given type placed in any individual tooth ($p < 0.05$ [Chi squared]). The overall fate of the 119 pairs is given in Table 5.3. 51 pairs were reviewed in the 6 month period prior to termination of the study. The mean length of service of the restorations in these pairs was 26.3 (13.2) months. A further breakdown of the length of follow up of these 51 pairs is shown in Table 5.4. 7 pairs have been under review for greater than 50 months, the longest pair being 55 months. A further 48 pairs were followed to failure/exfoliation of both teeth (mean length of service 22.7 [10.6] months) and 20 pairs were lost to follow up between 6 - 41 months after restoration placement (mean length of service 13.7 [8.2] months).

Fig. 5.1.

A histogram displaying the distribution of the pairs of restorations placed in the study according to the age of the patient at the time of placement.

Fig. 5.2.

A histogram displaying the distribution and quantity of the two types of restoration (ACR amalgam and cement restoration MCR minimal composite restoration) according to the teeth in which they were placed.

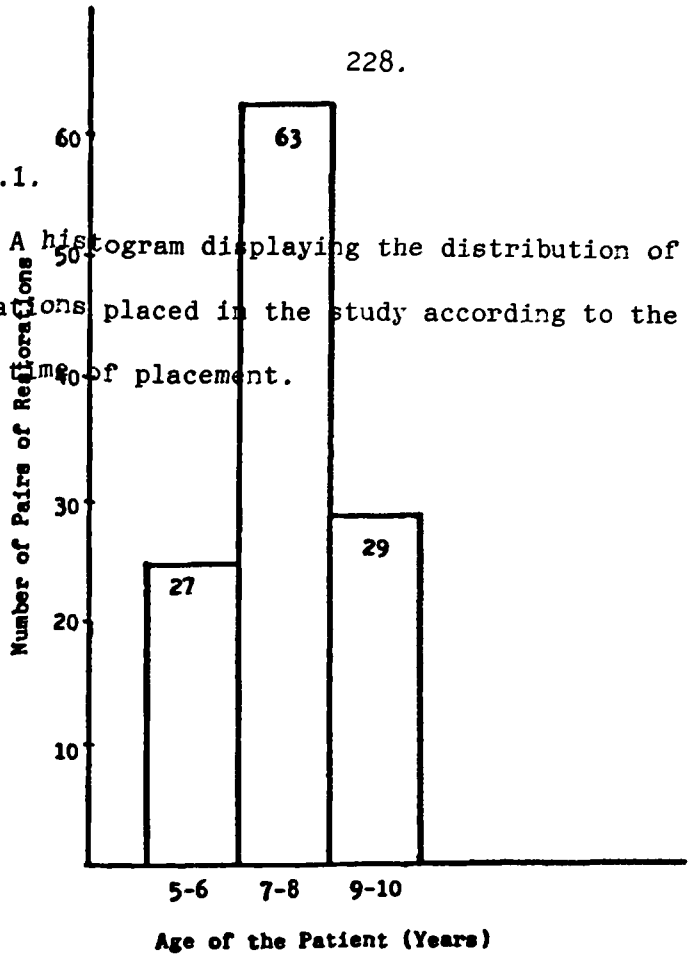


Fig. 5.1.

A histogram displaying the distribution of the pairs of restorations placed in the study according to the age of the patient at the time of placement.

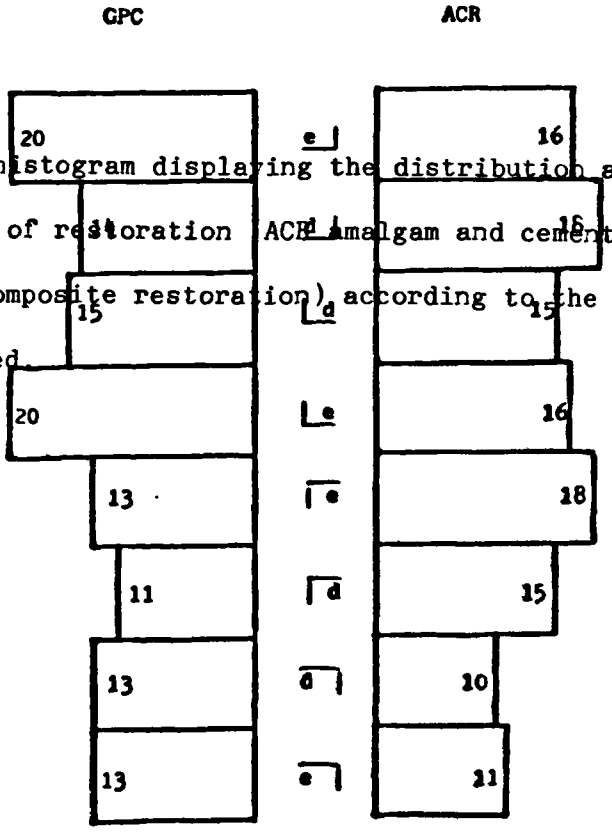
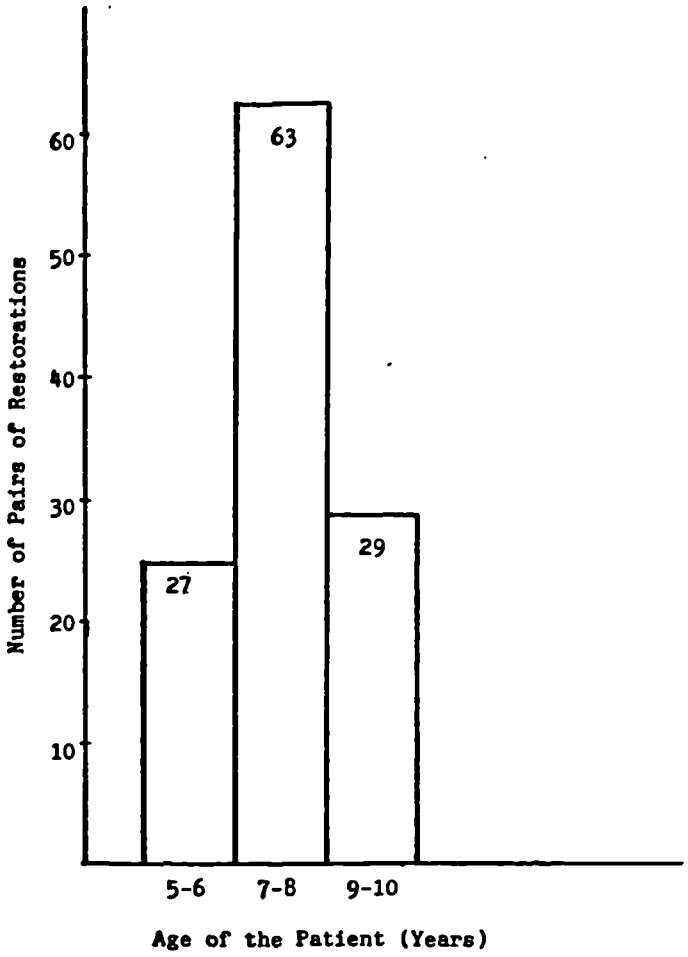


Fig. 5.2.

A histogram displaying the distribution and quantity of the two types of restoration ACR amalgam and cement restoration MCR minimal composite restoration) according to the teeth in which they were placed.


Number of Pairs of Restorations
60
50
40
30
20
10
63
27
29
5-6
7-8
9-10
Age of the Patient (Years)

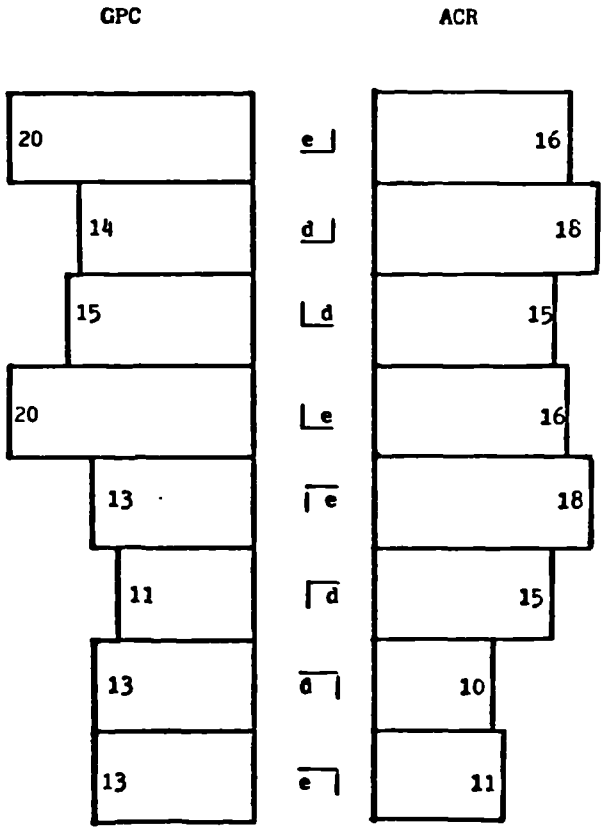

GPC
ACR
20
14
15
20
13
11
13
13
e
d
d
e
e
d
d
e
16
18
15
16
18
15
10
11

TABLE 5.1.

Subjects involved in the study to compare the durability of glass polyalkenoate cement restorations with amalgam restorations for the treatment of caries in deciduous molar teeth.

NUMBER OF PATIENTS	76
AGE RANGE	5 Years 6 months - 11 years 11 months
NUMBER OF PAIRS OF RESTORATIONS	119

TABLE 5.2.

The distribution of the restorations placed in the deciduous dentition.

	d		e	
	ACR	GPC	ACR	GPC
CLASS I		1	8	7
CLASS II	58	52	53	59

ACR = An amalgam cement restoration

GPC = A glass polyalkenoate cement restoration

TABLE 5.3.

Overall fate of the 119 pairs of restorations.

Bracketed figures are 1 standard deviation.

51 pairs reviewed in the 6 months leading up to termination date
(M.L.O.S. 26.3 (13.2) months)

48 pairs followed to failure/exfoliation of both teeth
(M.L.O.S. 22.7 (10.6) months)

20 pairs lost to follow up between 6 - 41 months of service
(M.L.O.S. 13.7 (8.2) months)

M.L.O.S. = Mean length of service.

TABLE 5.4.

A breakdown of the length of follow up for the 51 pairs of restorations reviewed within 6 months of the study termination date.

LENGTH OF FOLLOW UP	NUMBER OF PAIRS
> 50 months	7
40 - 50 months	3
30 - 40 months	4
20 - 30 months	21

TABLE 5.5.

The reasons for failure of the restorations.

	GPC	ACR
Total loss of restoration	17	4
Loss of restorative material	6	3
Fracture of restoration	6	5
Fracture of tooth	3	1
Recurrent caries	7	11
	39	24

During the course of the study, 11 glass polyalkenoate restorations exhibited marginal staining at a mean time of 18.6 (9.4) months after placement. 3 of these restorations subsequently failed, but the remainder are functioning satisfactorily. In addition, 44 teeth restored with amalgam (M.L.O.S. [13.6] months) and 34 teeth restored with glass polyalkenoate cement (M.L.O.S. 25.8 [13.3] months) exfoliated during the study.

The area of occlusal tooth surface replaced by restorative material was obtained from the visual assessments made on the gridded form at each recall visit. This area was traced on a magnetic digitising tablet with associated microcomputer analysis. Amalgam restorations occupied on average 28% of the occlusal surface of the tooth and glass polyalkenoate cement restorations 16%. This difference was highly significant comparing between upper e's and upper d's in the 2 materials ($p < 0.001$) and less significant comparing between lower e's ($p < 0.01$) and lower d's ($p < 0.05$ ANOVA). There was no significant difference in the amount of occlusal surface occupied by amalgam restorations between the upper and lower molars, but when considering glass polyalkenoate restorations, those in the upper molars were significantly smaller than those in the lower molars ($p < 0.05$ ANOVA).

63 (26.5%) restorations have failed, to date, during the follow up period. A restoration was regarded as failed if it had a score of 3 for anatomical form or 4 for marginal integrity, or if recurrent caries was present beneath the restoration. Of these failures, 24 (20.2%) were amalgam restorations and 39 (32.8%) were glass polyalkenoate cement restorations. The reasons for failure are shown in Table 5.5.

Statistical comparison of amalgam cement restorations and glass polyalkenoate cement restorations for anatomical form, marginal integrity and overall failure was by survival analysis techniques (B.M.D.P.,University of California).

The cumulative survival curves for an anatomical form score of 2 or more, and for a score of 3 are shown in Figs 5.3. and 5.4. These show that there was an early divergence of the curves in both cases. For both of them, there was a significant difference in performance both in the early stages of the trial ($p < 0.01$ Breslow) and in the latter stages ($p < 0.001$ Mantel-Cox for A.F. score of 2 or more, and $p < 0.01$ Mantel-Cox for A.F. score of 3) with the glass polyalkenoate cement exhibiting more wear.

The cumulative survival curves for marginal integrity scores of 2 or more, 3 or more, 4 or more and 5 are shown in Figs. 5.5., 5.6., 5.7., and 5.8. There was a significant difference in the rate of loss of marginal integrity for a score of 2 or more ($p < 0.01$ Breslow and $p < 0.001$ Mantel-Cox) with glass polyalkenoate cement performing better than amalgam cement restorations. For a marginal integrity score of 3 or more the amalgam restorations appear to perform slightly better than the glass polyalkenoates, but this difference is not significant. However, for marginal integrity scores of 4 or more and 5 there is a significant difference in the rate of loss of marginal integrity seen by the more marked divergence of the curves ($p < 0.01$ Breslow and $p < 0.01$ Mantel-Cox). At these higher scores Amalgam is performing better than glass polyalkenoate cement. The initial superiority of glass polyalkenoate cement restorations at the lower marginal integrity scores which is then translated into an inferiority at higher scores

Fig 5.3

RESTORATIONS WITH ANATOMICAL FORM CODED 2 OR HIGHER

CUMULATIVE PROPORTION SURVIVING A = AMAL P = POLY

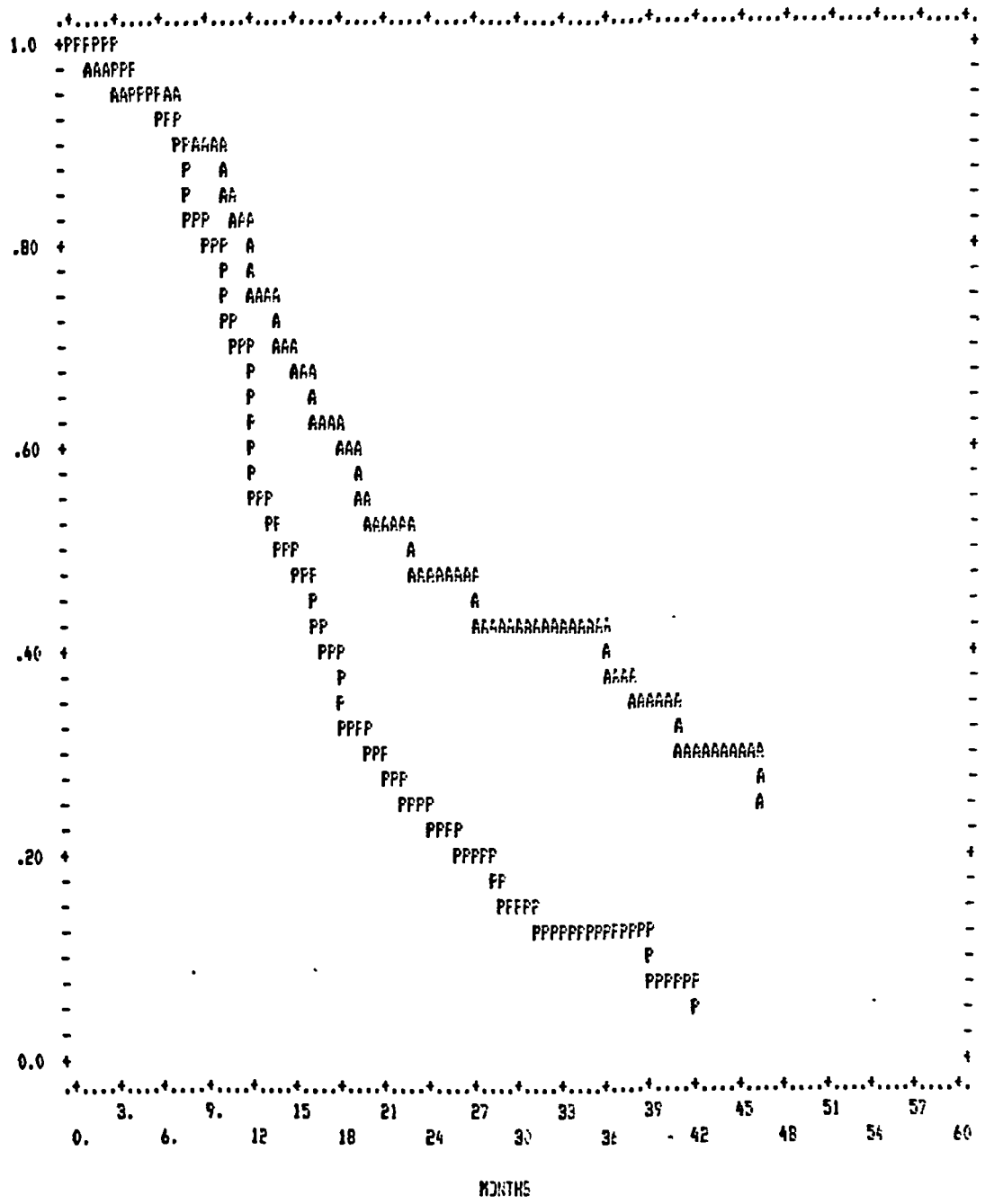


Fig 5.4

RESTORATIONS WITH ANATOMICAL FORM CODED 3 OR HIGHER

CUMULATIVE PROPORTION SURVIVING A = AMAL F = POLY

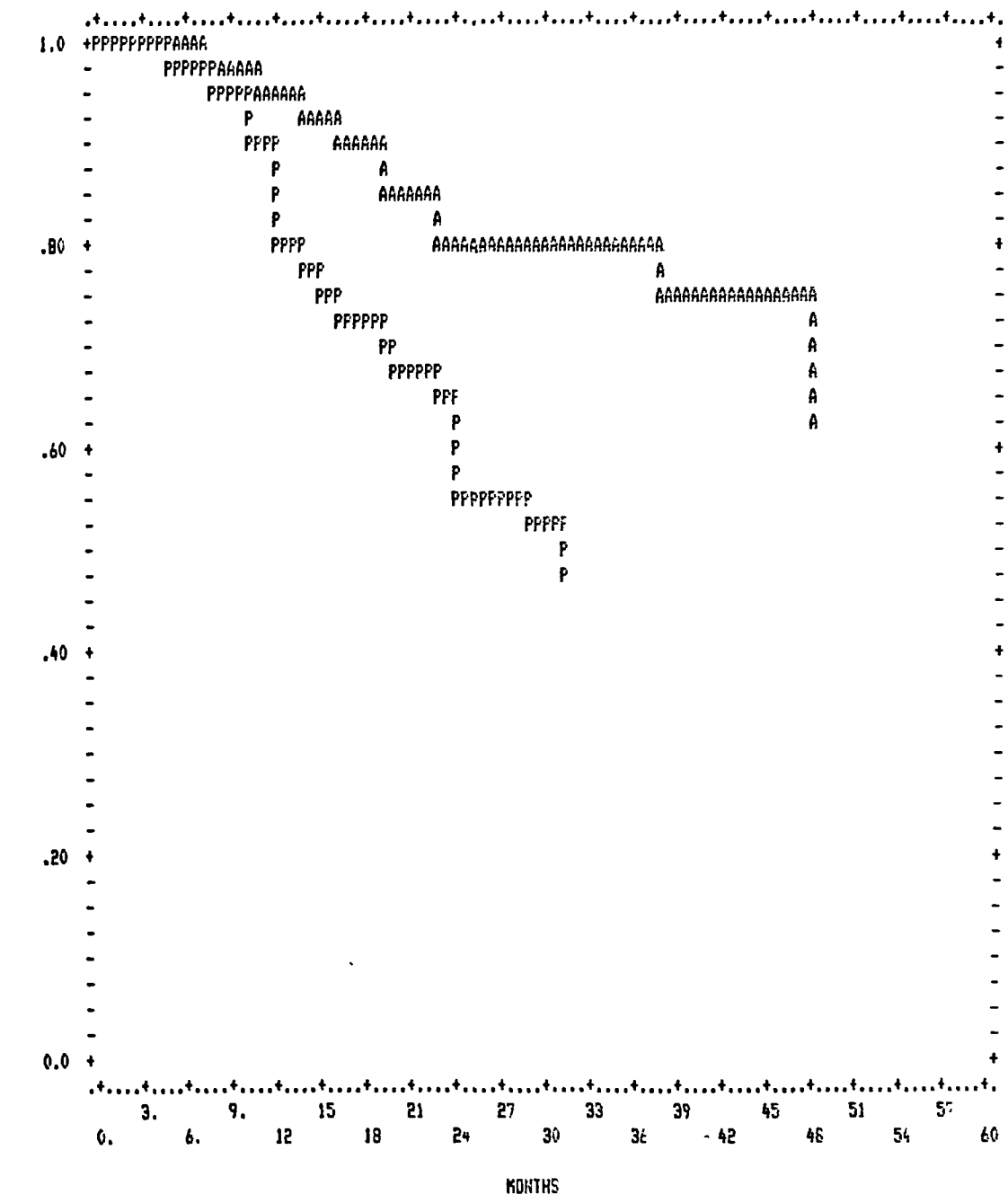


Fig 5.5

RESTORATIONS WITH MARGINAL INTEGRITY SCORE OF 2 OR MORE

CUMULATIVE PROPORTION SURVIVING A = AMAL P = POLY

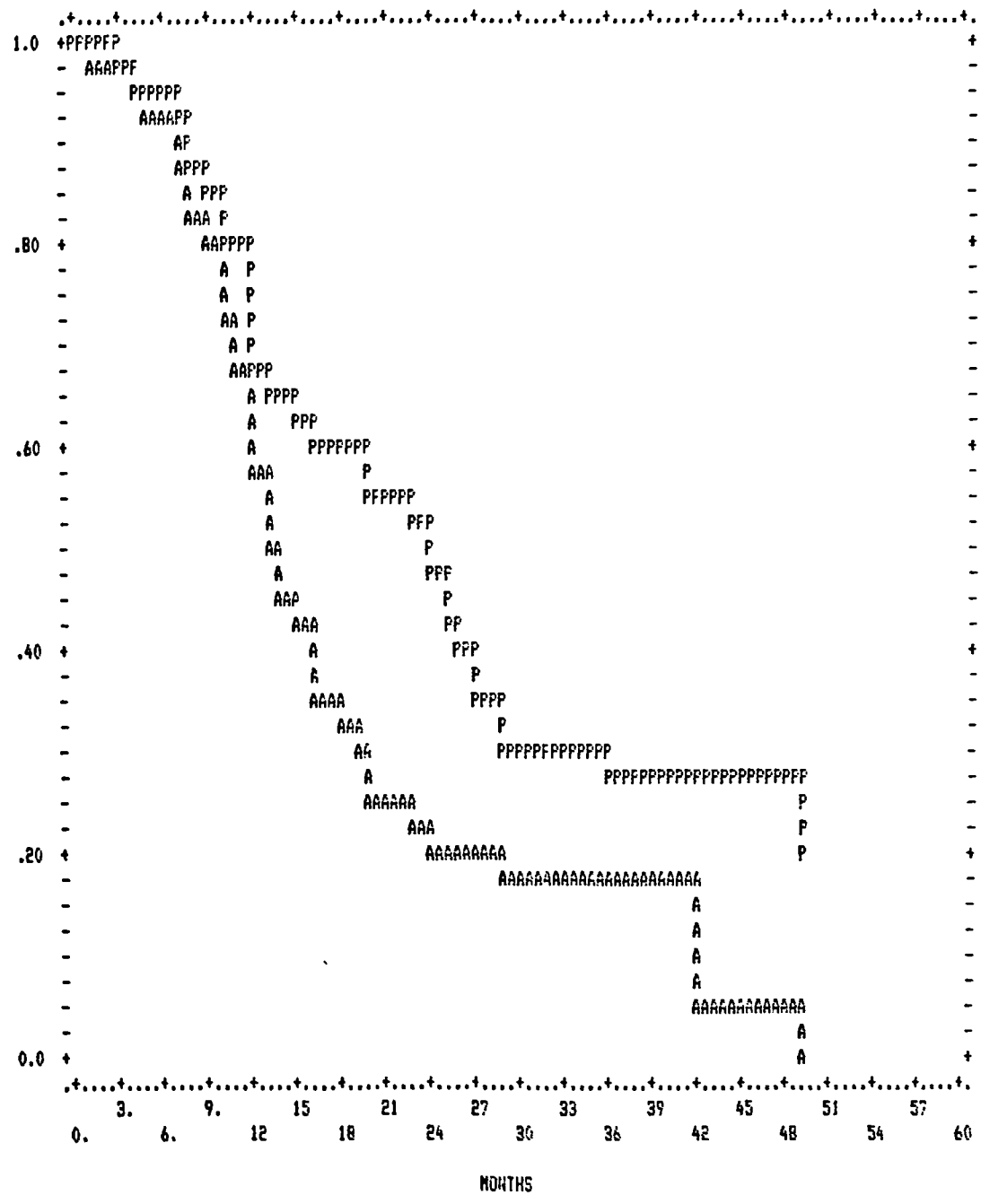


Fig 5.6

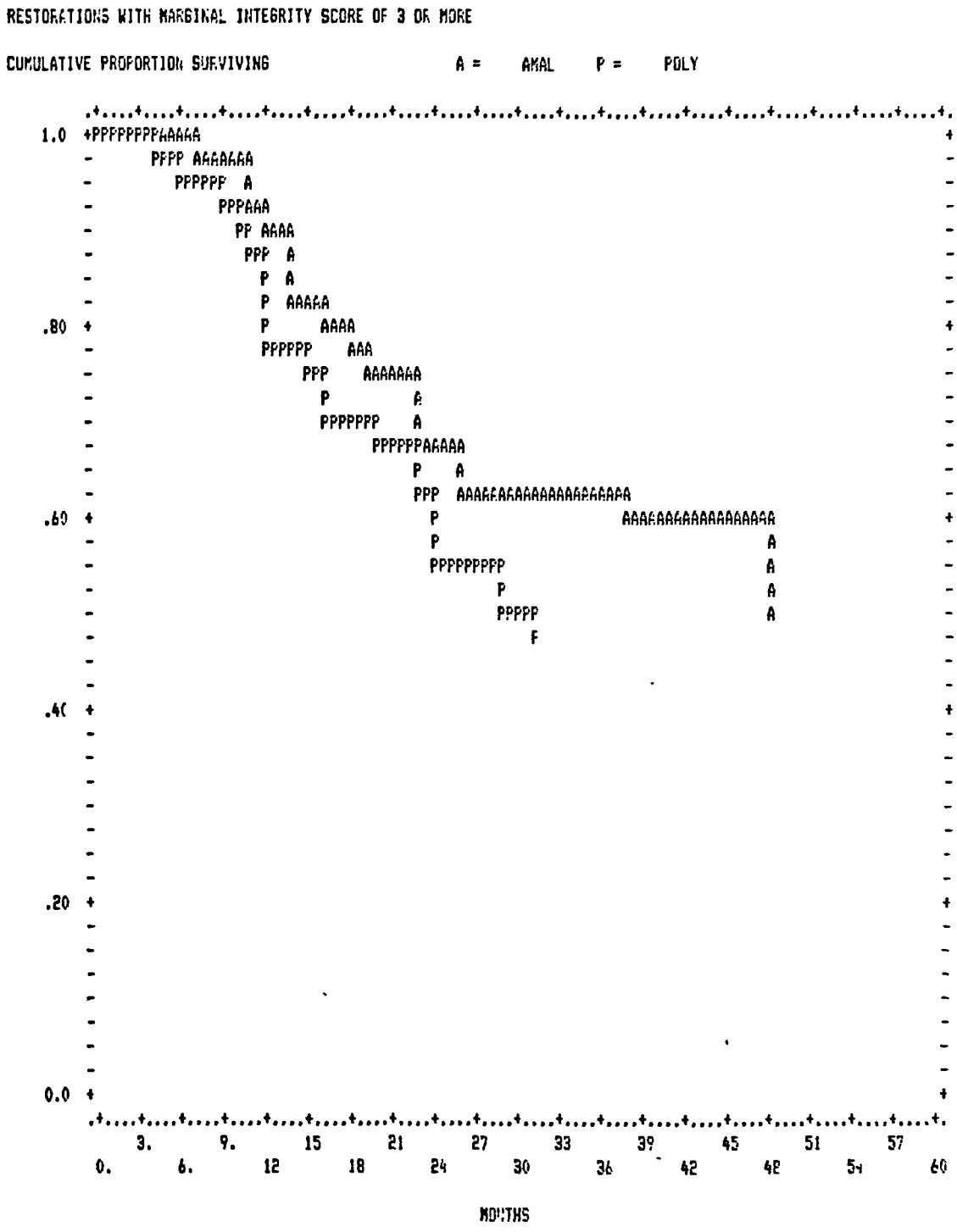

RESTORATIONS WITH MARGINAL INTEGRITY SCORE OF 3 OR MORE
CUMULATIVE PROPORTION SURVIVING
A = AMAL P = POLY
1.0
.80
.60
.40
.20
0.0
3. 9. 15 21 27 33 39 45 51 57
0. 6. 12 18 24 30 36 42 48 54 60
MONTHS

Fig 5.7

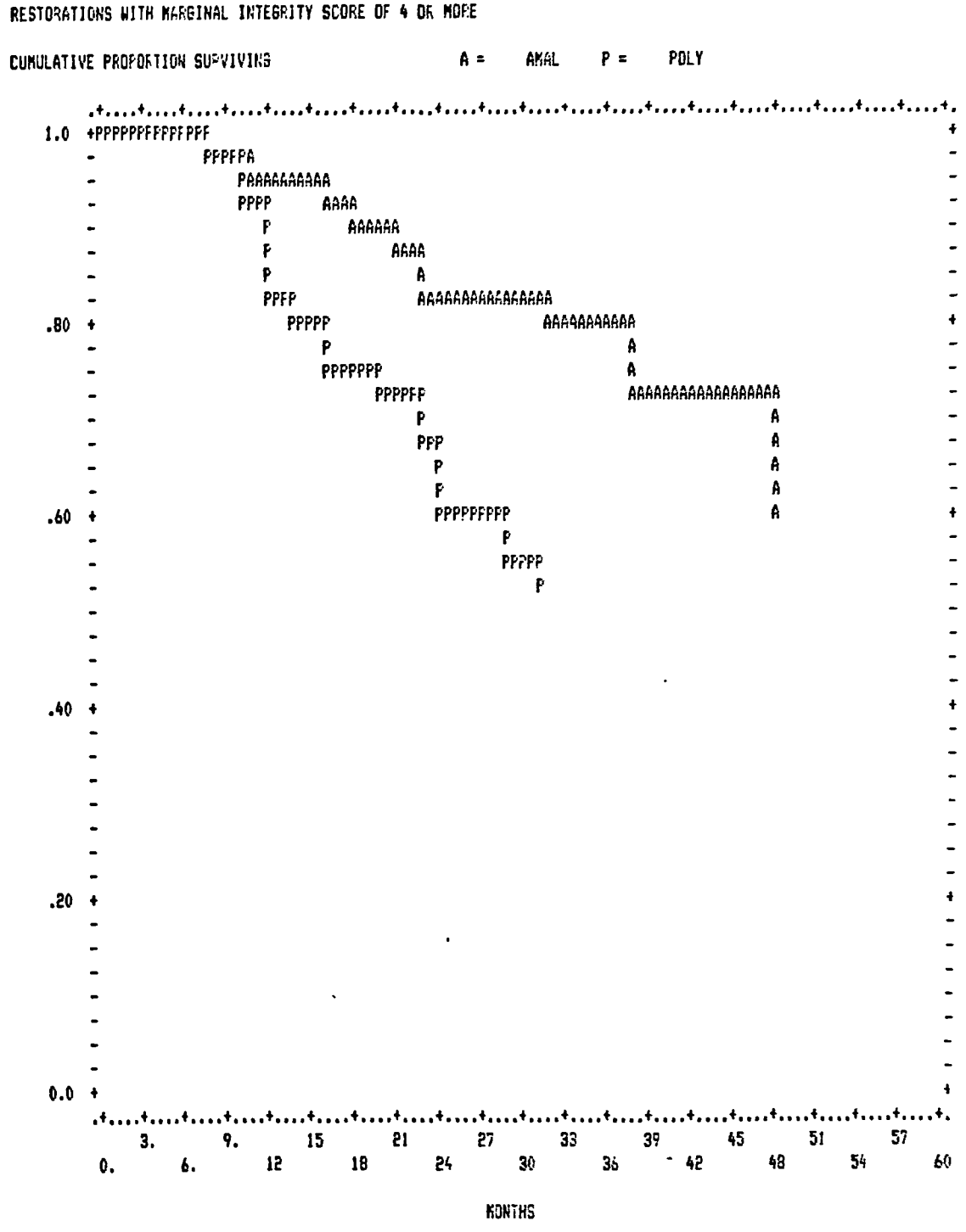
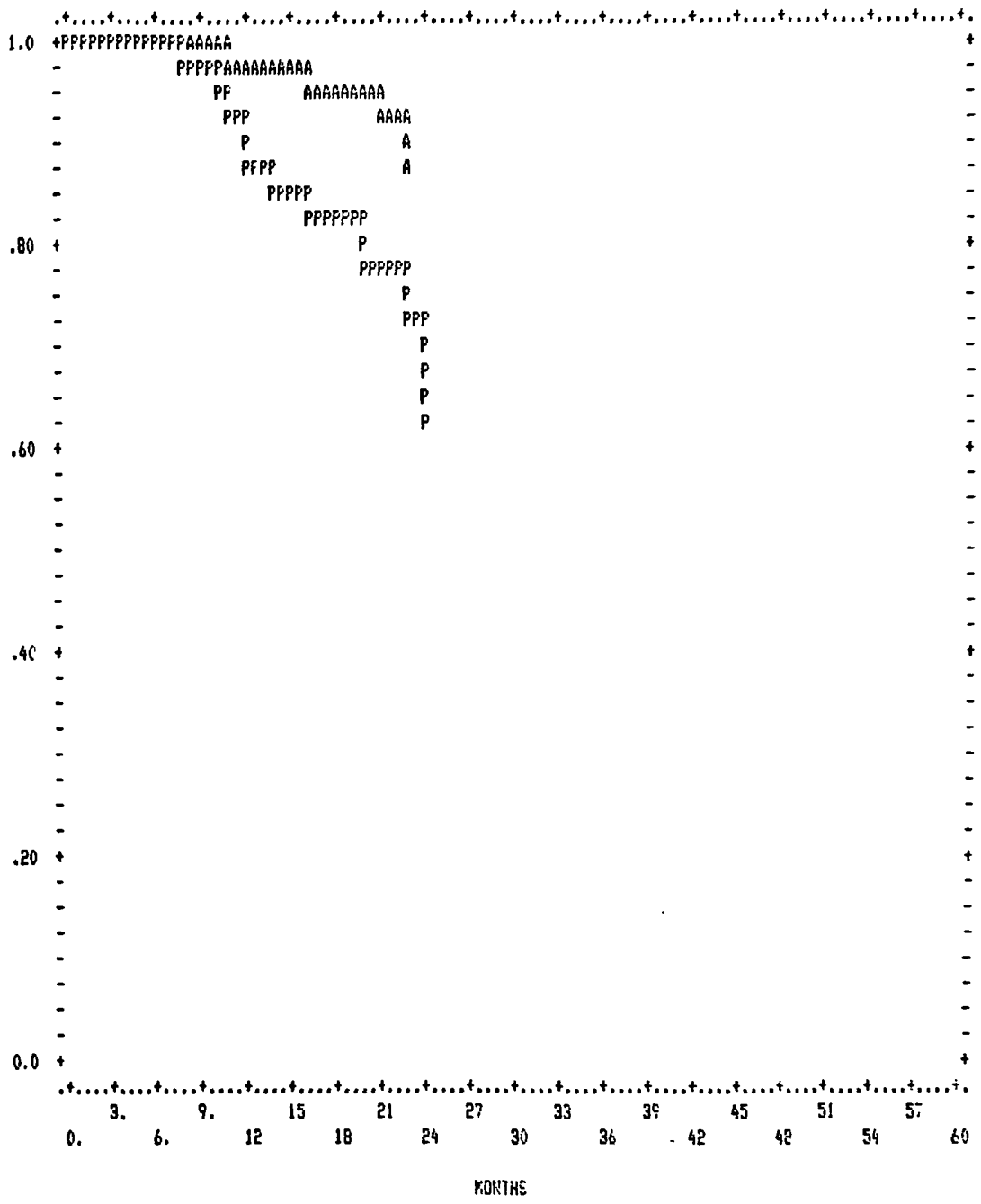

RESTORATIONS WITH MARGINAL INTEGRITY SCORE OF 4 OR MORE
CUMULATIVE PROPORTION SURVIVING
A = AMAL P = POLY
1.0
.80
.60
.40
.20
0.0
3. 9. 15 21 27 33 39 45 51 57
0. 6. 12 18 24 30 36 42 48 54 60
MONTHS

Fig 5.8

RESTORATIONS WITH MARGINAL INTEGRITY SCORE OF 5 OR MORE

CUMULATIVE PROPORTION SURVIVING A = AMAL P = POLY



can be explained by the fact that the amalgam cement restorations quickly attain a score of 2 and then remain relatively stable, while the glass polyalkenoates which initially show excellent marginal integrity, steadily deteriorate.

The cumulative survival curves for overall failure are shown in Fig. 5.9. There was a significant difference in performance between the 2 materials favouring amalgam both at the beginning of the test ($p < 0.01$ Breslow) and during the latter stages ($p < 0.01$ Mantel-Cox) and this can be seen by the early and sustained divergence of the two curves. The Median Survival Time (M.S.T.) for amalgam restorations was 41.4 (S.E. 2.24) months and for glass polyalkenoate restorations was 33.4 (S.E. 2.26) months.

The median survival times for restorations by age at placement 5 - 6, 7 - 8 or 9 - 10 years are shown in Table 5.6. There was no significant difference in the cumulative survival curves for the glass polyalkenoate restorations with age at placement (Fig. 5.10.) but amalgam restorations performed significantly better towards the end of the study ($p < 0.01$ Mantel-Cox) when placed in an older patient (Fig. 5.11.). When all restorations were grouped together (Fig. 5.12.), there was a similar significant difference (probably due to amalgam) in the cumulative survival curves towards the end of the study ($p < 0.05$ Mantel-Cox) favouring those restorations placed in the older patient.

The median survival times for restorations comparing performance in first and second deciduous molars are shown in Table 5.7. There was no significant difference in the cumulative survival curves at any stage in the study for GPC restorations alone, ACR alone or for GPC and ACR combined (Figs. 5.13., 5.14., 5.15.).

Fig 5.9

SURVIVAL OF AMALGAM AND POLYALKENOATE RESTORATIONS

CUMULATIVE PROPORTION SURVIVING A = AMAL P = POLY

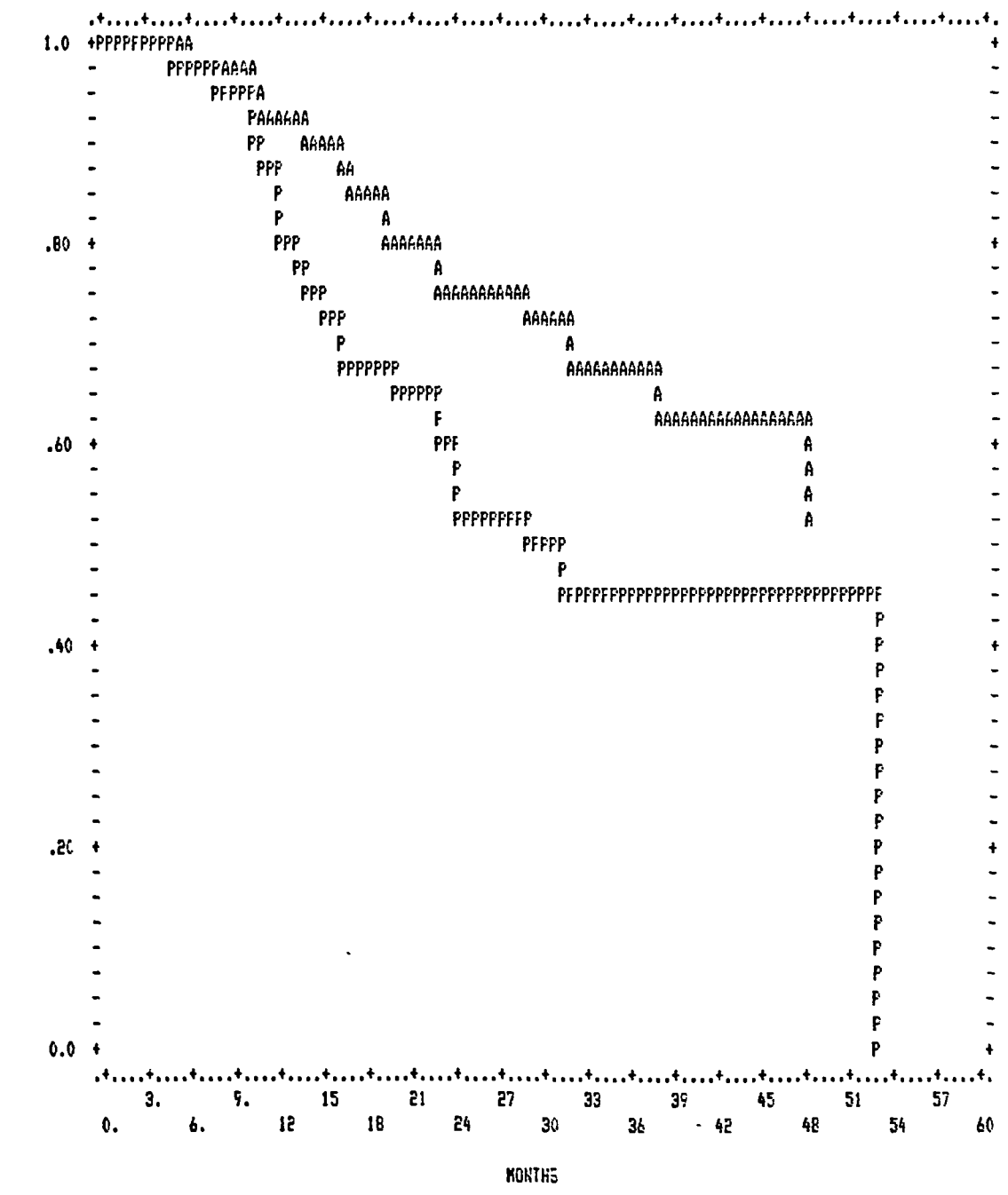


TABLE 5.6.

The Mean Survival Times for the restorations when calculated by age at time of placement.

AGE (YEARS)	ACR + GPC	STANDARD ERROR	GPC	STANDARD ERROR	ACR	STANDARD ERROR
5 - 6	33.9	3.0	28.7	3.9	37.8	4.0
7 - 8	36.7	2.2	33.6	3.1	39.6	3.3
9 - 10	42.3	2.8	36.5	4.6	49.0	0

TABLE 5.7.

The Mean Survival Times for the restorations comparing performance in first and second deciduous molars.

TOOTH TYPE	ACR + GPC	STANDARD ERROR	GPC	STANDARD ERROR	ACR	STANDARD ERROR
d's	33.9	2.6	26.1	2.5	40.2	3.4
e's	37.3	2.0	35.3	2.9	39.6	2.9

Fig 5.10

SURVIVAL OF POLYALKENOATE RESTORATIONS

CUMULATIVE PROPORTION SURVIVING 5 = 5-6 7 = 7-8 9 = 9-10

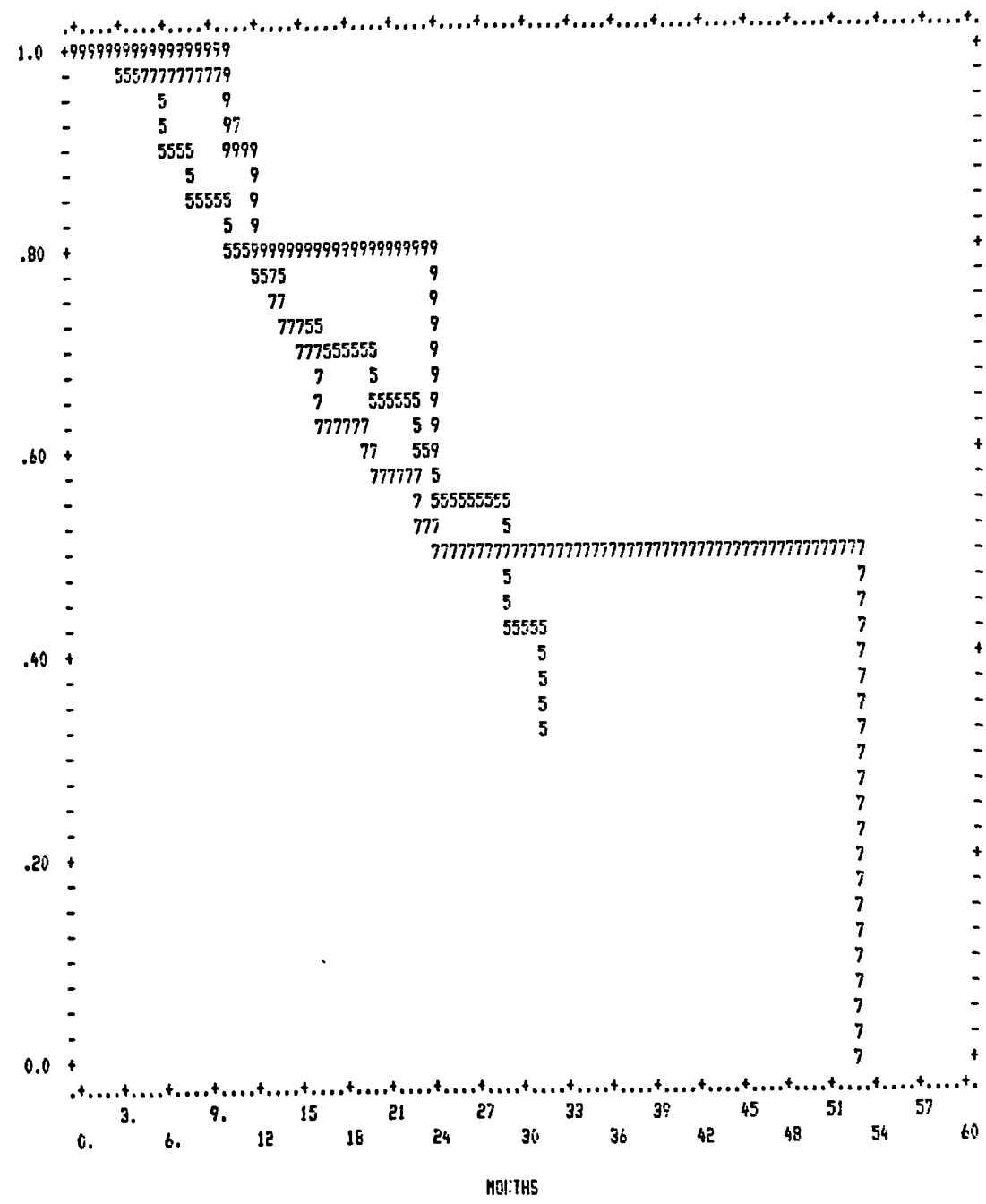


Fig 5.11

SURVIVAL OF AMALGAM RESTORATIONS

CUMULATIVE PROPORTION SURVIVING 5 = 5-6 7 = 7-8 9 = 9-10

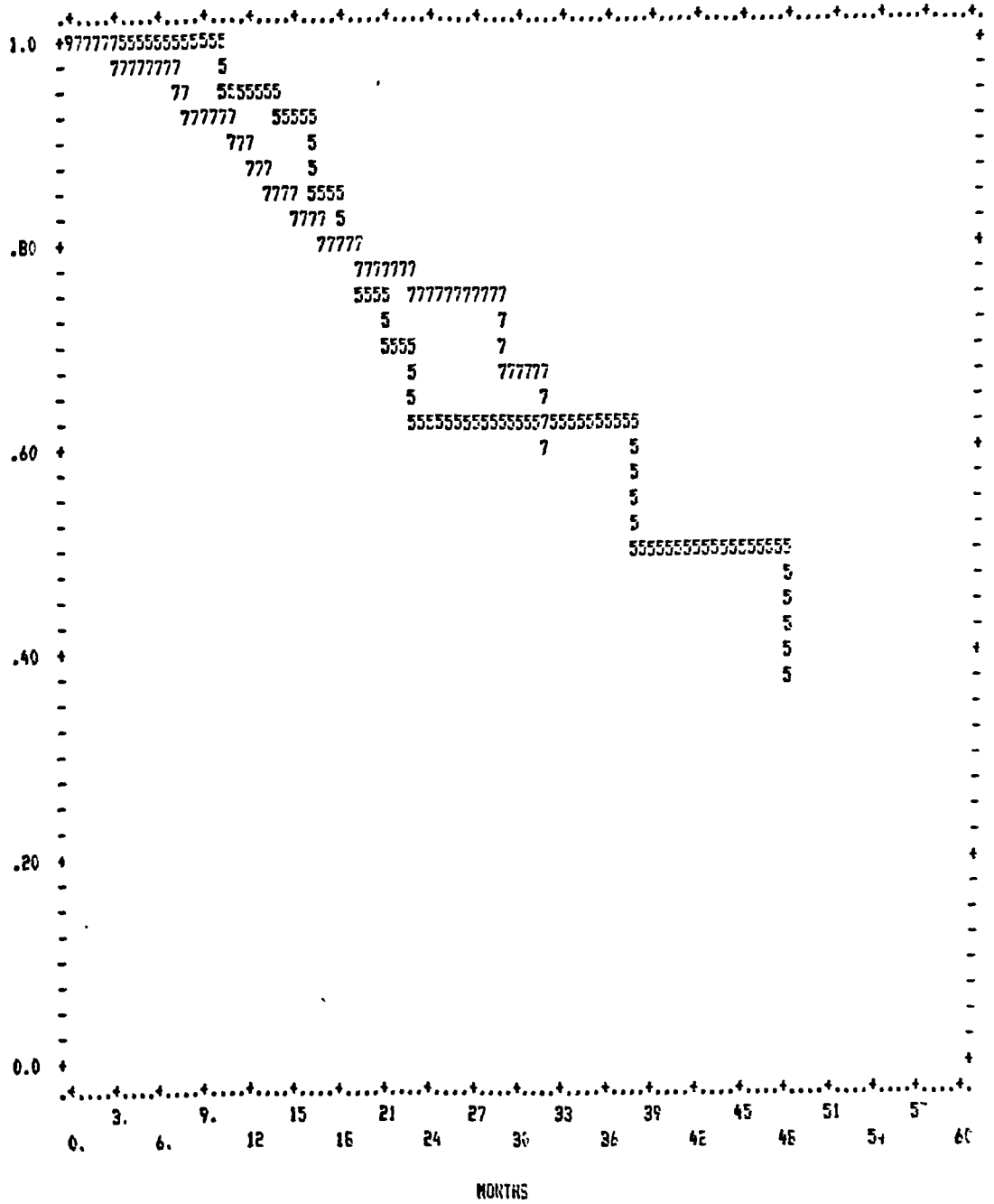


Fig 5.12

SURVIVAL OF POLYALKENOATE AND AMALGAM RESTORATIONS

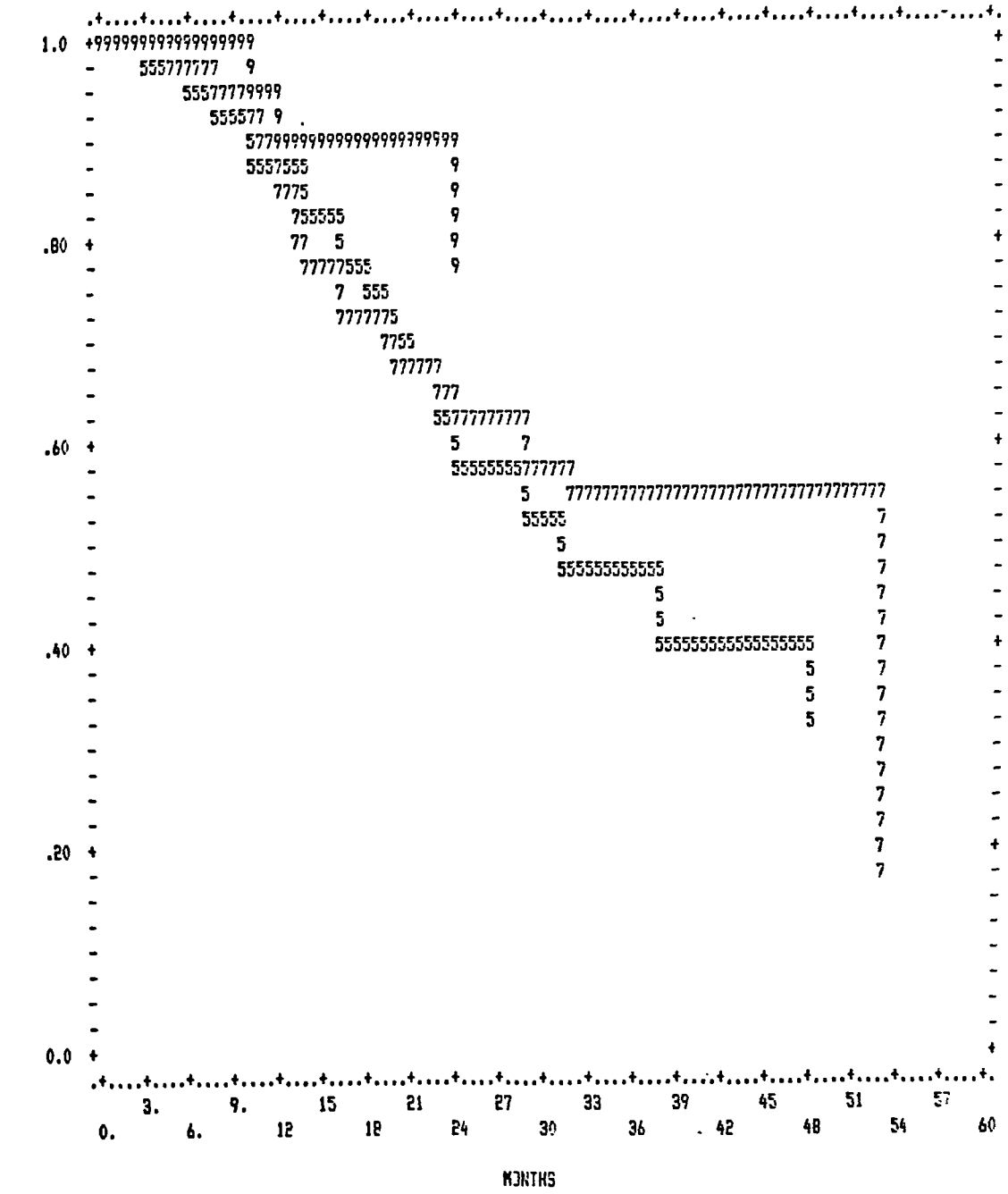


Fig 5.13

SURVIVAL OF POLYALKENOATE RESTORATIONS, BY TOOTH TYPE

CUMULATIVE PROPORTION SURVIVING D = D E = E

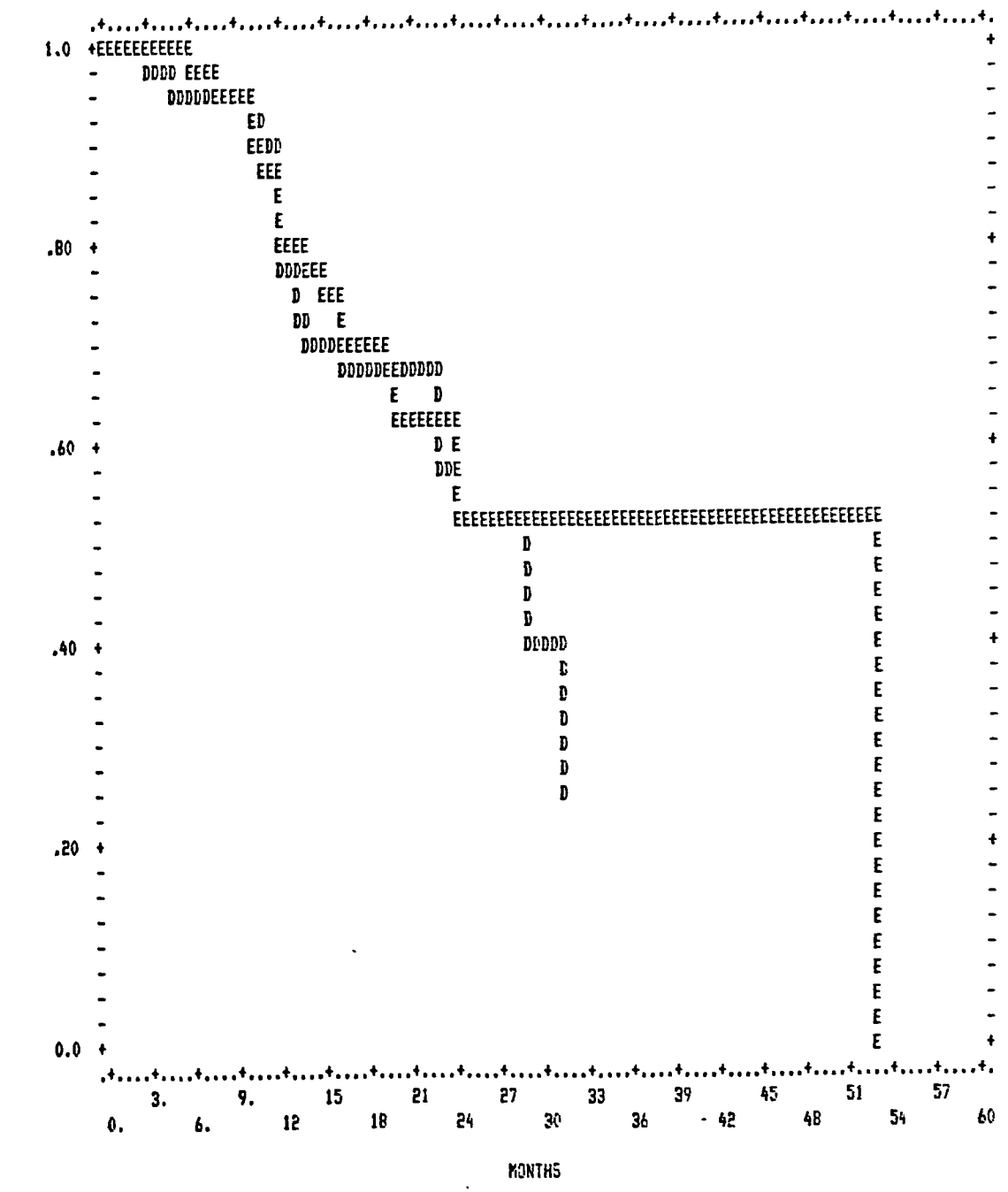


Fig 5.14

SURVIVAL OF AMALGAM RESTOFATIONS, BY TOOTH TYFE

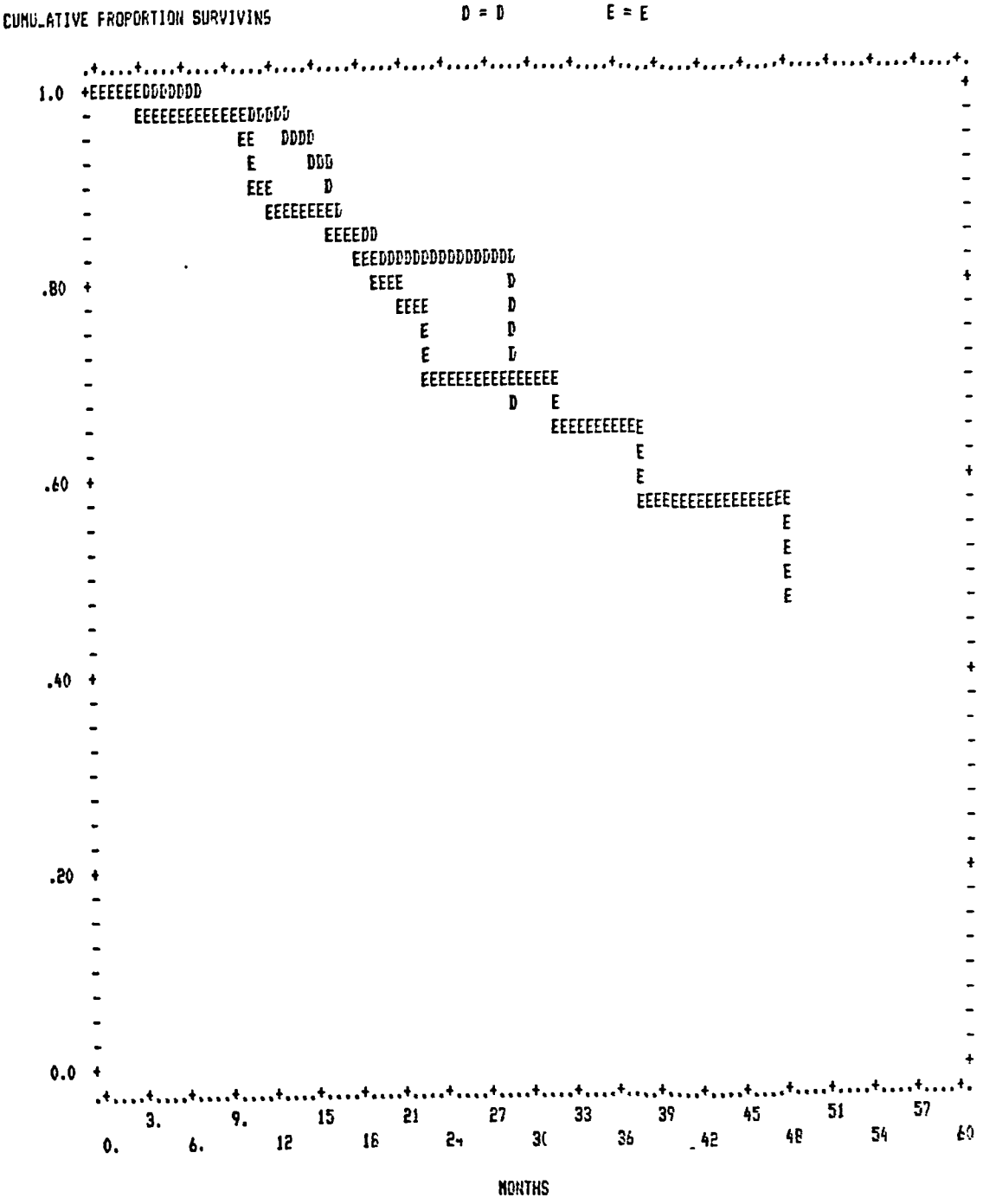
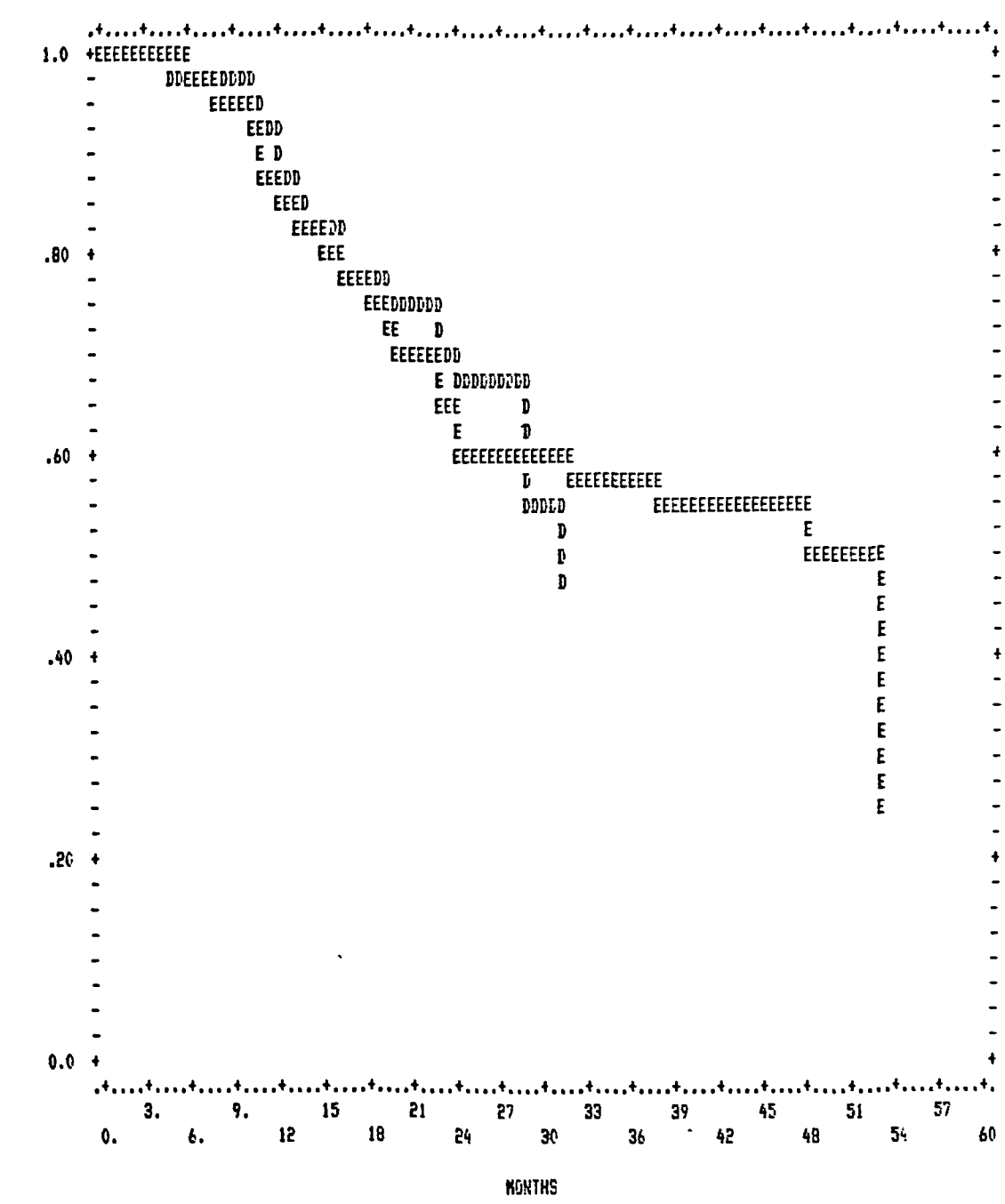


Fig 5.15

SURVIVAL BY TOOTH TYPE



The median survival times for restorations comparing performance in the upper and lower dental arches are shown in Table 5.8. There was no significant difference in the cumulative survival curves at any stage in the study for GPC restorations alone, ACR alone or for GPC and ACR combined (Figs. 5.16., 5.17., 5.18.).

5.1.2. MINIMAL COMPOSITE RESTORATIONS

154 patients were initially assessed for inclusion in the clinical trial. Of these, 6 were unsuitable as their second cavity was too large for a minimal composite restoration. A further 11 failed to attend for placement of either restoration, while 10 patients failed to return for their second restoration. 1 patient died. Thus, 126 patients received 174 pairs of restorations. The randomisation pattern for allocation of restorative materials was broken for 20 pairs of restorations (Table 5.9.).

Of these 126 patients, 103 returned for follow up appointments between October, 1982 and July 1988 (Table 5.10.). This group of 103 patients received 150 pairs of amalgam and minimal composite restorations. Clinician 1 (A.W.G.W.) placed 85 pairs and clinician 2 (R.R.W.) placed 65 pairs. The ages of the patients at the time of treatment and the distribution of the restorations are given in Figs. 5.19. and 5.20. There were no significant differences between the number of restorations of a given type placed in any individual tooth ($p < 0.05$ [Chi Squared]). Out of the 150 pairs of restorations, 94 were reviewed in the last 6 months of the study, and the mean life span of these was 34.5 (17.8) months. A further 15 pairs were reviewed between 6 and 12 months of the termination date and the mean

TABLE 5.8.

The Mean Survival Times for the restorations comparing performance in upper and lower dental arches.

ARCH	ACR + GPC	STANDARD ERROR	GPC	STANDARD ERROR	ACR	STANDARD ERROR
Upper	37.2	2.1	32.3	2.9	43.2	2.9
Lower	35.7	2.5	31.0	3.3	38.0	3.4

Fig 5.16

SURVIVAL OF POLYALKENOATE RESTORATIONS, BY DENTAL ARCH

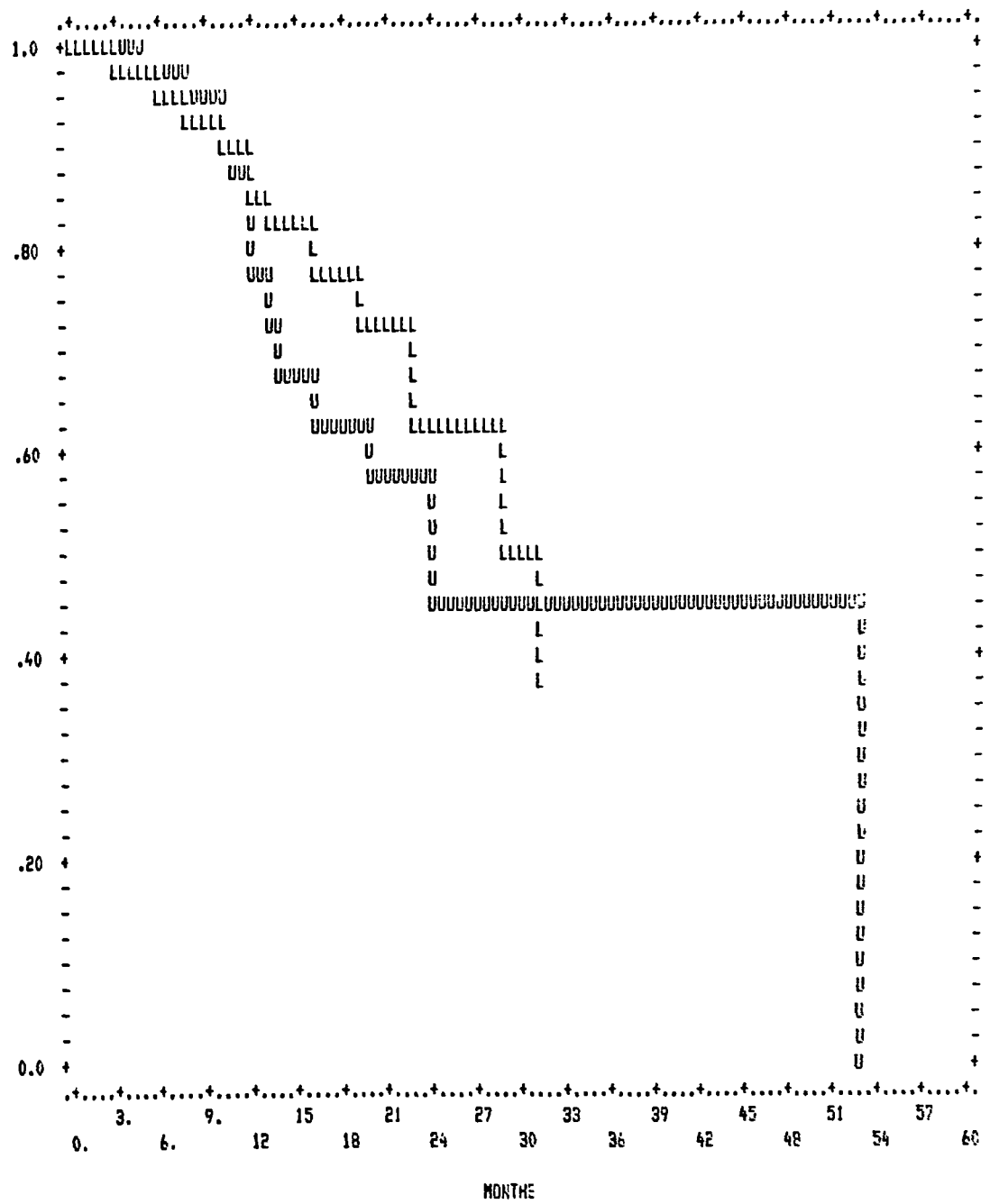


Fig 5.17

SURVIVAL OF AKALEAM RESTORATIONS, BY DENTAL ARCH

CUMULATIVE PROPORTION SURVIVING U = UPPER L = LOWER

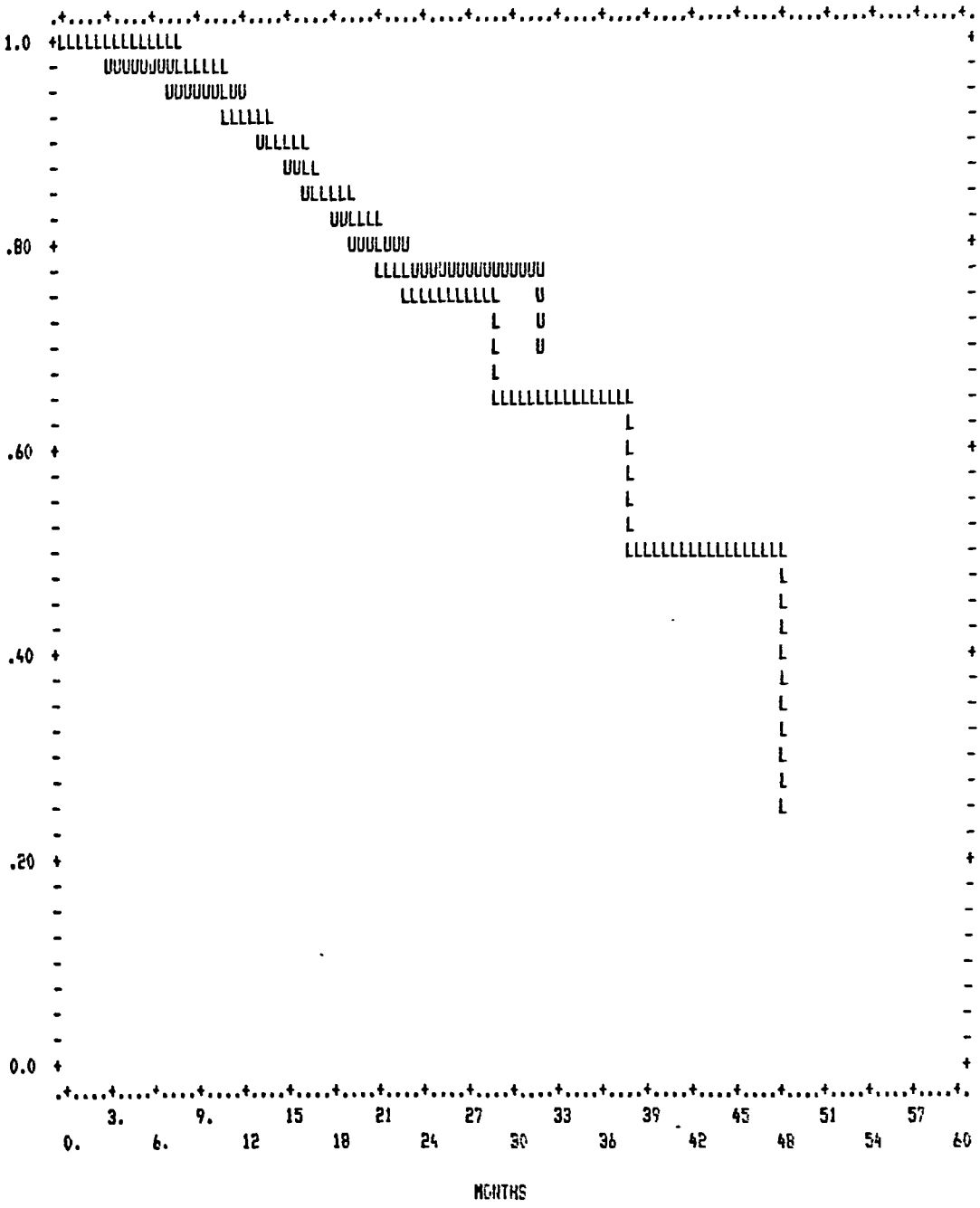


Fig 5.18

SURVIVAL BY DENTAL ARCH

CUMULATIVE PROPORTION SURVIVING U = UPPER L = LOWER

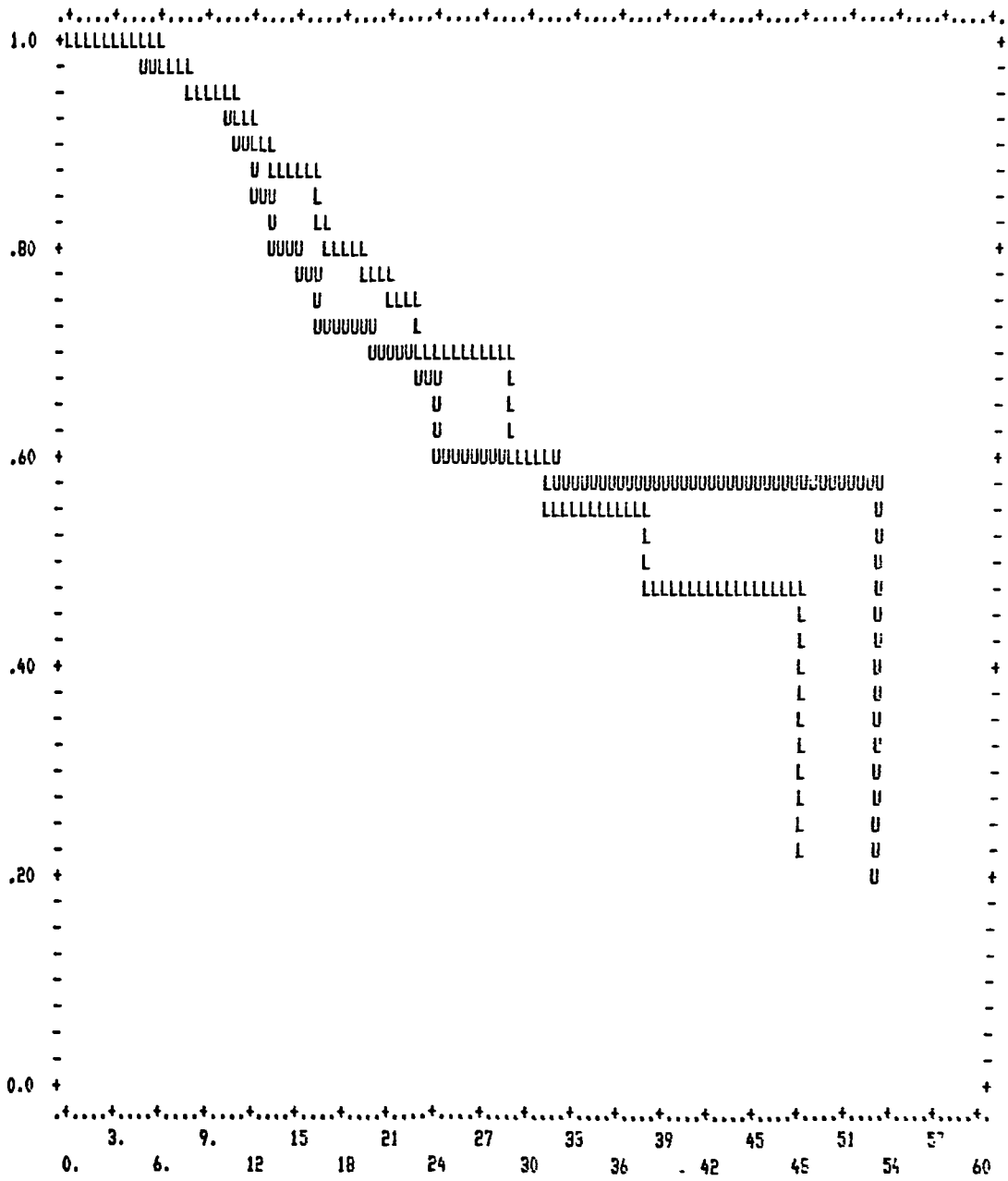


TABLE 5.9.

A breakdown of the occasions when the randomisation scheme was ignored during this clinical trial.

Randomisation Ignored	10 Pairs of restorations
Caries Control	3 Pairs of restorations
Direct Pulp Capping	7 Pairs of restorations

TABLE 5.10.

Subjects involved in the study to compare the durability of a minimal composite restoration with an amalgam restoration for the treatment of occlusal caries in permanent molar teeth.

Number of Patients	103
Age Range	6 years 9 months - 24 years
Number of pairs of restorations	150

TABLE 5.11.

A breakdown of the length of follow up for the 109 pairs of restorations reviewed within 0 - 6 and 6 - 12 months of the study termination date.

LENGTH OF FOLLOW UP	0 - 6 MONTHS	6 - 12 MONTHS
60 months	8 pairs	
50 - 60 months	24 pairs	5 pairs
40 - 50 months	5 pairs	4 pairs
30 - 40 months	6 pairs	1 pair

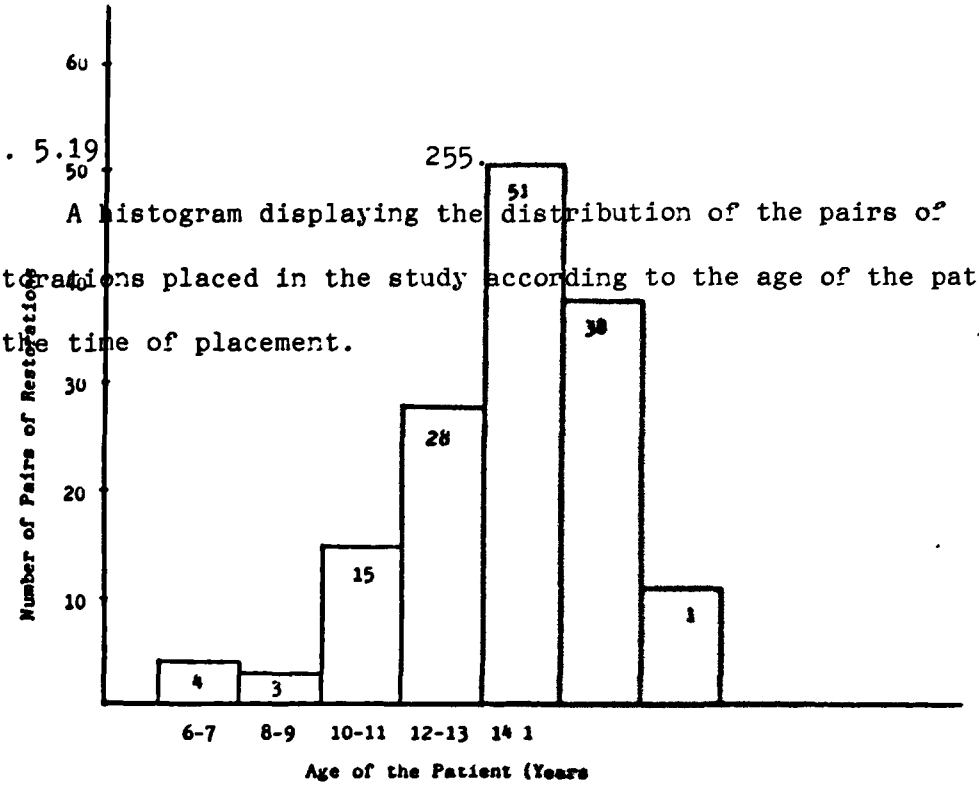
Fig. 5.19.

A histogram displaying the distribution of the pairs of restorations placed in the study according to the age of the patient at the time of placement.

Fig. 5.20.

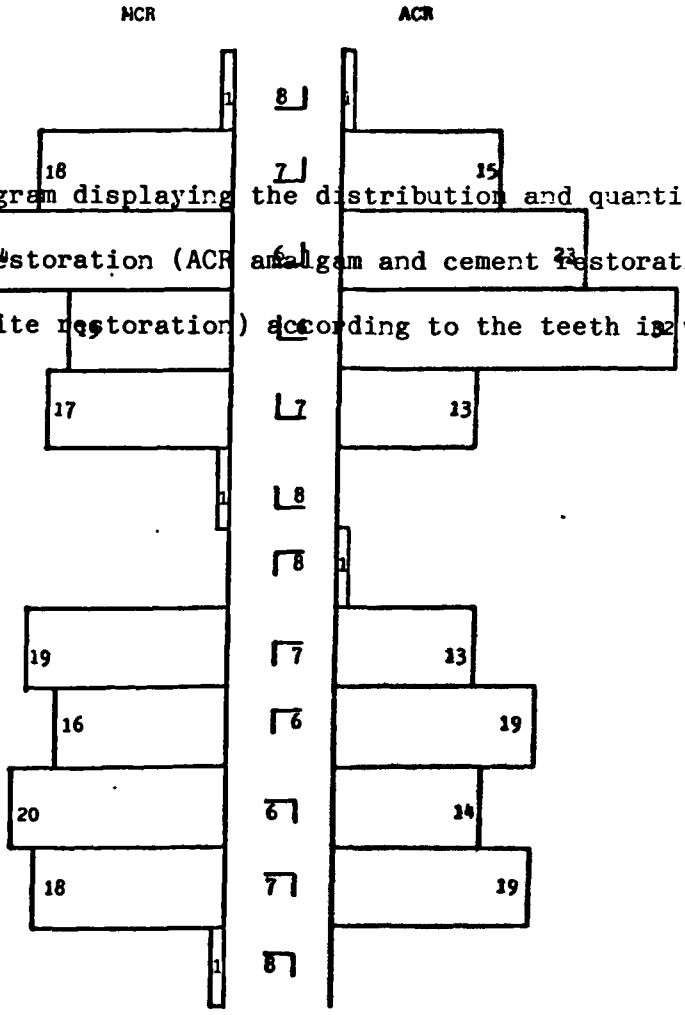
A histogram displaying the distribution and quantity of the two types of restoration (ACR amalgam and cement restoration, MCR minimal composite restoration) according to the teeth in which they were placed.

Fig. 5.19

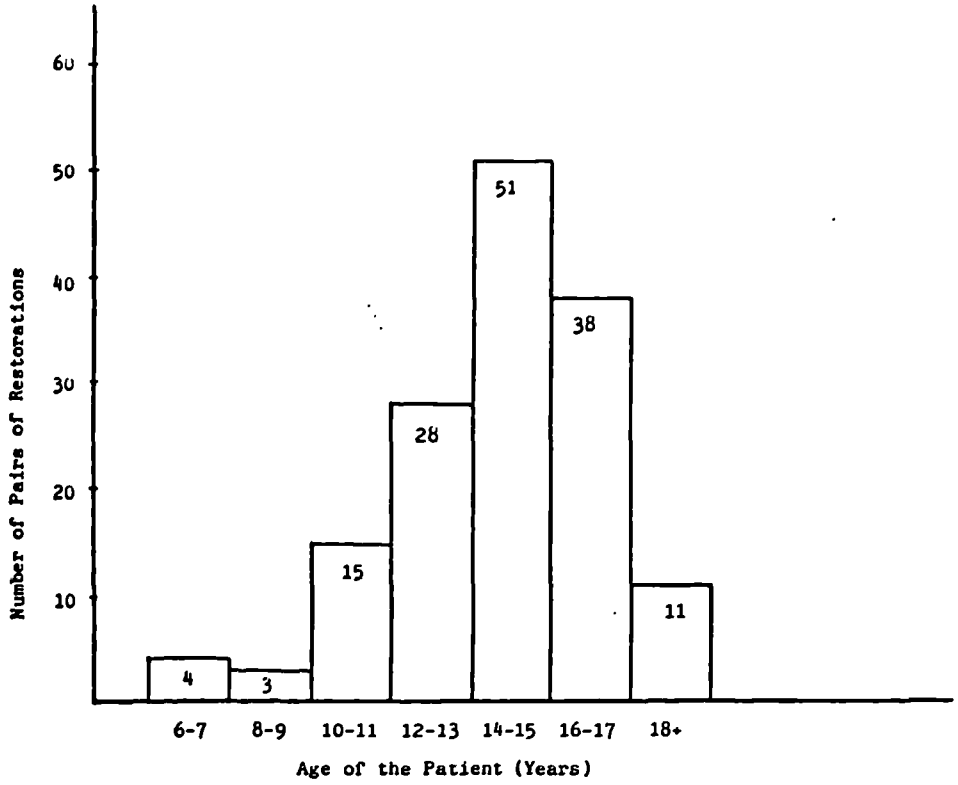


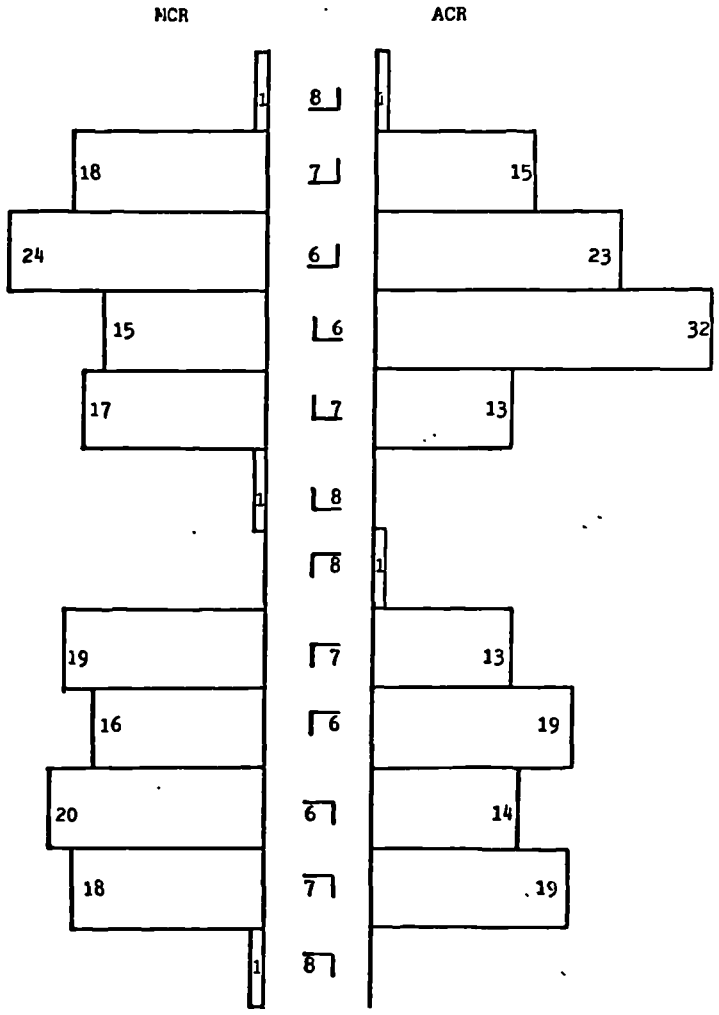
A histogram displaying the distribution of the pairs of restorations placed in the study according to the age of the patient at the time of placement.

Fig. 5.20.



A histogram displaying the distribution and quantity of the two types of restoration (ACR amalgam and cement restoration, MCR minimal composite restoration) according to the teeth in which they were placed.


Number of Pairs of Restorations
60
50
40
30
20
10
4
3
15
28
51
38
11
6-7
8-9
10-11
12-13
14-15
16-17
18+
Age of the Patient (Years)


NCR
ACR
1
8
18
7
15
24
6
23
15
6
32
17
7
13
1
8
1
8
19
7
13
16
6
19
20
6
14
18
7
19
1
8

life span of these was 36.7 (17.6) months. A total of 109 pairs were therefore reviewed within 12 months of the termination date and the mean life span of these restorations was 34.7 (17.8) months. A further breakdown of the length of follow up of these 109 pairs is shown in Table 5.11. 8 pairs have been under review for greater than 60 months, the longest pair being 67 months.

19 restorations have failed, to date, during the follow up period (Table 5.12.). A restoration was regarded as failed if it had a score of 3 for anatomical form or a score of 4 or 5 for marginal integrity, or if recurrent caries was present beneath the restoration. Of these failures, 11 were of amalgam restorations and 8 were of minimal composite restorations. Recurrent caries in 7 cases and caries involving another surface in 4 cases were the causes of the amalgam failures. Recurrent caries in 5 cases and catastrophioc loss of restorative material in 3 cases were the causes of the minimal composite failures. A further analysis of the 5 cases of recurrent caries showed that 3 occurred in another part of the occlusal surface from the original pit restoration with apparently intact fissure sealant, 1 occurred in another part of the occlusal surface with a deficient sealant and 1 occurred under the original pit restoration, with an apparently intact restoration. The mean length of service of the amalgam failures was 28.2 (9.7) months, and for the minimal composite failures was 25.8 (12.4) months.

10 minimal composite restorations had suffered significant in vivo wear, with an anatomical form score of 2 or 3 during the follow up period. 3 of these underwent catastrophic wear with anatomical form scores of 3 resulting in restoration failure after 8, 24, and 46

TABLE 5.12.

The number and age of failed restorations in the trial.

TYPE OF RESTORATION	NUMBER	AGE OF RESTORATION AT FAILURE MEAN S.D.
Amalgam cement (ACR)	11	28.2 (9.7)
Minimal composite (MCR)	8	25.8 (12.4)

TABLE 5.13.

The frequency of loss of fissure sealant from a given restoration and the mean length of service of the restoration at the time of loss. Bracketed figures are 1 standard deviation.

1st Occasion	49	17.4 (13.4) months
2nd Occasion	17	11.6 (6.9) months
3rd Occasion	9	12.3 (9.6) months
4th Occasion	3	27 (9.2) months

months in service, while 7 recorded anatomical form scores of 2 after 14, 17, 30, 31, 52, 63, 64 months in service. A further 5 minimal composite restorations recorded marginal staining after 13, 22, 23, and 57 months in service. Fissure sealant material was recorded as lost for a given restoration on 76 occasions. This occurred 49 times as a first occasion, 17 times as a second occasion, 9 times as a third occasion and 3 times as a fourth occasion for any given restoration (Table 5.13.).

The area of tooth tissue replaced by restorative material was obtained from the visual assessments made on the gridded forms (Figs. 4.13a and 4.13b) at each recall visit, by tracing the area on a magnetic digitising tablet with associated microcomputer analysis. Amalgam restorations occupied an average 25% of the occlusal surface of the tooth while minimal composite restorations occupied 5%. 'Pit' amalgam restorations in the mesial portion of the occlusal surface of upper first and second molars occupied 15% of the tooth surface. The minimal composite and amalgam restoration in the lower left second molars occupied a significantly greater proportion of the tooth surface then similar restorations in the remaining teeth ($p < 0.01$ [Stepwise ANOVA]).

Survival analysis statistical techniques (B.M.D.P. University of California) were used to monitor the anatomical form, marginal integrity, overall survival, survival by age and survival by dental arch of amalgam restorations, and the loss of fissure sealant on the first occasion from MCR's and the overall survival of MCR's. There was a steady deterioration in anatomical form for ACR's over the follow up period, and this is demonstrated in the cumulative survival curves shown in Figs. 5.21. and 5.22. ACR's quickly achieved marginal

Fig 5.21

AMALGAM RESTORATIONS WITH ANATOMICAL FORM CODED 2 OR HIGHER

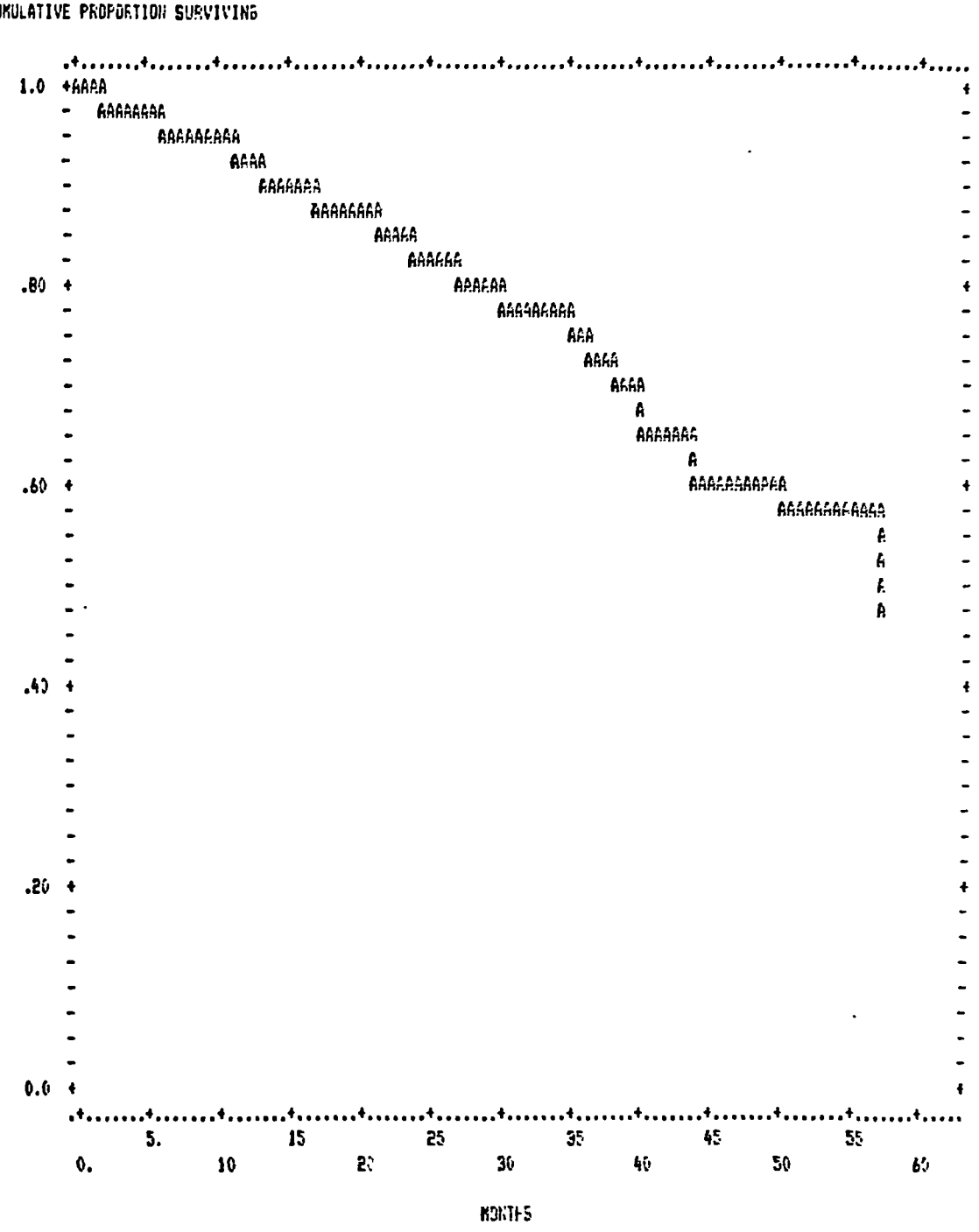
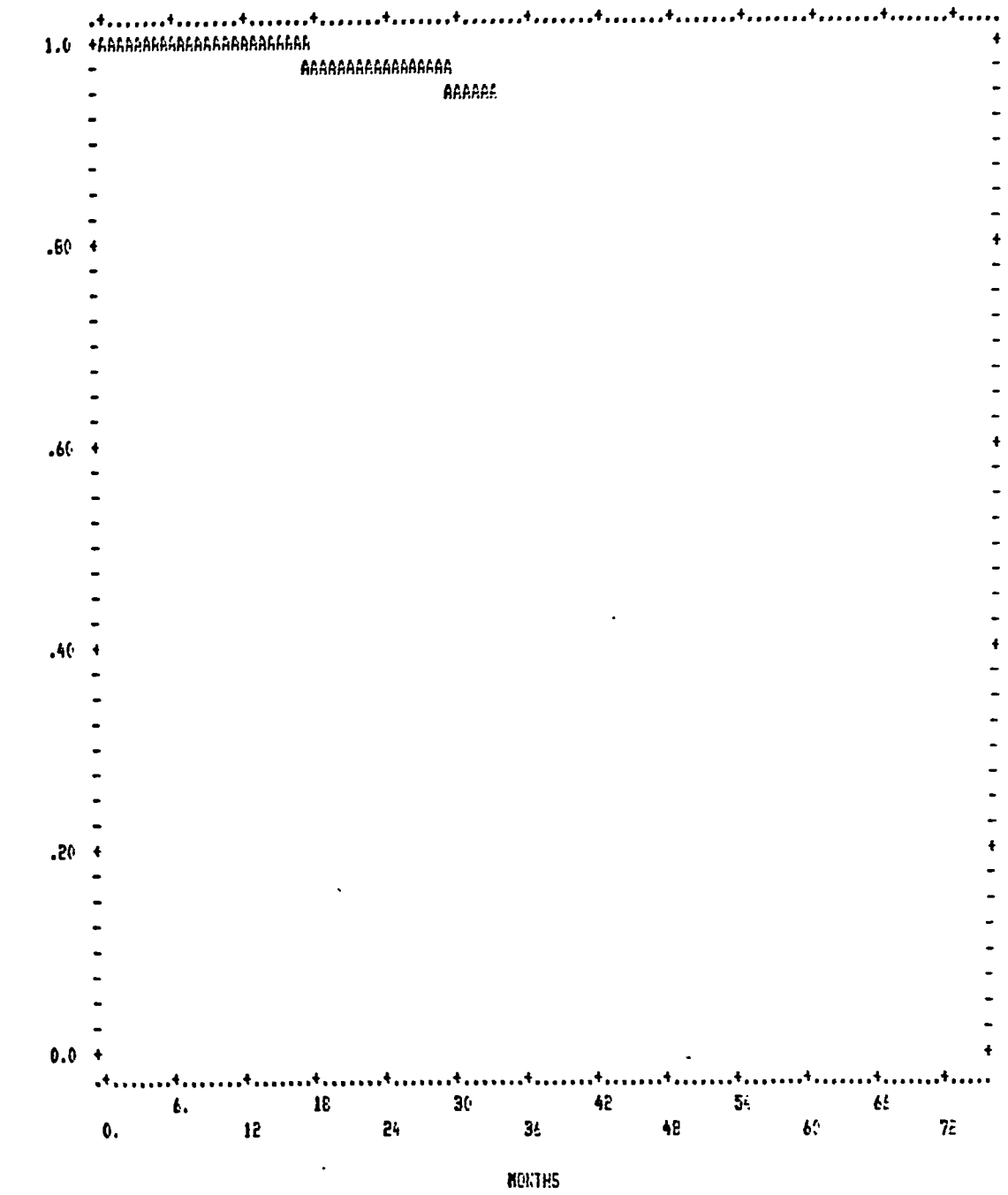


Fig 5.22

AMALGAM RESTORATIONS WITH ANATOMICAL FORM CODED 3



integrity scores of 2, but further progression to marginal integrity scores of 3, 4 and 5 was much slower, and this is demonstrated in the cumulative survival curves shown in Figs. 5.23., 5.24. and 5.25.

Analysis of overall survival gave a median survival time (MST) of 61.48 (S.E. 1.64) months for all ACR's. The cumulative survival curve for overall survival is shown in Fig. 5.26. Survival of restorations by age was assessed, and the MST and age groupings are shown in Table 5.14. There was no significant difference in MST's irrespective of age and placement. In age groups 6 - 7, 8 - 9 and 18+ none of the ACR's had failed and this is the cause of a standard error of 0 in those groups. The cumulative survival curves by age are shown in Fig. 5.27. Survival of ACR's by dental arch was also assessed and results are shown in Table 5.15. There was no significant difference in survival times between ACR's placed in the upper or lower dental arch. The cumulative survival curves by dental arch are shown in Fig. 5.28.

The loss of fissure sealant from minimal composite restorations was a relatively frequent occurrence. The cumulative survival curve based on partial loss of fissure sealant material on the first occasion is shown in Fig. 5.29. The MST of minimal composite restorations before partial loss of fissure sealant material was 38.62 (S.E. 2.11.) months. Partial loss of fissure sealant on the first occasion, when assessed by placement in either upper or lower arch showed no significant difference between MST's (Table 5.16.). The cumulative survival curves for loss of sealant by dental arch are shown in Fig. 5.30. Analysis of overall survival gave an MST of 63.25 (S.E. 1.36) months for all MCR's. The cumulative survival curve for

Fig 5.23

AMALGAM RESTORATIONS WITH MARGINAL INTEGRITY SCORE OF 2 OR MORE

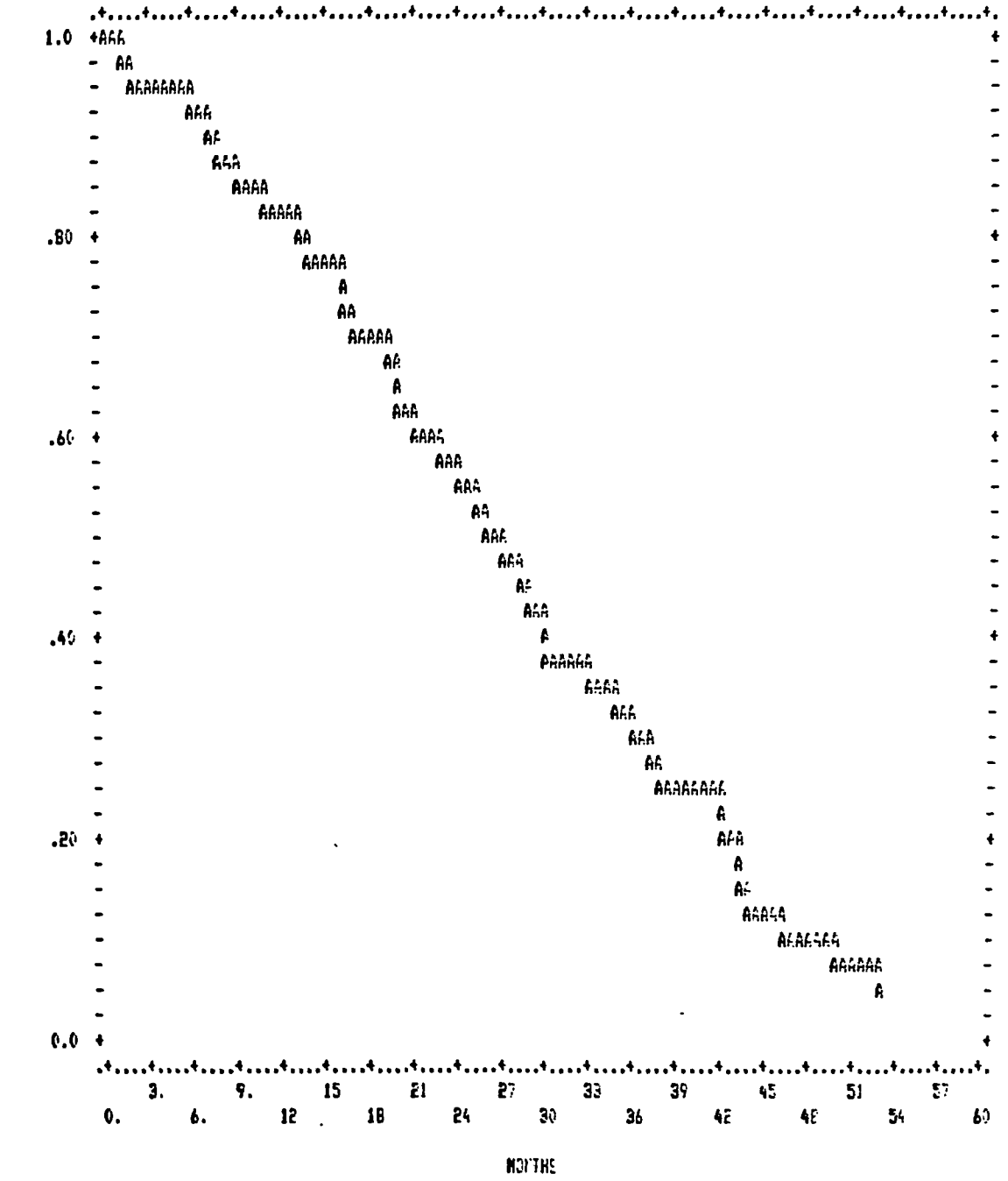


Fig 5.24

AMALGAM RESTORATIONS WITH MARGINAL INTEGRITY SCORE OF 3 OR MORE

CUMULATIVE PROPORTION SURVIVING

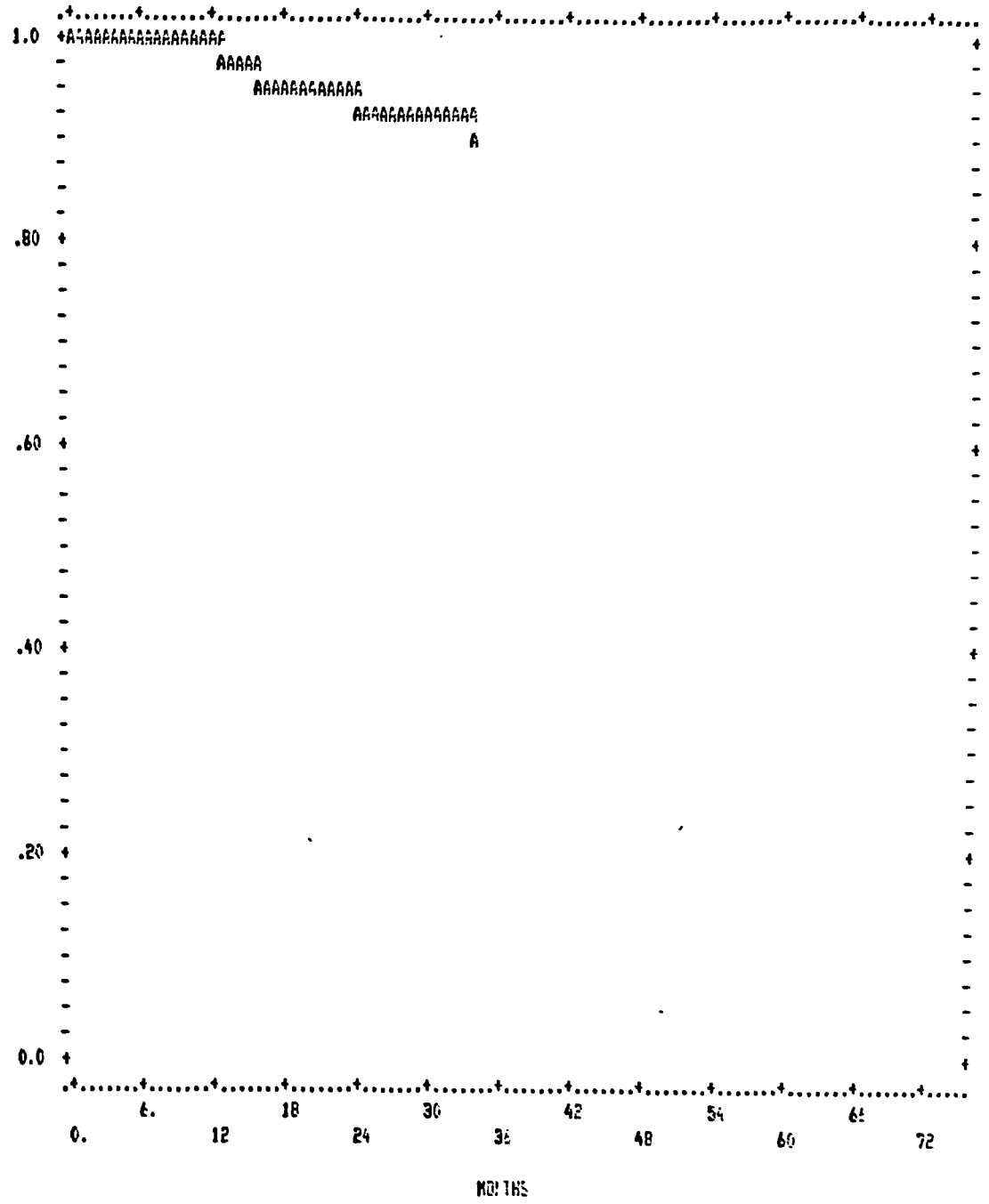


Fig 5.25

AMALGAM RESTORATIONS WITH MARGINAL INTEGRITY SCORE OF 4 OR MORE

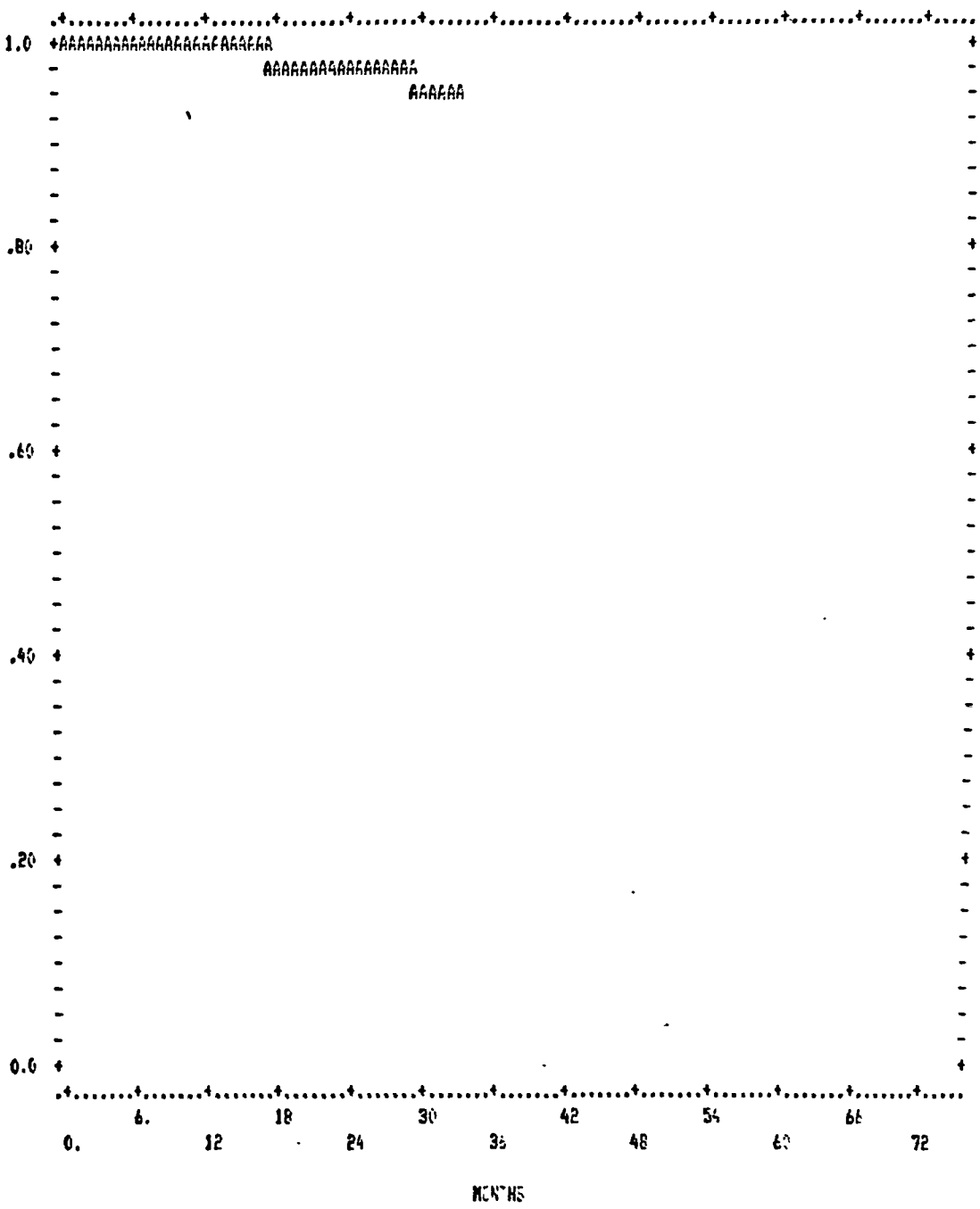


Fig 5.26

AMALGAM RESTORATIONS OVERALL SURVIVAL

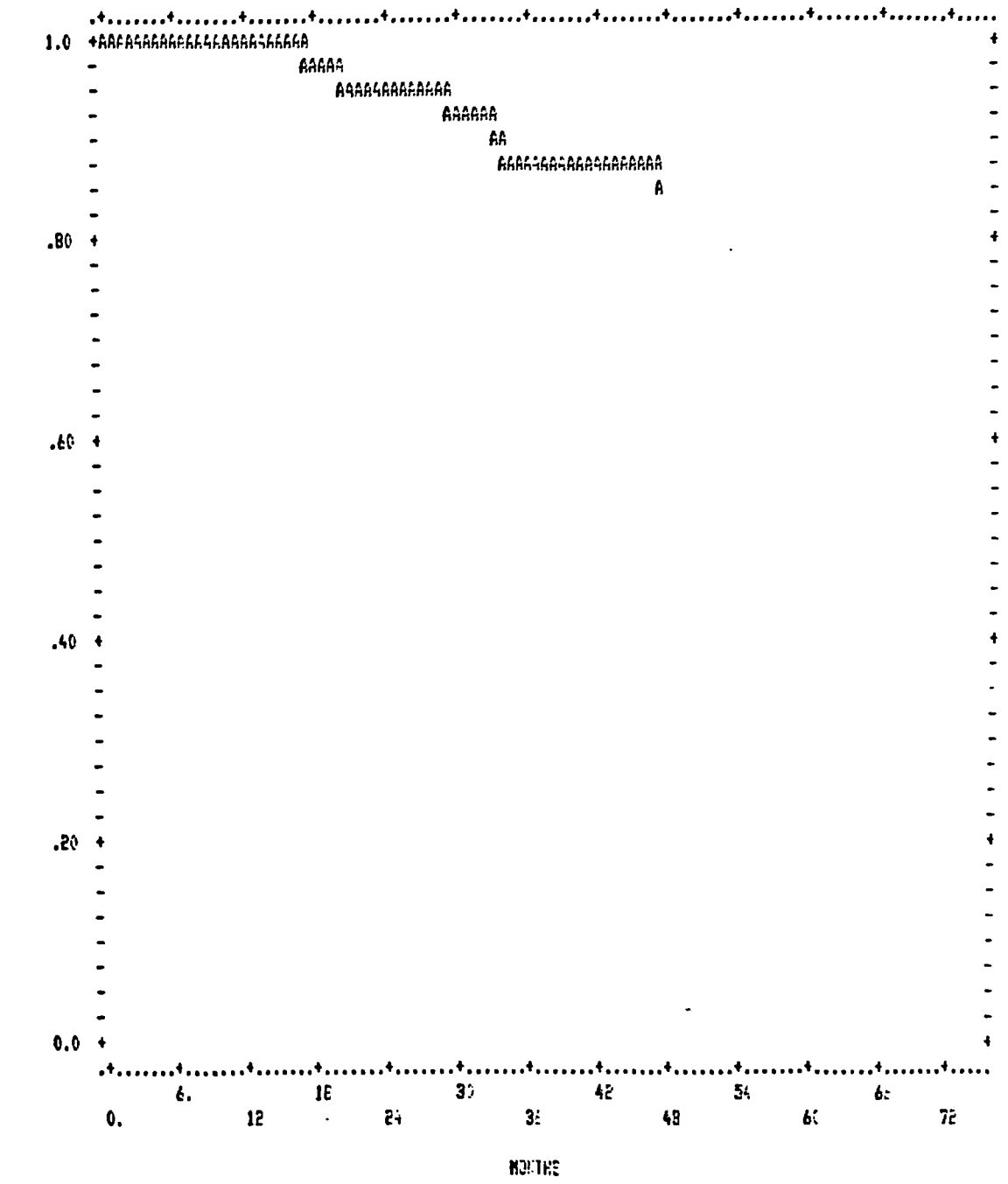


TABLE 5.14.

The median survival times for ACR's when calculated by age at the time of placement.

AGE OF PLACEMENT (YEARS)	MST (MONTHS)	S. ERROR
6 - 7	52.0	0
8 - 9	60.0	0
10 - 11	51.81	4.81
12 - 13	53.99	3.64
14 - 15	59.23	4.05
16 - 17	62.35	2.57
18+	61.0	0

TABLE 5.15.

The median survival times for ACR's when assessed by placement in upper or lower dental arch.

DENTAL ARCH	MST (MONTHS)	S. ERROR
Upper	61.76	2.21
Lower	59.67	2.50

TABLE 5.16.

The median survival times for MCR's prior to partial loss of fissure sealant material on the first occasion, when assessed by placement in upper or lower dental arch.

DENTAL ARCH	MST (MONTHS)	S. ERROR
Upper	36.72	2.69
Lower	38.93	3.04

Fig 5.27

AMALGAM RESTORATIONS OVERALL SURVIVAL BY AGE

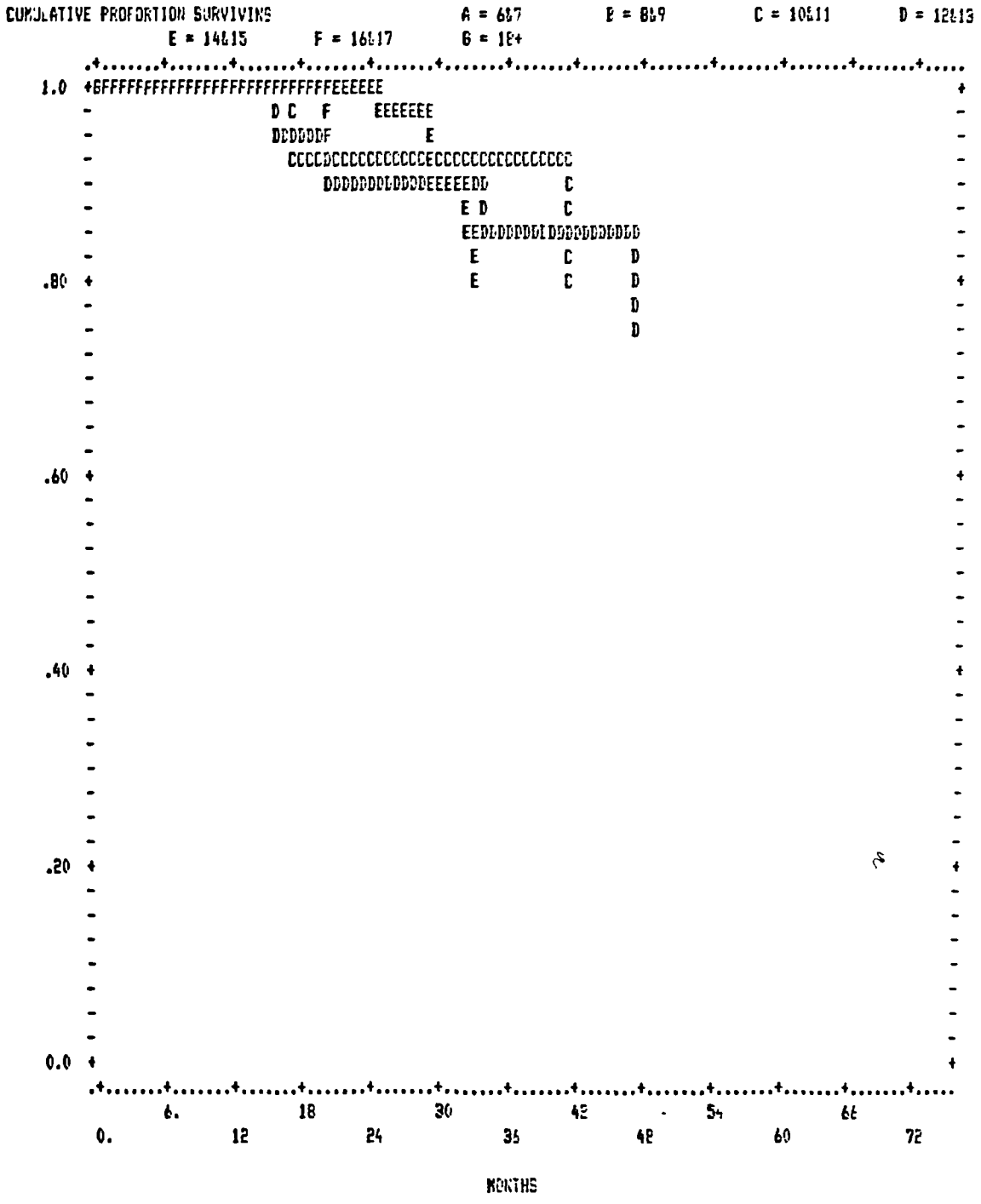


Fig 5.28

AMALGAM RESTORATIONS OVERALL SURVIVAL BY DENTAL ARCH

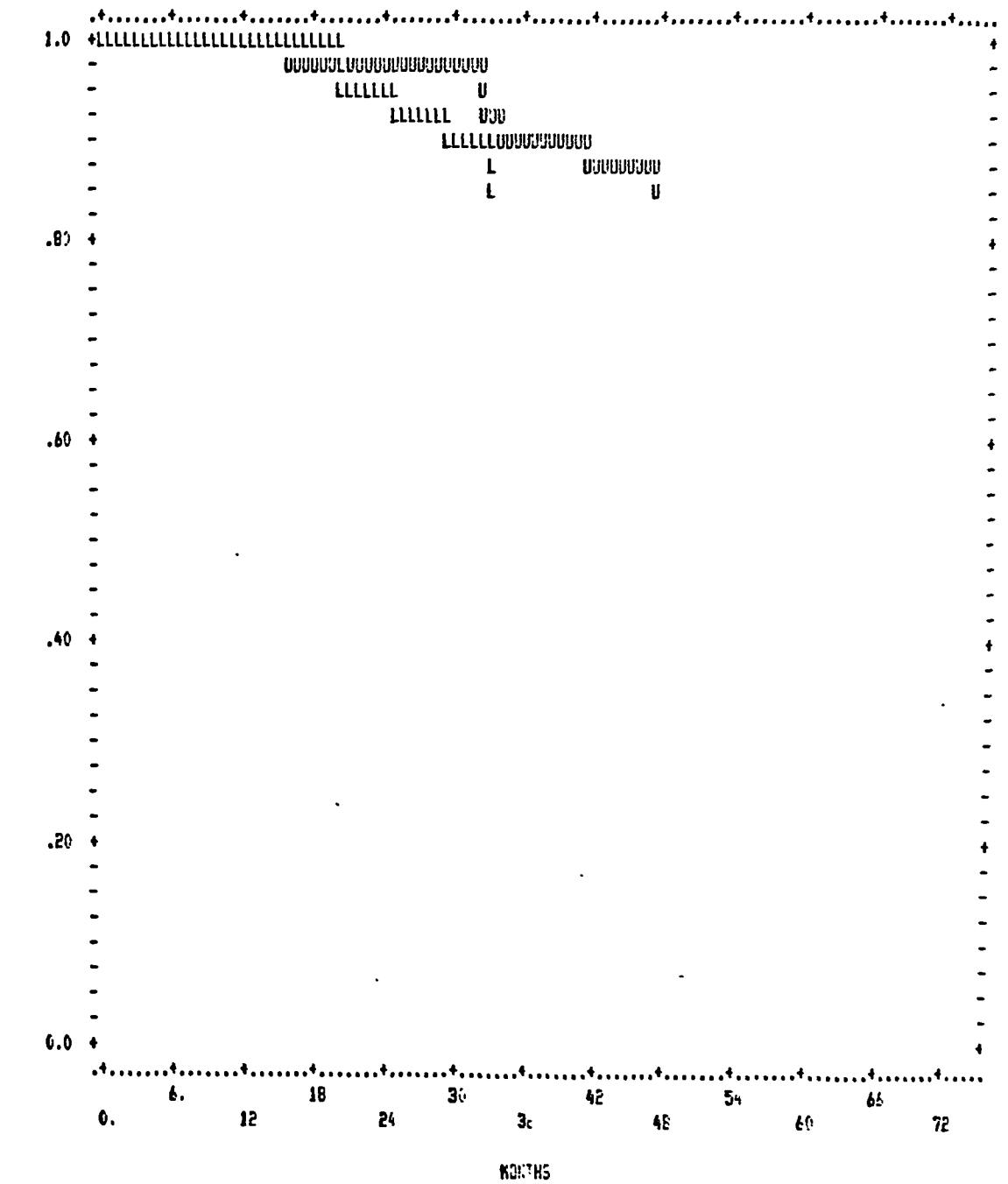


Fig 5.29

MINIMAL COMPOSITES LOSS OF FISSURE SEALANT ON FIRST OCCASION

CUMULATIVE PROPORTION SURVIVING

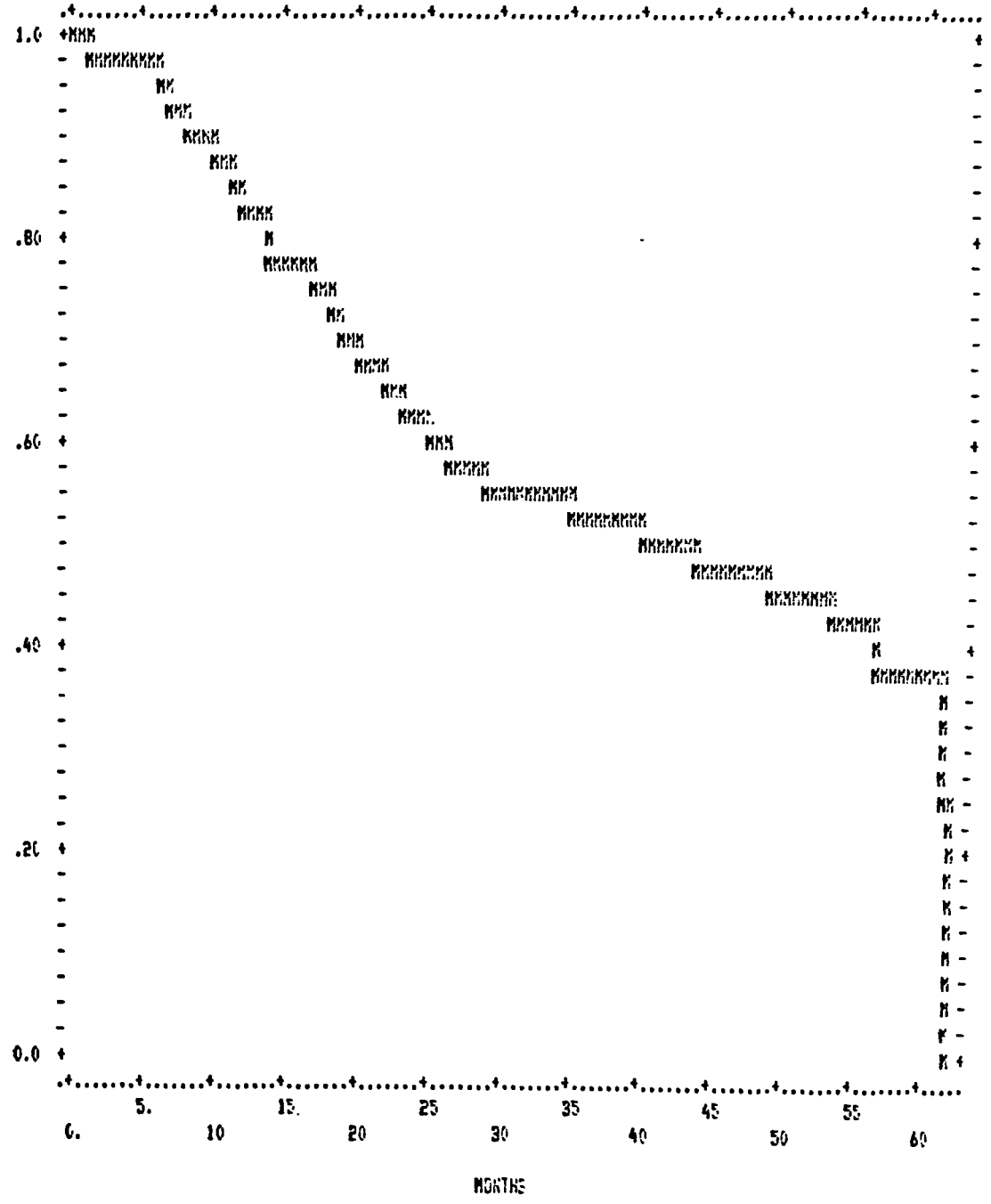
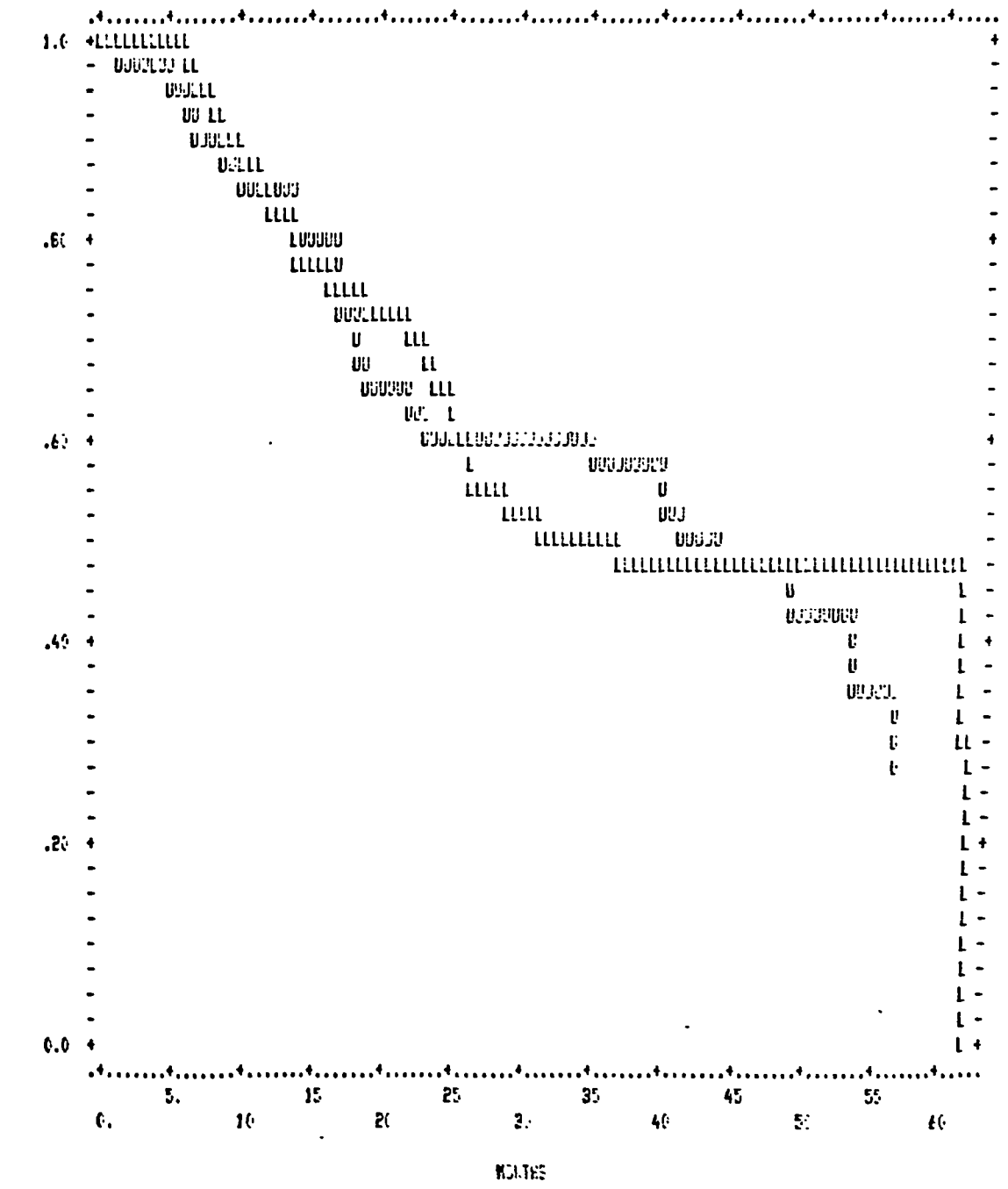


Fig 5.30

MINIMAL COMPOSITES LOSS OF FISSURE SEALANT ON FIRST OCCASION BY ARCH

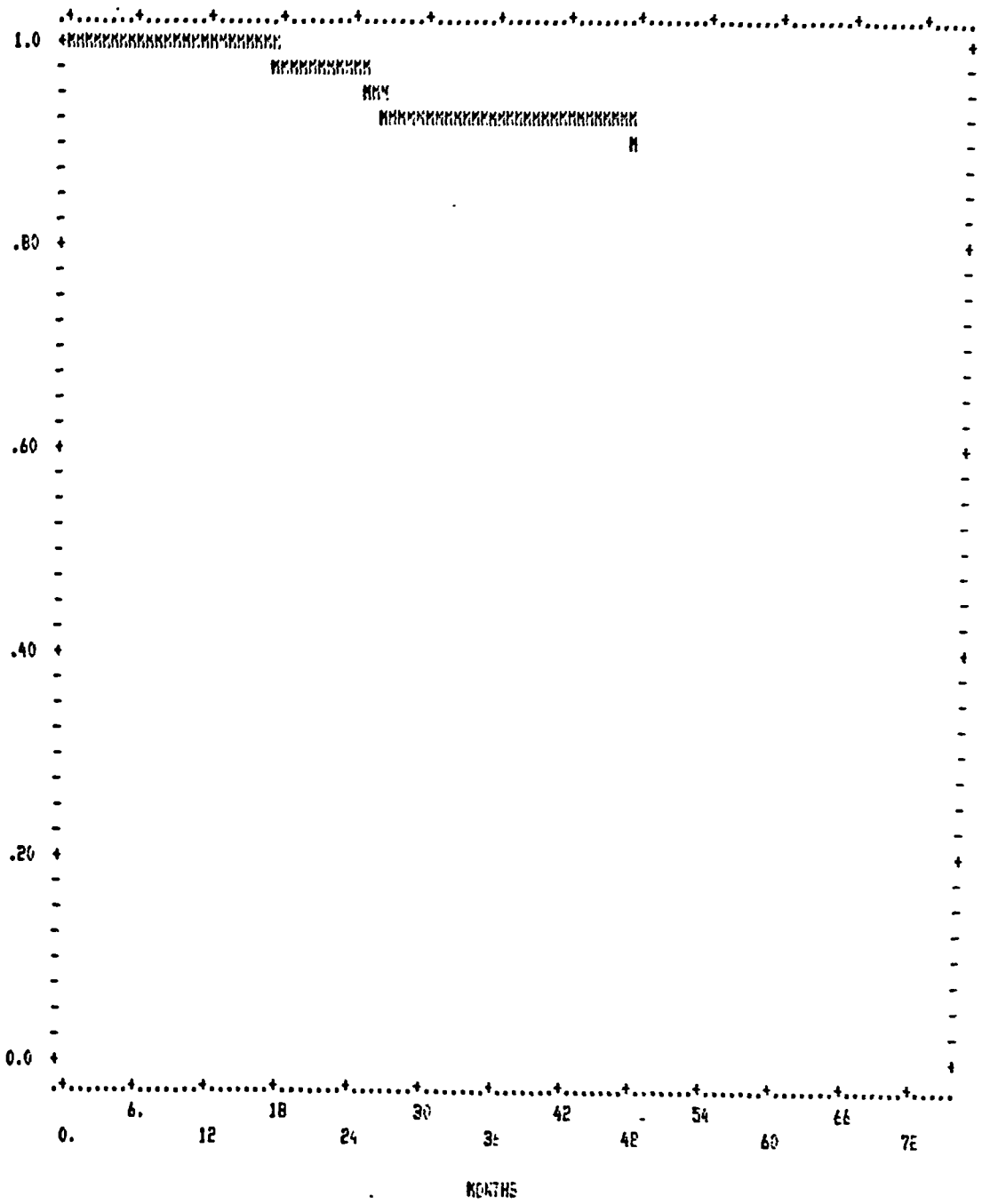


overall survival is shown in Fig. 5.31.

There was no significant difference between the MST of ACR [61.48 (1.64)] and that of MCR [63.25 (1.36)].

Fig 5.31

MINIMAL COMPOSITES OVERALL SURVIVAL



5.1.3. GLASS POLYALKENOATE CEMENT - COMPOSITE RESIN SANDWICH TECHNIQUE

27 patients were provisionally accepted as being suitable for inclusion in the clinical trial. However, after placement of the restorations, 3 patients did not return for review appointments. A total of 49 Class II restorations in 24 patients were assessed regularly between July 1986 and July 1988 (Table 5.17.). The number of restorations achieving each successive 6 monthly review appointment is shown in Table 5.18. The ages of the patients at the time of treatment and the distribution of the restorations are given in Figs. 5.32. and 5.33.

The cavity sizes of the 49 restorations are summarised in Table 5.19. according to the assessment criteria described in the material and method section. None of the restorations had an approximal box that extended apically below the cemento-enamel junction.

The restorations were assessed by modified USPHS criteria (Appendix 1). Assessment of anatomical form, marginal adaptation and surface roughness was carried out on both occlusal and approximal surfaces. Results are expressed, both as the number of restorations (and the percentage) achieving a particular category score with time (Table 5.20.).

Colour match was good throughout with only a small percentage of restorations being graded 'B'. There was no discomfort or sensitivity reported by the patients at any time on the study.

Cavomarginal discolouration was deemed to have occurred at grade 'B' (not in a pulpal direction) on a number of occasions. At 6 months of age 3% of restorations, at 12 months 11%, at 18 months 29% and at 24 months 36% of restorations exhibited grade 'B' discolouration.

TABLE 5.17.

Subjects involved in the study of glass polyalkenoate-composite resin sandwich restorations.

Number of Patients	24
Age Range	9 Years 10 months - 26 years
Number of Restorations	49 - 43 MO or DO - 6 MOD

TABLE 5.18.

A breakdown of the number of restorations achieving each successive follow up period.

NUMBER OF RESTORATIONS	FOLLOW UP PERIOD
49	6 months
38	12 months
31	18 months
11	24 months

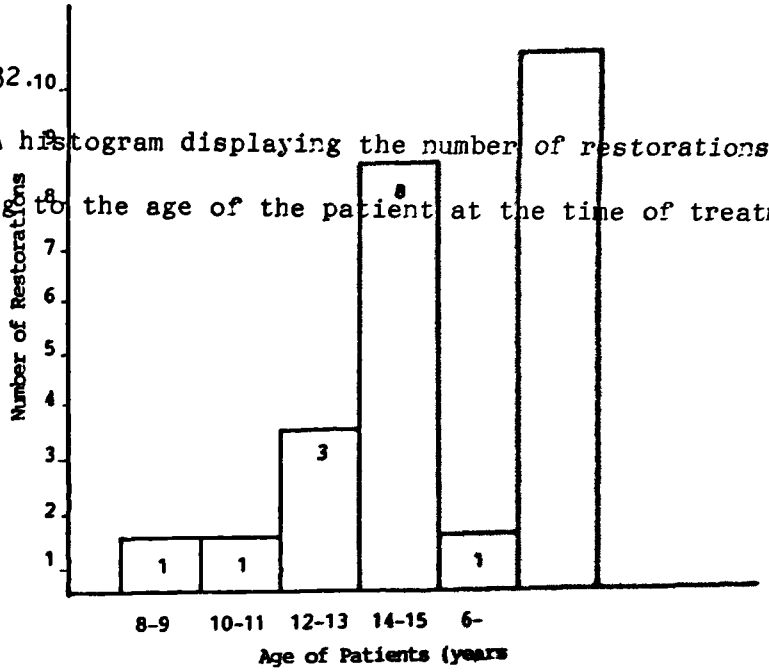
Fig. 5.32.

A histogram displaying the number of restorations placed according to the age of the patient at the time of treatment.

Fig. 5.33.

A diagram displaying the distribution and quantity of the restorations according to the teeth in which they were placed.

Fig. 5.32.

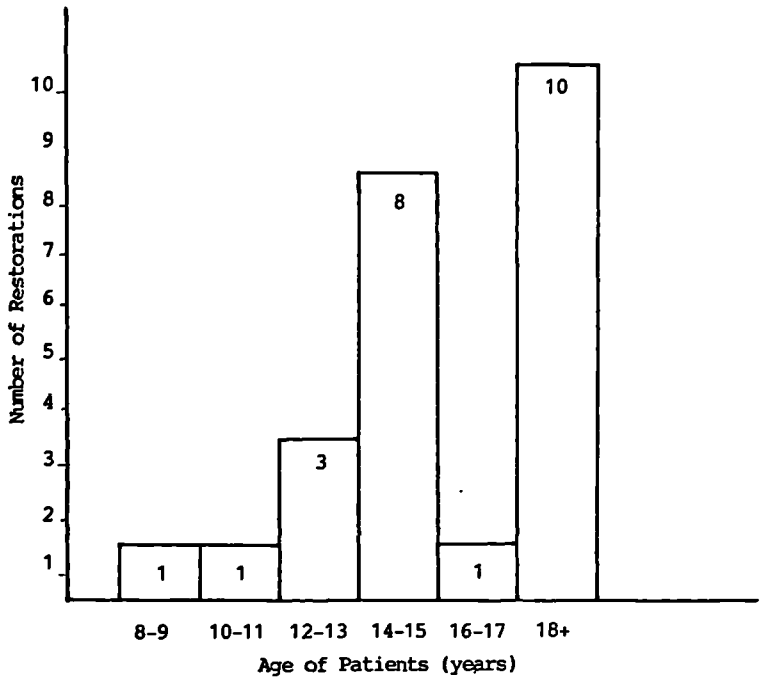


A histogram displaying the number of restorations placed according to the age of the patient at the time of treatment.

Fig. 5.33.

Tooth Type	17	16	15	14	24	25	26	27
Number	0	6	5	2	5	3	10	0
Number	2	5	2	0	0	3	1	1
Tooth Type	47	46	45	44	34	35	36	37

A diagram displaying the distribution and quantity of the restorations according to the teeth in which they were placed.



Tooth Type	17	16	15	14	24	25	26	27
Number	0	6	5	2	3	5	11	0
Number	2	5	2	0	0	3	4	1
Tooth Type	47	46	45	44	34	35	36	37

TABLE 5.19.

A summary of the cavity sizes of the 49 trial restorations.

		NUMBER OF RESTORATIONS
Occlusal	1	10
	2	25
	3	14
Approximal	1	9
	2	30
	3	10
Depth of Box	1	36
	2	13
	3	0

TABLE 5.21.

A summary of the cavity sizes of the Occlusin and Ketac Bond failures.

		OCCLUSIN FAILS	KETAC BOND FAILS
Occlusal	1	1	1
	2	3	5
	3	3	5
Approximal	1	0	0
	2	6	8
	3	1	3
Depth of Box	1	4	5
	2	3	6

TABLE 5.20.

Results expressed both as the number and percentage of restorations achieving a particular category score with time.

	6 MONTHS n = 49	12 MONTHS n = 38	18 MONTHS n = 31	24 MONTHS n = 11
COLOUR MATCH	A = 45 (92%) B = 4 (8%)	A = 35 (92%) B = 3 (8%)	A = 29 (94%) B = 2 (6%)	A = 11 (100%)
DISCOMFORT SENSITIVITY	A = 49 (100%)	A = 38 (100%)	A = 31 (100%)	A = 11 (100%)
CAVO-MARGINAL DISCOLOURATION	A = 46 (94%) B = 3 (6%)	A = 34 (89%) B = 4 (11%)	A = 22 (71%) B = 9 (29%)	A = 7 (64%) B = 4 (36%)
ANATOMICAL FORM OCCLUSAL	A = 43 (88%) B = 4 (8%) C = 2 (4%)	A = 32 (84%) B = 4 (11%) C = 2 (5%)	A = 27 (87%) B = 3 (10%) C = 1 (3%)	A = 11 (100%)
APPROXIMAL	A = 40 (82%) B = 4 (8%) C = 5 (10%)	A = 29 (76%) B = 6 (16%) C = 3 (8%)	A = 21 (68%) B = 5 (16%) C = 5 (16%)	A = 9 (82%) B = 1 (9%) C = 1 (9%)
MARGINAL ADAPTATION OCCLUSAL	A = 44 (90%) B = 1 (2%) C = 1 (2%) D = 3 (6%)	A = 34 (89%) B = 1 (3%) C = 0 D = 3 (8%)	A = 29 (94%) B = 1 (2%) C = 0 D = 1 (2%)	A = 11 (100%)
APPROXIMAL	A = 37 (76%) B = 4 (8%) C = 4 (8%) D = 4 (8%)	A = 26 (68%) B = 8 (21%) C = 1 (3%) D = 3 (8%)	A = 18 (58%) B = 8 (26%) C = 4 (13%) D = 1 (3%)	A = 10 (91%) B = 1 (9%)
SURFACE ROUGHNESS OCCLUSAL	A = 43 (88%) B = 3 (6%) C = 0 D = 3 (6%)	A = 33 (87%) B = 2 (5%) C = 0 D = 3 (8%)	A = 27 (87%) B = 2 (7%) C = 1 (3%) D = 1 (3%)	A = 11 (100%)
APPROXIMAL	A = 38 (78%) B = 1 (2%) C = 6 (12%) D = 4 (8%)	A = 28 (74%) B = 1 (2%) C = 6 (16%) D = 3 (8%)	A = 18 (58%) B = 0 C = 12 (39%) D = 1 (3%)	A = 10 (91%) B = 1 (9%)

The proximal margins of the Class II restorations were found to be relatively free of cavomarginal discolouration, such deterioration was most commonly found in relation to areas of complex morphology and marginal defects on stress bearing areas.

Regarding the occlusal surface of the restoration, that is the 'Occlusin only' surface, after 18 months of service 'A' grade scores were achieved for anatomical form (87%), marginal adaptation (94%) and surface roughness (87%). However, when considering the approximal surfaces, the corresponding 'A' grade scores at 18 months of service were: anatomical form (68%), marginal adaptation (58%) and surface roughness (58%). The discrepancy in the 2 surfaces was due to the small 1 - 2 mm. layer of glass polyalkenoate cement Ketac Bond in the base of the box, which, in a number of cases underwent continuous loss of material.

17 restorations have failed, to date, during the follow up period. A restoration was regarded as failed if it had a score of C for anatomical form or marginal adaptation, or if recurrent caries was beneath the restoration of those failures, 10 were due to loss of Ketac Bond from the base of the box, resulting in cervical gap formation, and the mean time to failure was 13.2 (6.8) months. 5 restorations failed due to fracture or loss of Occlusin composite resin and the mean time to failure of these was 8.0 (3.7) months. 1 restoration was a combined failure with fracture of Occlusin and loss of Ketac Bond at 18 months, and 1 restoration was replaced due to caries elsewhere in the tooth at 24 months. The cavity sizes of the Occlusin and Ketac failures are shown in Table 5.21. The numbers of failures involved are too small to be able to adequately interpret

any significance test comparing 'failure versus original cavity size'. Teeth restored with the Class II sandwich restorations described in this trial require careful radiographic interpretation. Fig. 5.3 4a. shows an upper left first molar immediately after mesio-occlusal restoration placement. The base of the box is within enamel approximately 1 mm. above the cemento enamel junction. Ketac Bond glass polyalkenoate cement then occupies 1 - 2 mm. of the finished approximal wall of the restoration and is an almost identical radiopacity to enamel. The occlusal surface and the remainder of the approximal tooth surface is restored with radiopqaue occlusin. The restoration is seen in Fig. 5.34b. after 18 months service where it achieved 'A' grades on all surfaces for AF, MA and SR. Fig. 5.35a shows a lower left first molar immediately after distal-occlusal restoration placement. After 18 months service, there has been some loss of Ketac Bond at the Occlusin-Ketac Bond box junction and this tooth, although achieving 'A' grades on its occlusal surface was graded AF - 'B', MA - 'B', and SR - 'C' on its approximal surface (Fig. 5.35b.). Fig. 5.36. shows a distal-occlusal restoration in an upper right second premolar, which although achieving 'A' grades on its occlusal surface, has lost sufficient Ketac Bond at the base of the box to grade it AF - 'C', MA - 'C' and SR - 'C' and thus requiring replacement. Fig. 5.37. shows a mesio-occlusal restoration in a lower right second molar and mesio-occlusal-distal restoration in a lower right first molar after just 6 months of service. There has been catastrophic loss of Ketac Bond from the distal box of the $\overline{6\ /}$ and the mesial box of the $\overline{7\ /}$. In addition the marginal ridge of $\overline{7\ /}$ has fractured. Both restorations required replacement.

Fig. 5.34a.

The / 6 immediately following MO restoration placement.

Fig. 5.34b.

The / 6 after eighteen months in service still achieving 'A' grade scores.

Fig. 5.35a.

The / $\overline{6}$ immediately following DO restoration placement.

Fig. 5.35b.

The / $\overline{6}$ after eighteen months in service showing some loss of Ketac Bond in the base of the box.

Fig. 5.36.

A distal-occlusal restoration in 5 / which has lost sufficient Ketac Bond in the base of the box to necessitate replacement.

Fig. 5.37.

Catastrophic loss of Ketac Bond in the base of the box, mesially in $\overline{7}$ / and distally in $\overline{6}$ / necessitating restoration placement.

Fig. 5.34a.

The / 6 immediately following MO restoration placement.

Fig. 5.34b.

The / 6 after eighteen months in service still achieving 'A' grade scores.

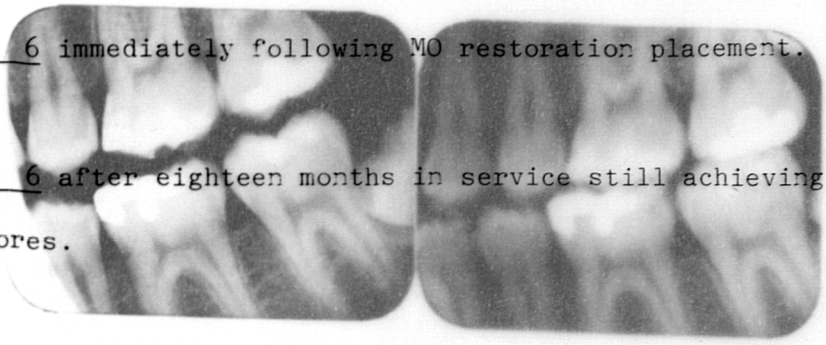


Fig. 5.35a.

The / 6 immediately following DO restoration placement.

Fig. 5.35b.

The / 6 after eighteen months in service showing some loss of Ketac Bond in the base of the box.

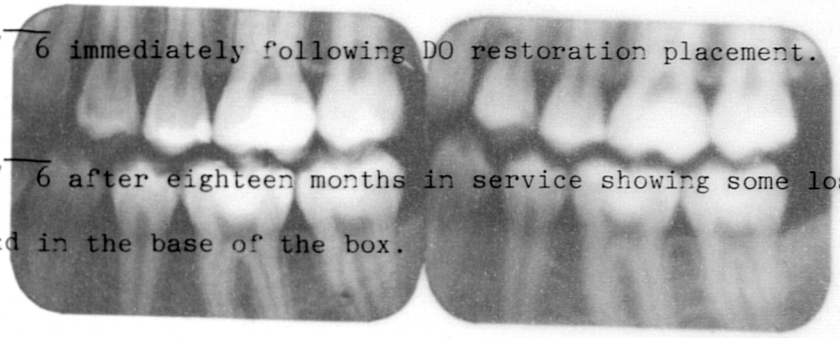


Fig. 5.36.

A distal-occlusal restoration in 5 / which has lost sufficient Ketac Bond in the base of the box to necessitate replacement.

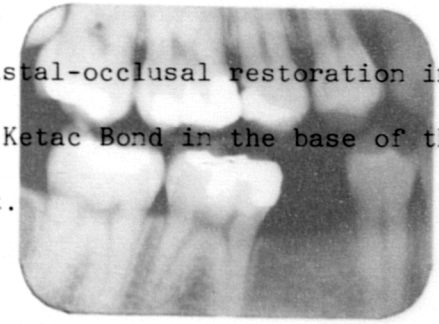
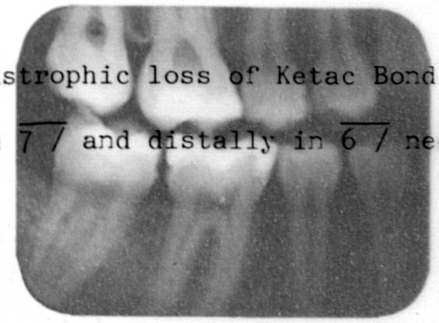


Fig. 5.37.

Catastrophic loss of Ketac Bond in the base of the box, mesially in 7 / and distally in 6 / necessitating restoration placement.



5.1.4. MICROFILLED COMPOSITE RESIN VENEERS

70 patients were initially assessed for inclusion in the clinical trial. Of these, 4 never achieved an acceptable level of oral hygiene, and as a result did not undergo veneer placement. Thus, 66 patients received 289 microfilled composite resin veneers and all returned for follow up appointments between November 1984 and July 1988 (Table 5.22.). All veneers were placed by 1 clinician (R.R.W.). The ages of the patients at the time of treatment and the distribution of the restorations are given in Figs. 5.38. and 5.39. Out of the 289 veneers, 224 (78%) were reviewed in the last 6 months of the study. A full breakdown of the length of follow up of the 289 veneers is shown in Table 5.23. The 6 oldest veneers were under review for 43 months.

The aetiology of the defects that necessitated the placement of veneers are shown in Table 5.24. By far the largest aetiological cause was Tetracycline staining. Orthodontic causes included minor rotations and residual spacing between teeth.

42 (14.5%) microfilled composite resin veneers have failed, to date, during the follow up period. The reasons for these failures are various and are shown in Table 5.25. Of the 42 failures, 36 were first failures and 6 were second failures (Table 5.26.). The data was analysed using survival analysis (B.M.D.P. University of California) and the median survival time (M.S.T.) of the veneers was 35.59 (S.E. 0.82) months. The cumulative survival curve for all restorations is shown in Fig. 5.40. There was no significant difference in M.S.T. between central incisors [35.14 (1.55) months] lateral incisors [35.35 (1.31.) months]and canines [37.2 (1.47) months]and the cumulative survival curves for these are shown in Fig. 5.41.

TABLE 5.22.

Subjects involved in the microfilled composite veneer study.

Number of patients	66
Age Range	8 years 6 months - 26 years
Number of veneers	289

TABLE 5.23.

A breakdown of the length of follow up for the 289 Microfilled Composite Resin Veneers.

LENGTH OF FOLLOW UP	NUMBER
> 30 months	28
20 - 29 months	113
15 - 19 months	42
10 - 14 months	61
6 - 9 months	45

TABLE 5.24.

Aetiological causes necessitating the placement of the 289 Microfilled Composite Resin Veneers in this study.

Tetracycline staining	47%
Hypoplasia	18%
Fluorosis/Mottling	9%
Non vital	17%
Orthodontic/Hypodontia	9%

Fig. 5.38.

A histogram displaying the distribution of veneers placed in the study according to the age of the patient at the time of placement.

Fig. 5.39.

A histogram displaying the distribution and quantity of veneers according to the teeth on which they were placed.

Fig. 5.38.

A histogram displaying the distribution of veneers placed in the study according to the age of the patient at the time of placement.

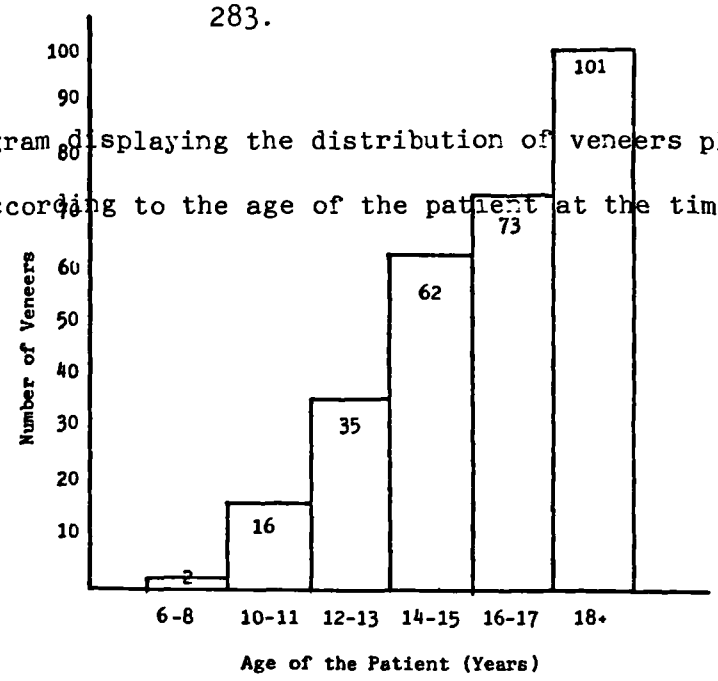
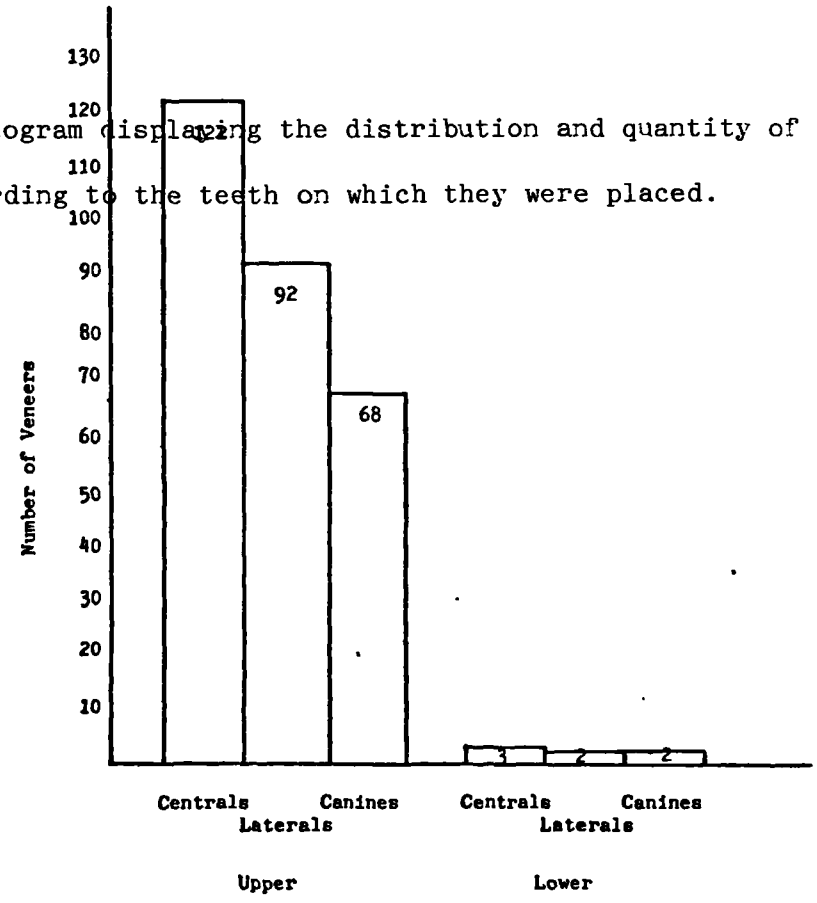
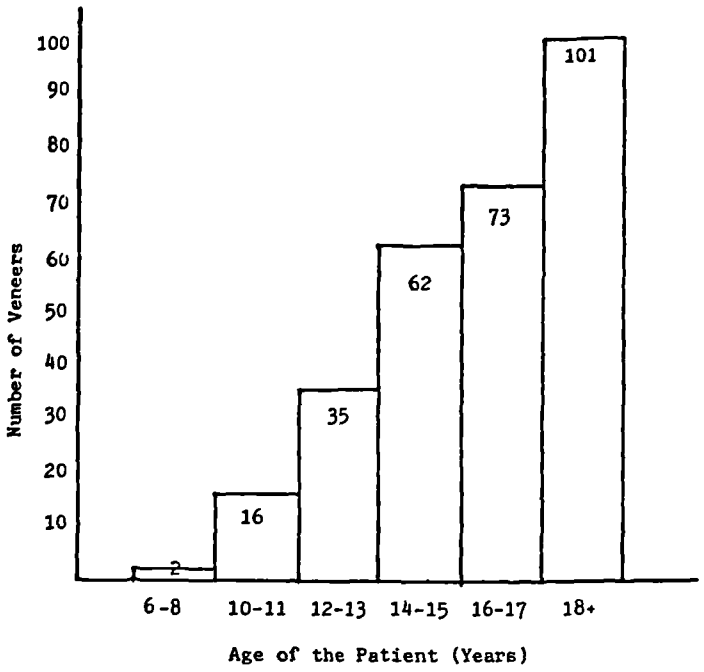


Fig. 5.39.

A histogram displaying the distribution and quantity of veneers according to the teeth on which they were placed.




Number of Veneers
100
90
80
70
60
50
40
30
20
10
101
73
62
35
16
2
6-8
10-11
12-13
14-15
16-17
18+
Age of the Patient (Years)

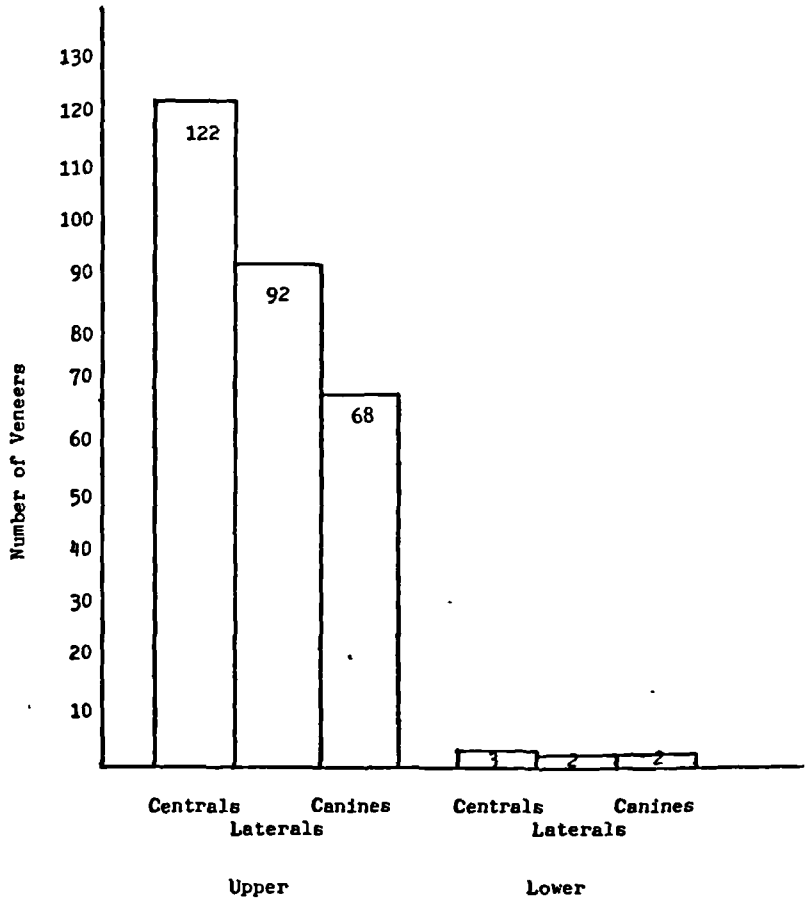

Number of Veneers
130
120
110
100
90
80
70
60
50
40
30
20
10
122
92
68
3
2
1
2
Centrals
Laterals
Canines
Centrals
Laterals
Canines
Upper
Lower

TABLE 5.25.

The causes of failure of the 42 microfilled composite veneers.

Food eating	11	(Boiled sweets (4), Nuts (2), Toffee (2), Apple (1), Cucumber (1), Gum (1))
Bruxism	8	
Habits	7	(Opening sweet packet (3), Pen biting (2), Cutting Sellotape (1), Opening a bottle (1))
Trauma	4	(Drinking Cup (2), Fist (1), Fall (1))
Poor Aesthetics	3	
Adhesive failure	3	
Unknown	6	

TABLE 5.26.

A breakdown of the 42 microfilled composite resin veneer failures.

	TOTAL	1st FAILURE	2nd FAILURE
Centrals	20	19	1
Laterals	15	12	3
Canines	7	5	2

Fig 5.40

HELIOCOLOR MICROFILLED VENEERS OVERALL SURVIVAL

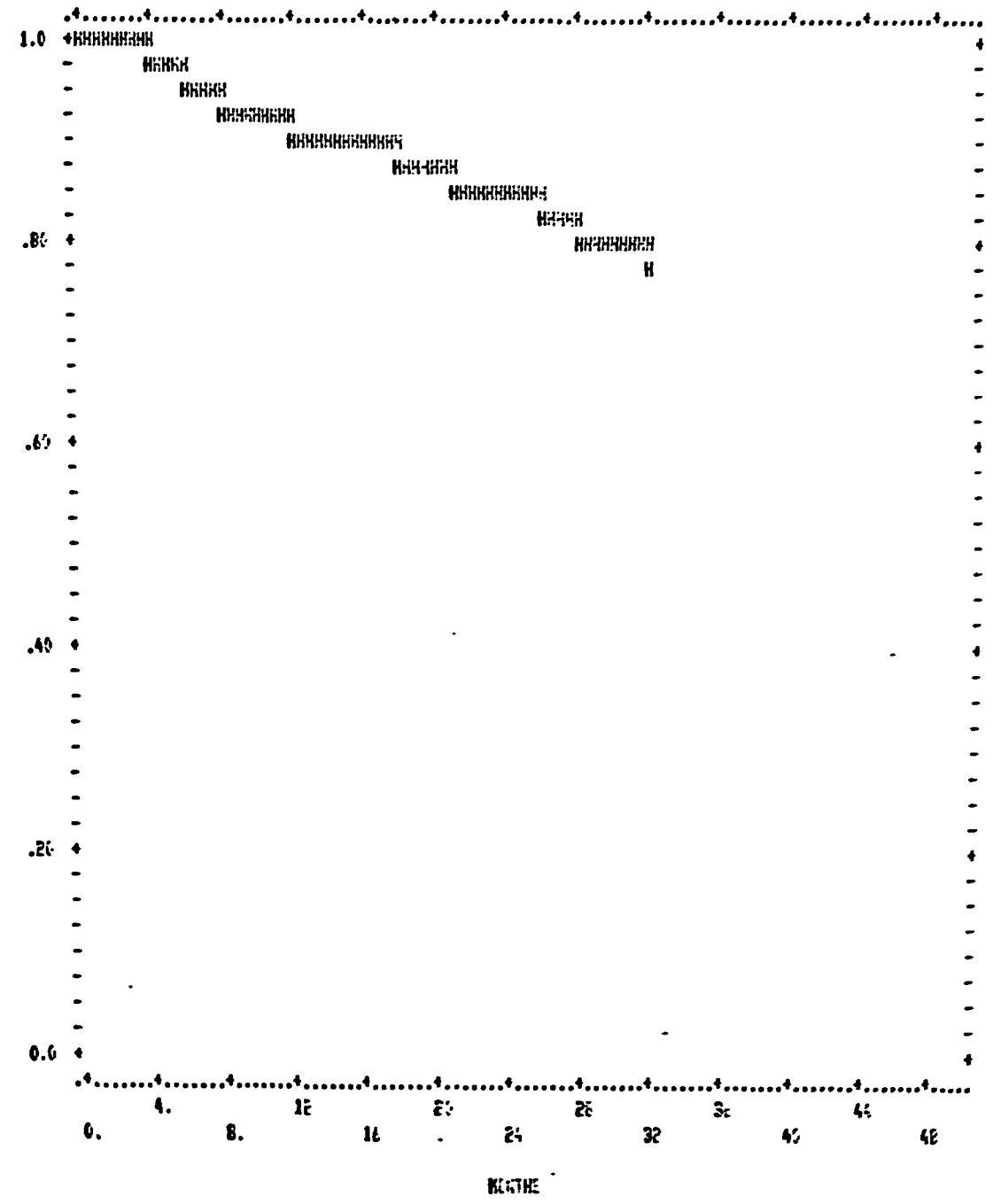
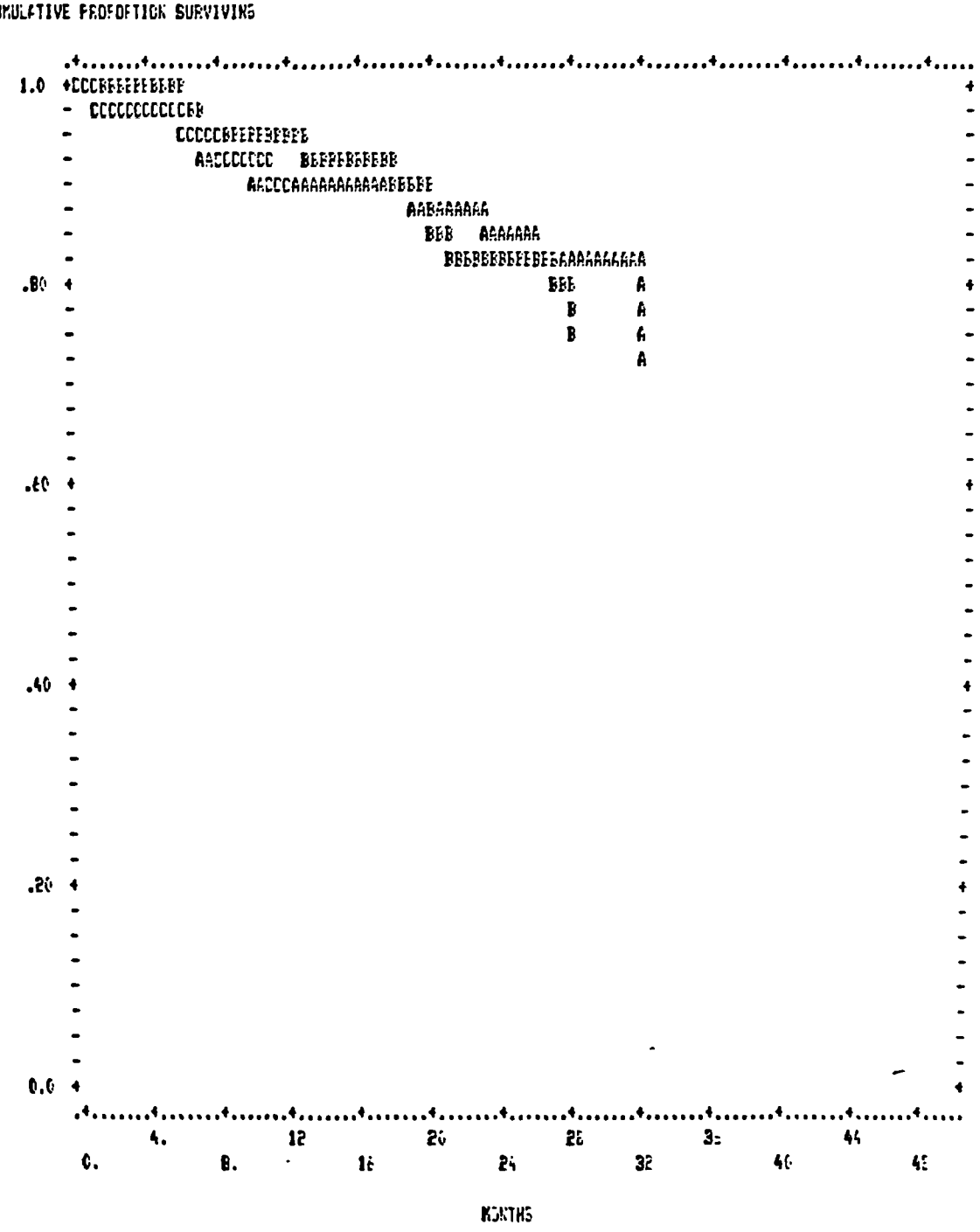


Fig 5.41

HELIOCOLOR MICROFILLED VENEERS OVERALL SURVIVAL BY TOOTH TYPE

A = Centrals B = Laterals C = Canines



Marginal staining occurred on 18 veneers (6.2%) during the follow up period. In all these instances, the staining had not been great enough to attract the attention of the patient and the stain itself was easily removed with Soflex discs. Frank facial staining occurred in 2 veneers during the follow up period and occurred in a patient who was a heavy smoker. This was easily removed by a rubber cup containing prophylaxis paste. The mean time for marginal staining to occur was 26.3 (5.7) months after veneer placement.

There was no significant difference in gingival health after placement of the labial veneers (Wilcoxon signed ranks test).

5.1.5. CONTROLLED ENAMEL REMOVAL BY THE HYDROCHLORIC ACID-PUMICE ABRASION TECHNIQUE

80 anterior teeth in 30 patients were treated by the technique between September 1987 and July, 1988. All of the patients are under 6 monthly review and none have failed to return.

19 patients exhibited 'fluorotic' like white and brown staining of the teeth affecting the whole dentition. On only 3 occasions was if possible to implicate a probable excessive intake of fluoride ion in the aetiology. 11 patients exhibited localised white and brown lesions of which the aetiology was obscure and not helped by a lack of previous records regarding trauma to the deciduous dentition.

No complaints were received of per or postoperative pain from the technique, nor of postoperative sensitivity to hot, cold or sweet liquids or foods. There was no reduction in tooth vitality to ethyl chloride and in no cases did stain recur.

Only 1 tooth failed to respond to treatment. This was a particularly discrete yellow lesion in the incisal third of an upper left central incisor. All the other teeth improved in appearance as a result of the technique, and patient satisfaction was universal. All brown stains were completely removed in every case and the reduction of white stains was of the order of 60 - 100%. Figs. 5.42a. and b., 5.44.a. and b., and 5.45.a. and b. demonstrate the aesthetic improvement in 4 patients.

5.1.6. REPRODUCIBILITY STUDIES

In order to obtain some measure of the level of reproducibility of clinical assessment between clinician 1 (A.W.G.W.) and clinican 2

Fig. 5.42a.

1 / 1 prior to

treatment.

Fig. 5.42b.

1 / 1 after 8 x 5 sec.

application of HCL-

pumice.

Fig. 5.43a.

3 2 1 / 1 2 3

prior to

treatment.

Fig. 5.43b.

3 2 1 / 1 2 3

after 10 x 5 sec.

applications of

HCL-pumice.

Fig. 5.42a.

1 / 1 prior to treatment.

Fig. 5.42b.

1 / 1 after 8 x 5 sec. application of HCL-pumice.

Fig. 5.43a.

3 2 1 / 1 2 3 prior to treatment.

Fig. 5.43b.

3 2 1 / 1 2 3 after 10 x 5 sec. applications of HCL-pumice.

Fig. 5.44a.

2 1 / 1 2 prior to treatment.

Fig. 5.44b.

2 1 / 1 2 after 8 x 5 sec. applications of HCL-pumice.

Fig. 5.45a.

1 / 1 prior to treatment.

Fig. 5.45b.

1 / 1 after 5 x 5 sec. applications of HCL-pumice.

Fig. 5.44a.

2 1 / 1 2 prior to treatment.

Fig. 5.44b.

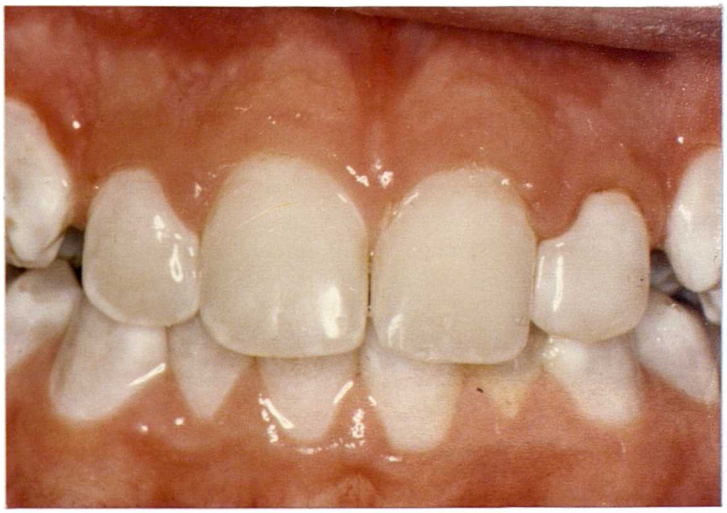
2 1 / 1 2 after 8 x 5 sec. applications of HCL-pumice.

Fig. 5.45a.

1 / 1 prior to treatment.

Fig. 5.45b.

1 / 1 after 5 x 5 sec. applications of HCL-pumice.



(R.R.W.) for both the glass polyalkenoate and minimal composite resin restoration trials, reproducibility studies were undertaken on 2 occasions. The first study was undertaken at the end of the first year of involvement of clinican 2 (R.R.W.) and included 32 pairs of restorations. The final study was during the last 6 months leading up to the termination date for both studies and included 23 pairs of restorations. On each occasion, the patient was first examined by clinican 2 (R.R.W.) and then by clinican 1 (A.W.G.W.). At no time were the scores of the first examiner available to the second examiner, and no scoring chart was studied at all until the termination of each reproducibility study.

Amalgam, glass polyalkenoate and composite resin restorations were scored according to the criteria in Appendix 1.

The results are shown in Tables 5.27., 5.28, 5.29., 5.30. Scores by clinican 1 (A.W.G.W.) are represented on the vertical axis and those by clinician 2 (R.R.W.) on the horizontal axis. Full concordance between the 2 clinicians are the scores entered in the diagonal (top left to bottom right). For anatomical form in amalgam and glass polyalkenoate restorations full concordance was achieved in 30 out of 32 restorations in the first study and 19 out of 23 restorations in the second study. For marginal integrity in amalgam and glass polyalkenoate restorations full concordance was achieved in 28 out of 32 restorations in the first study and 21 out of 23 restorations on the second study. For caries in amalgam and glass polyalkenoate restorations full concordance was achieved in all but 1 restoration over both studies. For minimal composite restorations full concordance was achieved in 26 out of 28 restorations in the

first study, and 18 out of 21 cases in the second study. The level of concordance between examiners in both reproducibility studies was high.

TABLE 5.27.

Reproducibility data for Anatomical Form (A.F.) for amalgam and glass polyalkenoate restorations.

Clinician 2 (R.R.W.)

Clinician 1 (A.W.G.W.)

A.F.	1	2	3	T
1	22	1		23
2	1	7		8
3			1	1
T	23	8	1	32

First Study

Clinician 2 (R.R.W.)

Clinician 1 (A.W.G.W.)

A.F.	1	2	3	T
1	18	1		19
2	3			3
3			1	1
T	21	1	1	23

Second Study

TABLE 5.28.
Reproducibility data for Marginal Integrity (M.I.) for amalgam and glass polyalkenoate restorations.

Clinician 2 (R.R.W.)

Clinician 1 (A.W.G.W.)

M.I.	1	2	3	4	5	T
1	15	3				18
2	1	11				12
3			1			1
4				1		1
5						0
T	16	14	1	1	0	32

First Study

Clinician 2 (R.R.W.)

Clinician 1 (A.W.G.W.)

M.I.	1	2	3	4	5	T
1	7	2				9
2		13				13
3						0
4						0
5					1	1
T	7	15	0	0	1	23

Second Study

TABLE 5.29.

Reproducibility data for caries (Car) with first and second studies combined, for the amalgam and glass polyalkenoate restorations.

Clinician 2 (R.R.W.)

Clinician 1 (A.W.G.W.) Car	0	1	T
0	52		52
1	1	2	3
T	53	2	55

First and Second Studies

TABLE 5.30.

Reproducibility data for Minimal Composite Restorations (M.C.R.).

Clinician 2 (R.R.W.)

Clinician 1 (A.W.G.W.)

M.C.R.	1	2	3	4	T
1	18				18
2	2	7			9
3					0
4				1	1
T	20	7	0	1	28

First Study

Clinician 2 (R.R.W.)

Clinician 1 (A.W.G.W.)

M.C.R.	1	2	3	4	T
1	5	1			6
2	2	8			10
3					0
4				5	5
T	7	9	0	5	21

Second Study

5.2. IN VITRO STUDIES (GLASS POLYALKENOATE AND CERMET CEMENTS)

5.2.1. EROSION RESISTANCE

(a) Erosion as a function of cement age and type. Comparative results for Ketac Fil, Ketac Bond, Chelon, Coltene 018804 B and Ketac Silver are given in Table 5.31., and these are further presented in Fig 5.46. as a function of depth loss in microns against time using a logarithmic scale. There were significant differences in performance: between materials ($p < 0.01$ ANOVA) between specimen ages ($p < 0.01$) ANOVA) and between materials with age ($p < 0.01$ ANOVA). Fig. 5.46. shows that Ketac Fil and Chelon behaved similarly, while the Ketac Bond and Ketac Silver did likewise. Coltene on the other hand, behaved independently of these other materials. A Tukey comparison of means was performed to localise significant differences in performance between the cements (Table 5.31.). After 15 minutes least cement loss occurred with Ketac Silver $\overset{ns}{<}$ Ketac Bond $\overset{p<0.01}{<}$ Coltene $\overset{p<0.01}{<}$ Ketac Fil $\overset{p<0.01}{<}$ Chelon. After 60 minutes least cement was lost with Ketac Bond $\overset{ns}{<}$ Ketac Silver $\overset{p<0.01}{<}$ Coltene $\overset{p<0.01}{<}$ Chelon $\overset{ns}{<}$ Ketac Fil. After 24 hours least cement was lost with Ketac Silver $\overset{ns}{<}$ Ketac Bond $\overset{p<0.01}{<}$ Chelon $\overset{ns}{<}$ Ketac Fil $\overset{p<0.01}{<}$ Coltene. After 7 days least cement was lost with Ketac Silver $\overset{ns}{<}$ Ketac Bond $\overset{p<0.01}{<}$ Ketac Fil $\overset{ns}{<}$ Chelon $\overset{p<0.01}{<}$ Coltene. After 28 days least cement was lost with Ketac Silver $\overset{ns}{<}$ Ketac Bond $\overset{p<0.01}{<}$ Chelon $\overset{p<0.01}{<}$ Ketac Fil $\overset{p<0.01}{<}$ Coltene. Ketac Silver and Ketac Bond underwent significantly less loss of cement compared to the other materials.

All cements apart from Coltene lost progressively less cement with increasing time of storage prior to erosion cycling ($p < 0.01$

TABLE 5.31.

Variation in the susceptibility to erosion for the glass polyalkenoate cements Ketac Fil, Ketac Bond, Chelon and Coltene 018804 B, and the glass cermet cement Ketac Silver, with respect to cement age and type. Mean depth loss is recorded in microns. Bracketed figures are one standard deviation.

CEMENT TYPE	SPECIMEN AGE				
	15 mins.	60 mins.	24 hours	7 days	28 days
K. Fil	128.75 (12.70)	95.54 (14.01)	56.04 (4.8)	39.92 (6.52)	46.68 (7.08)
K. Bond	39.67 (6.47)	29.79 (6.24)	23.29 (2.71)	24.03 (2.01)	20.20 (4.0)
Chelon	145.11 (10.97)	94.63 (2.68)	52.03 (6.6)	40.14 (9.34)	29.71 (7.24)
Coltene	71.08 (4.62)	73.55 (4.45)	78.22 (5.34)	71.35 (8.61)	76.73 (8.0)
K. Silver	38.92 (5.67)	32.97 (2.64)	17.86 (3.6)	17.15 (1.77)	12.17 (1.63)

Tukey Test significance: ns if means differ by < 8.55

$p < 0.05$ if means differ by > 8.55

$p < 0.01$ if means differ by > 9.68

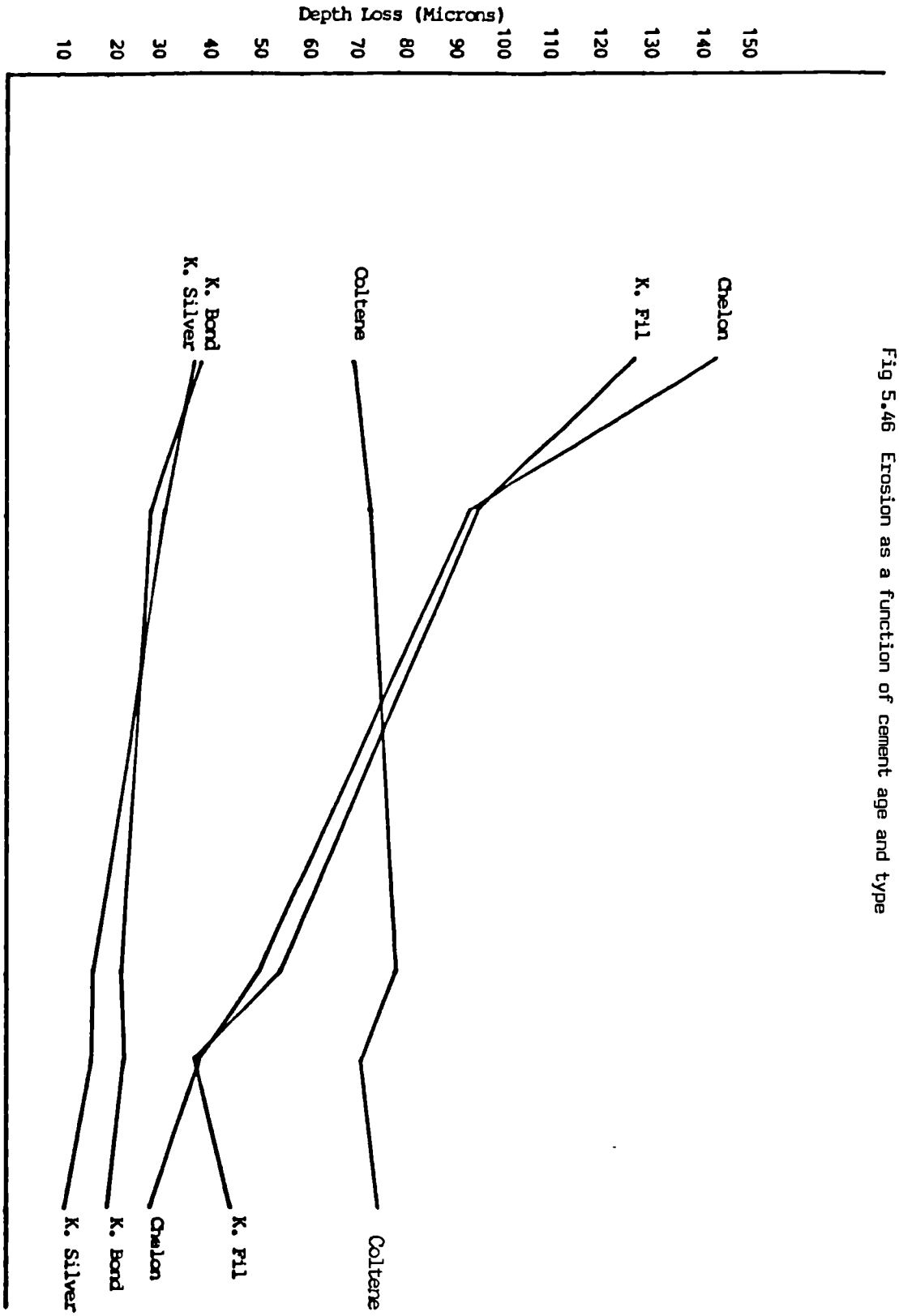


Fig 5.46 Erosion as a function of cement age and type

Tukey 15 min v. 28 day results). There was no significant difference in the amount of cement lost for Coltene after 15 minutes, 60 minutes, 24 hours, 7 days, and 28 days (Tukey).

There was no significant erosion under the halves of specimens that were varnished.

(b) Erosion as a function of varying powder:liquid ratios of cement.

Comparative results for the p:l ratios of Chelon of 8.38:1, 7.54:1, 6.7:1, 5.86:1 and 5.02:1 are given in Table 5.32., and represented as a bar chart in Fig. 5.7. There were significant differences in performance: between different p:l ratios ($p < 0.01$ ANOVA), between specimen ages ($p < 0.01$ ANOVA) and between some p:l ratios with age ($p < 0.01$ ANOVA). A Tukey comparison of means was performed to localise significant differences in performance between the p:l ratios (Table 5.32.). After 15 minutes significantly less cement was lost with increased p:l ratio 8.38:1 and with the decreased p:l ratio 5.02:1 compared to the recommended ratio of 6.7:1 ($p < 0.01$ Tukey). Most cement was lost by the decreased p:l ratio 5.86:1 compared to 6.7:1 ($p < 0.01$ Tukey), however, after 60 minutes, this latter ratio lost the least amount of cement. By 28 days, the least amount of cement loss was occurring with the higher p:l ratios: 8.38:1 $\overset{p<0.01}{<}$, 7.54:1, $\overset{ns}{<}$ 6.7:1, $\overset{ns}{<}$ 5.86:1, $\overset{p<0.01}{<}$ 5.02:1.

For all p:l ratios the greatest amount of cement loss was seen in specimens that were tested after 15 minutes and the least in those tested after 28 days ($p < 0.01$ Tukey 15 minutes v. 28 days).

TABLE 5.32.

Variation in the susceptibility to erosion for the differing powder:liquid ratios of the glass polyalkenoate cement Chelon with respect to cement age. Depth loss recorded in microns. Bracketed figures are one standard deviation.

P:L RATIO	SPECIMEN AGE				
	15 mins.	60 mins.	24 hours	7 days	28 days
8.38:1	131.87 (5.53)	85.01 (4.5)	50.74 (7.41)	9.34 (6.35)	5.19 (4.45)
7.54:1	146.33 (7.27)	91.75 (8.05)	23.88 (8.29)	32.04 (8.35)	25.19 (11.7)
6.7:1	145.11 (10.97)	94.63 (2.68)	52.03 (6.6)	40.14 (9.34)	29.71 (7.24)
5.86:1	175.52 (11.86)	84.15 (4.9)	89.65 (6.0)	52.81 (12.01)	35.09 (8.44)
5.02:1	138.22 (12.18)	106.03 (9.84)	75.65 (11.43)	49.43 (6.91)	63.13 (10.98)

Tukey Test Significance: ns if means differ by < 8.11

$p < 0.05$ if means differ by ≥ 8.11

$p < 0.01$ if means differ by ≥ 9.18

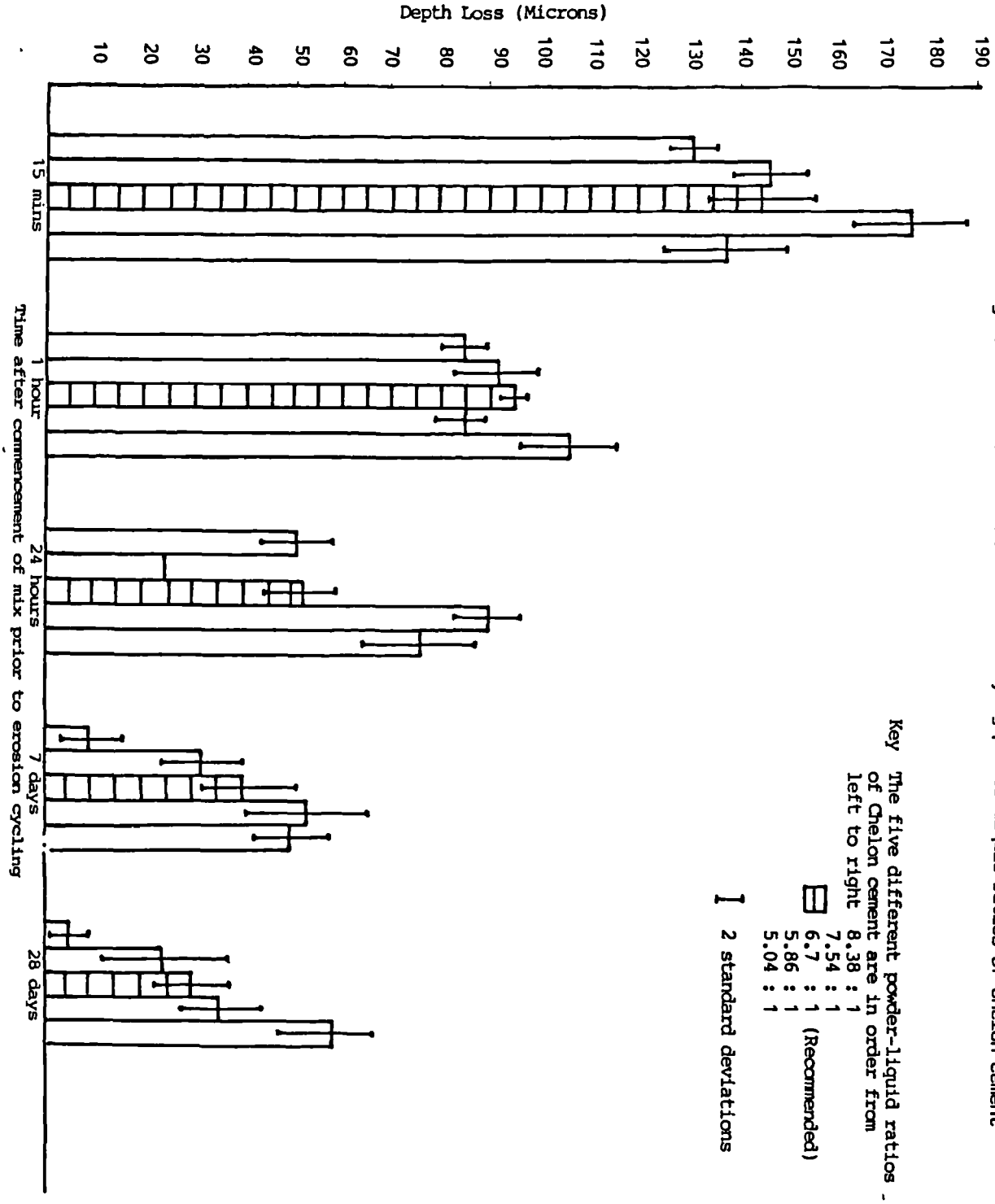


Fig 5.47 Erosion as a function of varying powder:liquid ratios of chelon cement

Comparative results for the p:l ratios of Ketac Bond 4.26:1, 3.83:1, 3.4:1, 2.97:1 and 2.55:1 are given in Table 5.33., and represented as a bar chart in Fig. 5.48. There were significant differences in performance: between different p:l ratios ($p < 0.01$ ANOVA) between specimen ages ($p < 0.01$ ANOVA) and some p:l ratios behaved more differently with age than others ($p < 0.01$ ANOVA). A Tukey comparison of means was performed to localise significant differences in performance between the p:l ratios (Table 5.33.). After 15 minutes, significantly more cement was lost with the higher p:l ratios 3.83:1 and 4.26:1 compared to the recommended 3.4:1 ($p < 0.01$ Tukey). There was no significant difference in loss between the recommended and the lower p:l ratios of 2.97:1 and 2.55:1. By 28 days, there was no significant difference in depth loss between either 4.26:1, 3.83:1, or 2.55:1 compared with the recommended 3.4:1. However, 2.97:1 had lost significantly more cement ($p < 0.01$ Tukey).

5.2.2. DIAMETRAL COMPRESSIVE TENSILE STRESS

(a) The variation in mechanical properties with material composition.

It is usual to report the results of mechanical property testing as the number of tests carried out, the mean strength and standard deviation. A normal distribution is assumed. Low values of strength may be explained by assuming specimen faults and porosities, abnormally high values can only be accounted for by assuming that the true or ideal strength of the material is being approached (McCabe and Carrick 1986). In many instances, it would be helpful to know the probability of failure at a particular stress level. A distribution capable of dealing with this has been described (Weibull 1951), and

TABLE 5.33.

Variation in the susceptibility to erosion for the differing powder:liquid ratios of the glass polyalkenoate cement Ketac Bond with respect to cement age. Depth loss recorded in microns. Bracketed figures are one standard deviation.

P:L RATIO	SPECIMEN AGE				
	15 mins.	60 mins.	24 hours	7 days	28 days
4.26:1	48.27 (6.13)	48.12 (7.33)	33.94 (3.55)	30.69 (3.08)	15.96 (5.2)
3.83:1	53.10 (6.08)	33.39 (3.49)	36.91 (8.2)	15.23 (2.85)	17.93 (5.12)
3.4:1	39.67 (6.47)	29.79 (6.24)	23.29 (2.71)	24.03 (2.01)	20.20 (4.0)
2.97:1	36.66 (7.66)	27.89 (5.51)	19.41 (4.63)	28.09 (3.07)	27.21 (1.75)
2.55:1	40.03 (6.86)	24.39 (2.13)	20.99 (2.72)	39.64 (5.16)	20.83 (5.72)

Tukey Test Significance: ns if means differ by < 4.84

$p < 0.05$ if means differ by ≥ 4.84

$p < 0.01$ if means differ by ≥ 5.48

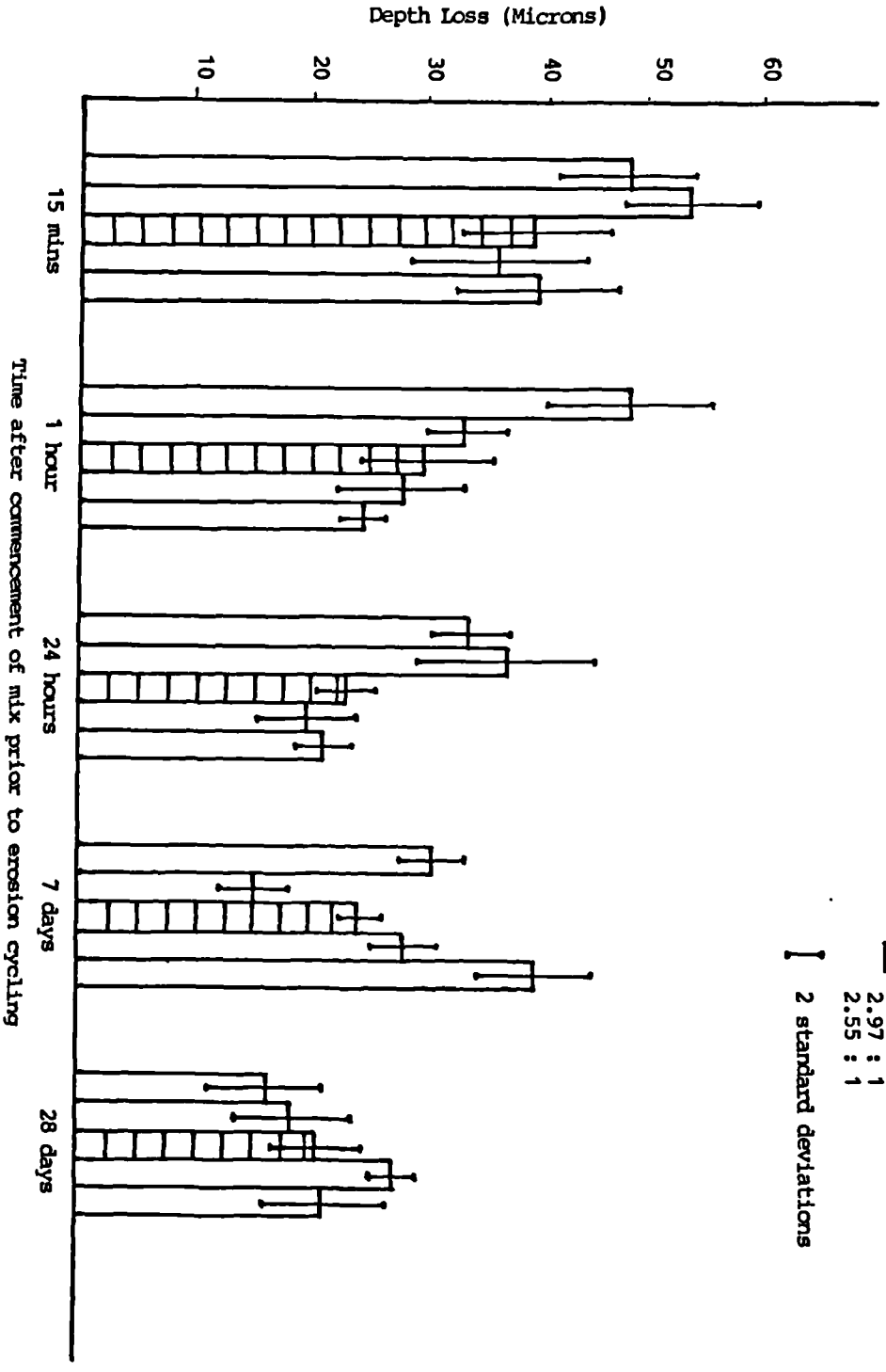


Fig 5.48 Erosion as a function of varying powder:liquid ratios of Ketac Bond

applied to dental materials (McCabe and Carrick 1986). The Weibull equation relating the probability of failure (Pf) to at or below a stress (σ) is:

$$Pf = 1 - \exp\left\{ - \left(\frac{\sigma - \sigma_u}{\sigma_o}\right)^m \right\}$$

Where σ_u σ_o and m are constants. The constant σ_u is usually assumed to be zero and is the lowest level of stress at which Pf approaches zero. The constant σ_o is a normalising parameter and m is termed the Weibull Modulus. A low value of m. indicates a wide distribution of fracture stress values with a long tail at low values of stress. A high m value is indicative of a close grouping of fracture stress values.

Rank values (n) were assigned to the specimens according to their values of Compressive Strength. The weakest specimen was rank 1 and the strongest rank N (where N is the total number of specimens). The probability of failure (Pf) at each level of stress was then calculated:

$$Pf = \frac{n}{N + 1}$$

Fracture probability versus Stress (MPa) was plotted for each group of specimens. The best Weibull plot was calculated from a least-squares fit of the data to ln ln (1/1-Pf) against lnσ. The Weibull Modulus, Standard Error of Modulus, Limiting Stress and the Mean Strength were also calculated using the same computer program.

Comparative results for Ketac Bond, Ketac Fil 8 and 15 minute specimens, Coltene 018804 B and Ketac Silver, are shown in Table 5.34.

TABLE 5.34.

Quantitative analysis of diametral compressive tensile stress results for the glass polyalkenoate cements Ketac Bond, Ketac Fil and Coltene 018804 B and the glass cermet cement Ketac Silver. 30 specimens test for each cement.

MATERIAL	MEAN STRENGTH(MPa)	STANDARD DEVIATION	CORRELATION COEFFICIENT	WEIBULL MODULUS	S. ERROR OF MODULUS
K. Bond	4.48	0.96	0.94	5.14	0.24
K. Fil 8	10.60	2.15	0.98	5.09	0.14
K. Fil 15	9.67	2.02	0.92	5.20	0.28
Coltene	6.10	2.48	0.90	2.80	0.17
K. Silver	10.04	2.27	0.96	4.76	0.17

Tukey Test Significance: ns if means differ by < 1.48

$p < 0.05$ if means differ by > 1.48

$p < 0.01$ if means differ by > 1.79

There was a significant difference in diametral compressive tensile strength between the variables ($p < 0.001$ ANOVA) with a ranking order in decreasing order of magnitude of Ketac Fil 8 > Ketac Silver > Ketac Fil 15 > Coltene > Ketac Bond.

A Tukey comparison of means to localise significant differences (Table 5.35.) showed that Ketac Bond and Coltene performed significantly poorer than all the other variables ($p < 0.01$ Tukey). Statistical comparison of variables for Weibull Modulus is shown in Table 5.36. with Ketac Bond, Ketac Fil 8, Ketac Fil 15, and Ketac Silver all being significantly greater than Coltene. A high Weibull Modulus value indicates a greater dependability or reliability than a low value.

TABLE 5.35.

Tukey Test paired comparisons of variable means. Significance at 1% level where stated.

VARIABLE CODE	K. BOND	K. FIL 8	K. FIL 15	COLTENE	K. SILVER
K. Bond		$p < 0.01$	$p < 0.01$	ns	$p < 0.01$
K. Fil 8	$p < 0.01$		ns	$p < 0.01$	ns
K. Fil 15	$p < 0.01$	ns		$p < 0.01$	ns
Coltene	ns	$p < 0.01$	$p < 0.01$		$p < 0.01$
K. Silver	$p < 0.01$	ns	ns	$p < 0.01$	

TABLE 5.36.

Statistical analysis of compressive tensile stress testing results. Weibull Modulus significance at 5% level calculated from +/- 2 x S. Error of Modulus.

COMPARING	WEIBULL MODULUS
K. Bond v. K. Fil 8	ns
K. Bond v. K. Fil 15	ns
K. Bond v. Coltene	$p < 0.05$ Favours K. Bond
K. Bond v. K. Silver	ns
K. Fil 8 v. K. Fil 15	ns
K. Fil 8 v. Coltene	$p < 0.05$ Favours K. Fil 8
K. Fil 8 v. K. Silver	ns
K. Fil 15 v. Coltene	$p < 0.05$ Favours K. Fil 15
K. Fil v. K. Silver	ns
Coltene v. K. Silver	$p < 0.05$ Favours K. Silver

Graphical representation of results (Fig. 5.49.) generated by the Weibull analysis shows the plot of cumulative probability failure versus stress for the different glass polyalkenoate and cermet cements. Each of the lines is constructed from 30 test specimens and is typical of results generated by the Weibull analysis. The test specimen points and final curve for Coltene 018804 B are shown in Fig. 5.50. In Fig. 5.49. there is a significant probability of failure at low stress values for Coltene 018804 B, Ketac Bond performs better than the Coltene cement, Ketac Fil 15 and Ketac Silver better still, and Ketac Fil 8 best of all. Although graphic representation helps us to predict cumulative failure probability ranking between cements, a more accurate impression is gained by comparing probability of failure calculations obtained from the Weibull equation (Table 5.37.). This shows that at a stress value of 1 MPa Coltene 018804 B has a 1,000 times greater failure probability than Ketac Fil 8, a 900 times greater failure probability than Ketac Fil 15, a 400 times greater failure probability than Ketac Silver and a 16 times greater failure probability than Ketac Bond. Ketac Bond has 60 - 70 times greater failure probability than the Ketac Fil specimens and a 27 times greater failure probability than Ketac Silver.

Overall, in terms of mean strength, Weibull Modulus and probability of failure calculations, Ketac Fil 8, Ketac Fil 15 and Ketac Silver performed better than Ketac Bond and Coltene 018804 B.

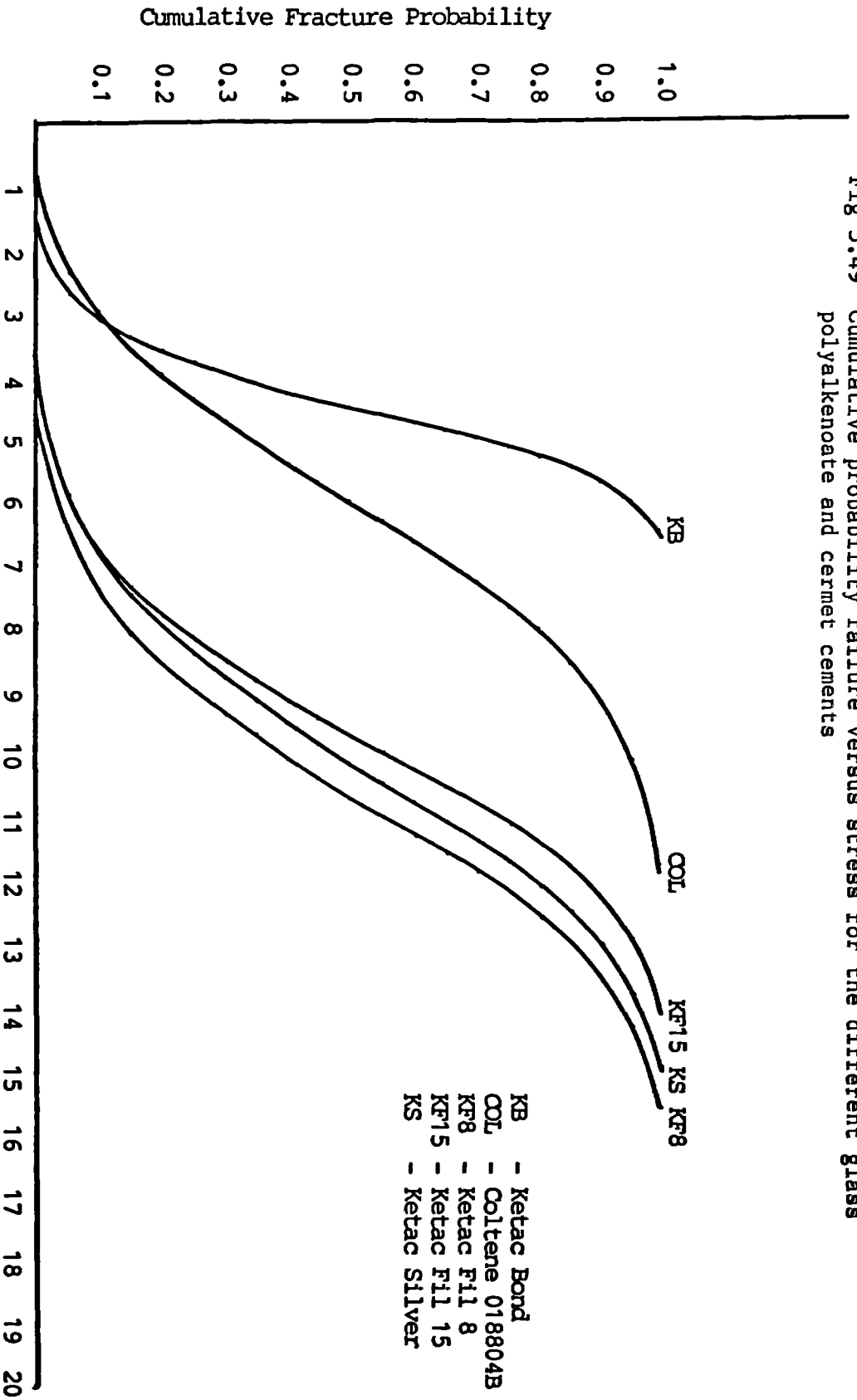


Fig 5.49 Cumulative probability failure versus stress for the different glass polyalkenoate and cermet cements

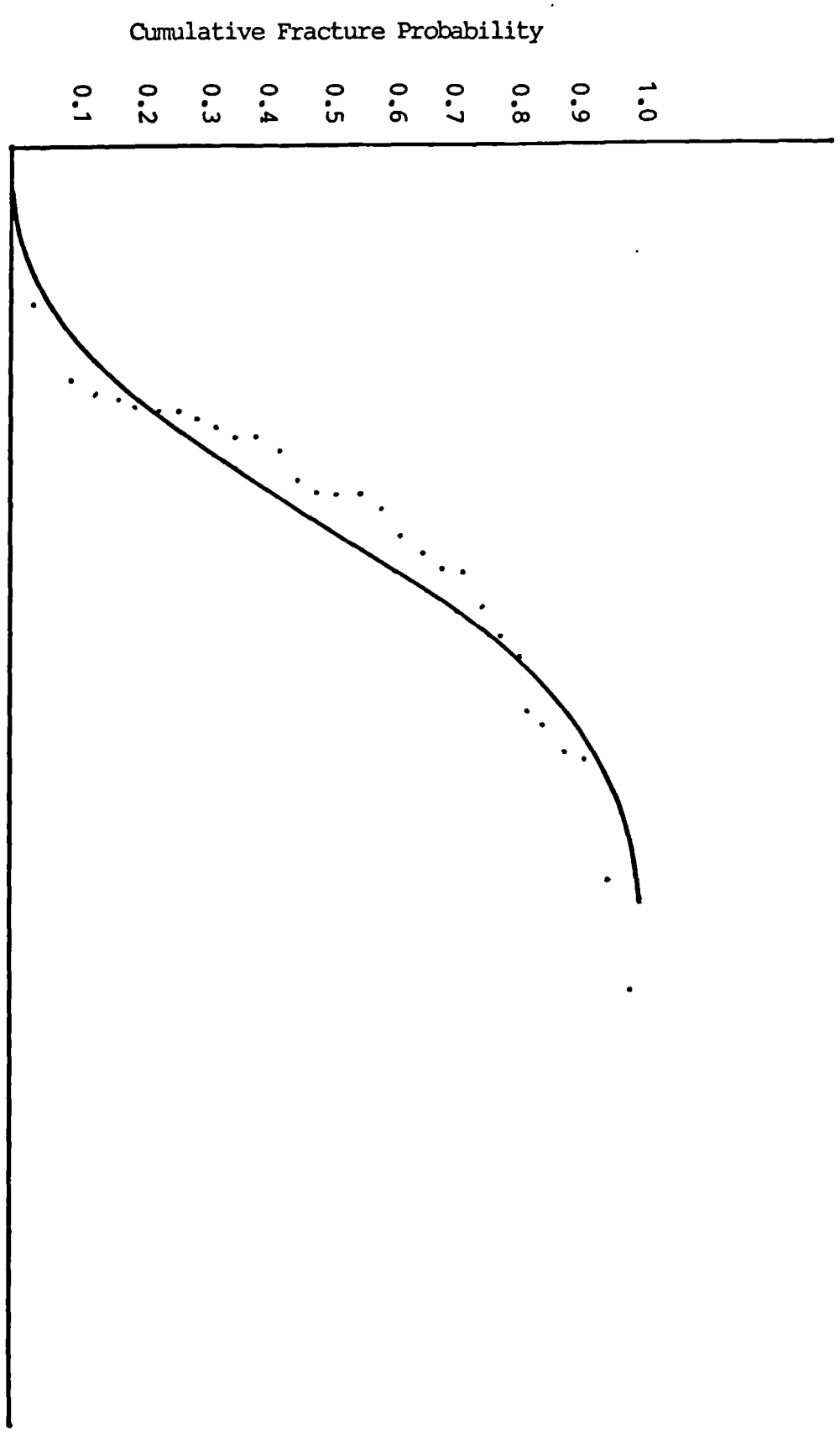


Fig 5.50 Cumulative probability curve derived from 30 test specimen results

TABLE 5.37.

Calculated probability of failure at stated stresses (MPa) for the glass polyalkenoate cements Ketac Bond, Ketac Fil 8 and 15, Coltene 018804 B and the glass cermet Ketac Silver.

CEMENT	PROBABILITY OF FAILURE x 10^{-4}		
	1MPa	2MPa	3MPa
Ketac Bond	2.96	103	803
Ketac Fil 8	0.04	1.34	10.57
Ketac Fil 15	0.05	1.79	14.79
Coltene 018804 B	46	312	939
Ketac Silver	0.11	3	20.9

(b) The variation in mechanical properties with variation in the powder:liquid ratio of Ketac Bond specimens.

Comparative results for the p:l ratios of Ketac Bond are shown in Table 5.38. There was a significant difference in diametral compressive tensile strength between the variables ($p < 0.01$ ANOVA) with a ranking order in decreasing order of magnitude of 3.4:1 (recommended) > 2.97:1 > 3.83:1 > 2.55:1 > 4.26:1. A Tukey comparison of means to localise significant differences (Table 5.38.) found no significant difference in compressive tensile stresses between the recommended ratio of 3.4:1 and those p:l ratios closest to it namely 2.97:1 and 3.83:1. However, the extreme p:l ratios of 2.55:1 and 4.26:1 had a significantly lower compressive tensile stress ($p < 0.05$ and $p < 0.01$ Tukey) when compared to the recommended 3.4:1.

Statistical comparison of variables against the recommended ratio (3.4:1) for Weibull Modulus (Table 5.39.) showed that the recommended ratio was significantly more dependable in every case ($p < 0.05$).

Graphical representation of results (Fig. 5.51.) generated by the Weibull analysis shows the plot of cumulative probability of failure versus stress for the different powder:liquid ratios of Ketac Bond glass polyalkenoate cement. This suggests there is an increased probability of failure at low stress values for the powder:liquid ratios 4.26:1, 3.83:1, 2.97:1 and 2.55:1 compared to 3.4:1, the manufacturers recommended ratio. A more accurate impression can be gained by comparing probability of failure calculations obtained from the Weibull equation (Table 5.40.) This demonstrates that at a stress value of 1MPa the 'other ratios' have between a 40 and 60 times greater

TABLE 5.38.

Quantitative analysis of Diametral Compressive Tensile Stress results for powder:liquid ratios by weight of 4.26:1, 3.83:1, 3.4:1 (recommended), 2.97:1 and 2.55:1 for Ketac Bond glass polyalkenoate cement.

KETAC BOND P:L RATIO	MEAN STRENGTH (MPa)	STANDARD DEVIATION	CORRELATION COEFFICIENT	WEIBULL MODULUS	S. ERROR OF MODULUS
4.26:1	3.26	1.01	0.99	3.35	0.07
3.83:1	3.75	1.36	0.93	2.88	0.15
3.4:1	4.48	0.96	0.94	5.14	0.24
2.97:1	4.01	1.42	0.91	2.89	0.17
2.55:1	3.48	1.21	0.98	2.95	0.08

Tukey Test Significance: ns if means differ by < 0.88

$p < 0.05$ if means differ by > 0.88

$p < 0.01$ if means differ by > 1.06

TABLE 5.39.

Statistical analysis of Compressive Tensile Stress Testing values for Ketac Bond between the recommended p:l ratio (3.4:1) and other p:l ratios Weibull Modulus Significance was calculated from +/- 2 x S. Error of Modulus.

COMPARING	MEAN STRENGTH
3.4:1 v. 4.26:1	$p < 0.05$ Favours 3.4:1
3.4:1 v. 3.83:1	$p < 0.05$ Favours 3.4:1
3.4:1 v. 2.97:1	$p < 0.05$ Favours 3.4:1
3.4:1 v. 2.55:1	$p < 0.05$ Favours 3.4:1

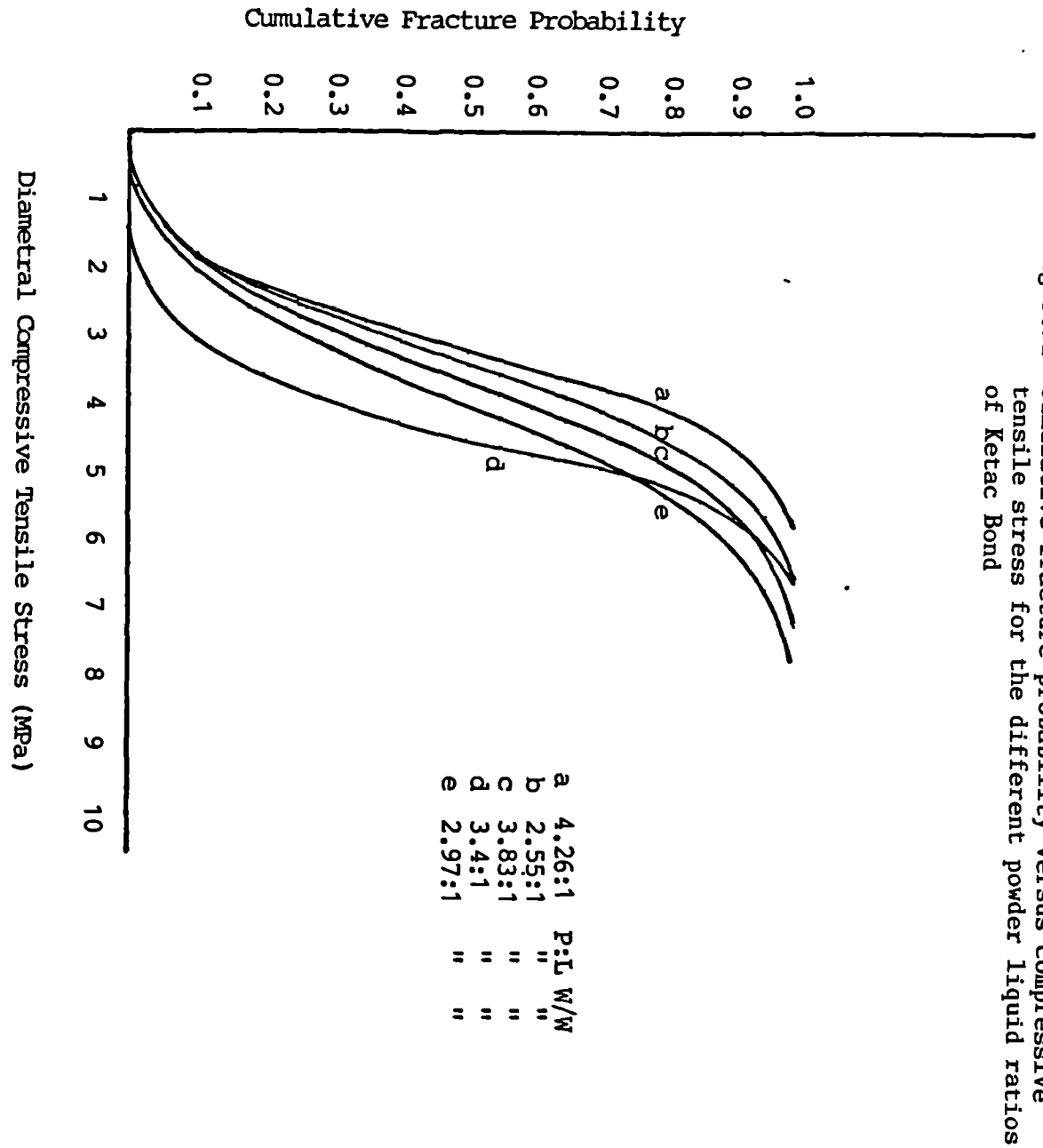


Fig 5.51 Cumulative fracture probability versus compressive tensile stress for the different powder liquid ratios of Ketac Bond

TABLE 5.40.

Calculated probability of failure calculations at stated stresses (MPa) for the varying powder:liquid ratios of Ketac Bond glass polyalkenoate cement.

KETAC BOND	PROBABILITY OF FAILURE x 10^{-3}		
	1MPa	2MPa	3MPa
4.26:1	13	126	409
3.83:1	16	109	312
3.4:1	0.3	10	80
2.97:1	12	85	250
2.55:1	18	129	367

failure probability than the recommended ratio, and at the higher stress values although the probability of failure for the recommended ratio rises, it still performs advantageously compared to the 'other ratios'.

Overall, in terms of mean strength, Weibull Modulus and probability of failure calculations, the powder:liquid ratio recommended by the manufacturer (3.4:1) performs better than the other powder:liquid ratios.

5.2.3. BIOMECHANICAL PROPERTIES

5.2.3.1. THERMAL ANALYSIS (REACTION KINETICS)

(a) The differential thermal analysis (D.T.A.) parameters for the 2 cements Ketac Bond and Coltene 018804 B mixed at recommended powder:liquid ratios are given in Table 5.41. (The third parameter is the area under the exothermic curve per mg. weight of specimen. All the parameters are described in Section 5.2.3.1.) The results of statistical analysis using Students' t Test to compare each cement at each measured parameter of the exothermic reaction are shown in Table 5.42. At both 23°C and 37°C the largest peak exotherm °C and the largest rise °C per mg. weight of cement all favour the newer cement Coltene 018804 B. That is the exothermic reaction in this cement is significantly reduced compared to Ketac Bond. On the other hand at 23°C and 37°C Ketac Bond achieves a quicker time to peak exotherm (setting time) and also a shorter time to cool to 5% of the maximum.

Intra-cement analysis to ascertain the effect of temperature on the 2 cements at each parameter (Table 5.43.) showed no significant difference for Ketac Bond between 23°C and 37°C for the parameters of the exothermic reaction. However, a significant difference at the 3 parameters [Peak Exotherm °C: Rise °C per mg. weight: Area $(cm.)^2$/wt.] was found for Coltene with lower values being obtained at 23°C.

For both Ketac Bond and Coltene a quicker setting time, and time taken to cool to 5% of the exotherm was noted for the 37°C experiments.

TABLE 5.41.

Variations in the magnitude and duration of the exotherm associated with setting for Ketac Bond and Coltene 018804 B polyalkenoate cements tested at 23°C and 37°C at recommended powder:liquid ratios. Bracketed figures are 1 standard deviation.

	MATERIAL	P:L RATIO	PEAK EXOTHERM °C	RISE °C PER mg. WT.	AREA (cm^2) / WT. (mg.)	TIME TO T.MAX (MINS.)	TIME TO 5% T.MAX (MINS)
23°	K. Bond	3.4:1	5.58 (1.18)	0.07 (0.01)	0.31 (0.04)	2.97 (0.15)	8.05 (0.31)
	Coltene	6.9:1	0.83 (0.29)	0.01 (0.0)	0.26 (0.09)	7.33 (1.15)	25.63 (1.07)
37°	K. Bond	3.4:1	8.0 (1.32)	0.09 (0.01)	0.28 (0.01)	2.45 (0.0)	6.32 (0.29)
	Coltene	6.9:1	2.66 (0.58)	0.03 (0.01)	0.45 (0.1)	4.53 (0.32)	15.83 (1.15)

Fig. 5.42.

Statistical analysis (Students' T Test) between Katac Bond and Coltene 018804B at either 23°C or 37°C for the measured parameters of the exothermic reaction.

T. TEST	MATERIAL	PEAK EXOTHERM °C	RISE °C per mg. wt.	$\frac{\text{AREA (cm)}^2}{\text{Wt. (mg.)}}$	TIME TO T. MAX. (Mins)	TIME TO 5% T.MAX (Mins.)
23°C	K. Bond v. Coltene	$p < 0.01$ Favours Coltene	$p < 0.001$ Favours Coltene	ns	$p < 0.01$ Favours K. Bond	$p < 0.001$ Favours K. Bond
37°C	K. Bond v. Coltene	$p < 0.01$ Favours Coltene	$p < 0.01$ Favours Coltene	$p < 0.05$ Favours K. Bond	$p < 0.001$ Favours K. Bond	$p < 0.001$ Favours K. Bond

TABLE 5.43.

Statistical analysis (Students T Test) between Ketac Bond and Coltene 018804 B at either 23°C 23 °C or 37°C for the measured parameters of the exothermic reaction.

T. TEST	MATERIAL	PEAK EXOTHERM °C	RISE °C PER mg. WT.	AREA ($cm.^2$) / WT. (mg.)	TIME TO T.MAX (MINS.)	TIME TO 5% T.MAX (MINS)
23°	K. Bond Coltene	$p < 0.01$ Favours Col	$p < 0.001$ Favours Col	ns	$p < 0.01$ Favours KB	$p < 0.001$ Favours KB
37°	K. Bond Coltene	$p < 0.01$ Favours Col	$p < 0.01$ Favours Col	$p < 0.05$ Favours KB	$p < 0.001$ Favours KB	$p < 0.001$ Favours KB

(b) The D.T.A. parameters for the varying powder:liquid ratios of Ketac Bond glass polyalkenoate cement tested at 23°C and 37°C are shown in Table 5.44.

At 23°C the effect of altering the powder:liquid ratio on the Peak exotherm °C, the Rise °C per mg. weight, and the Area ($cm.^2$) under the trace per wt. (mg.) was not significant (ANOVA). However, the effect on the time to T.Max. and the time to 5% of T.Max were significant ($p < 0.01$ ANOVA) with those specimens containing more powder taking longer (Table 5.45.).

At 37°C the effect of altering the powder:liquid ratio was not significant with regard to Rise °C per mg. wt. and Time to T.Max, but was significant with regard to Peak exotherm °C ($p < 0.01$ ANOVA), Area ($cm.^2$) per mg. wt. ($p < 0.01$ ANOVA) and Time to 5% T.MAx ($p < 0.05$ ANOVA) with those specimens containing more powder achieving higher exotherms and taking longer to cool to 5% of T.Max (Table 5.45.).

Two way ANOVA comparing the different powder:liquid ratios at 23°C and 37°C for each D.T.A. paramter has shown significant differences between the two temperatures for all powder:liquid ratios ($p < 0.01$ ANOVA), and significant differences between each powder:liquid ratio at both temperatures ($p < 0.01$ ANOVA) but no interaction between temperature and powder:liquid ratio, that is to say that there is no more difference between the values for each powder:liquid ratio at 23°C than there is at 37°C.

TABLE 5.44.

Variations in the magnitude and duration of the exotherm associated with setting for Ketac Bond polyalkenoate cement tested at 23°C and 37°C at the powder:liquid ratios shown.

Bracketed figures are 1 standard deviation.

TEMP	MATERIAL	P:L RATIOS	PEAK EXOTHERM °C	RISE °C PER mg. WT.	AREA ($cm.^2$) / WT. (mg.)	TIME TO T. MAX. (MINS.)	TIME TO 5% T. MAX (MINS.)
23°C	K. Bond	2.55:1	5.23 (0.32)	0.07 (0.004)	0.25 (0.02)	2.82 (0.03)	7.15 (0.45)
		2.98:1	5.58 (1.38)	0.07 (0.01)	0.25 (0.02)	2.67 (0.06)	6.78 (0.26)
		3.4:1	5.58 (1.18)	0.07 (0.01)	0.31 (0.04)	2.97 (0.15)	8.05 (0.31)
		3.83:1	6.66 (1.53)	0.06 (0.01)	0.29 (0.06)	3.12 (0.13)	8.72 (0.37)
		4.26:1	6.5 (0.5)	0.07 (0.01)	0.33 (0.03)	3.15 (0.05)	9.3 (0.05)

contin/d .....

37°C	K. Bond	2.55:1	6.0 (1.15)	0.08 (0.01)	0.22 (0.03)	2.57 (0.08)	6.62 (0.03)
		2.98:1	5.9 (1.9)	0.07 (0.02)	0.23 (0.01)	2.73 (0.28)	6.52 (0.42)
		3.4:1	8.0 (1.32)	0.09 (0.01)	0.28 (0.01)	2.45 (0)	6.32 (0.29)
		3.83:1	9.83 (1.53)	0.10 (0.02)	0.33 (0.01)	2.45 (0.13)	7.27 (0.32)
		4.26:1	10.17 (1.26)	0.11 (0.01)	0.32 (0.01)	2.57 (0.08)	6.55 (0.09)

TABLE 5.45.

Summary of statistical analysis (one way analysis of variance) between the varying powder:liquid ratios at each D.T.A. parameter at (1) 23°C and (2) 37°C.

ONE WAY ANOVA	PEAK EXOTHERM °C	RISE °C WT. (mg.)	$\frac{\text{AREA (cm.}^2\text{)}}{\text{WT. (mg.)}}$	TIME TO T. MAX (MINS.)	TIME TO 5% T. MAX (MINS.)
23°C	ns	ns	ns	$p < 0.01$	$p < 0.01$
37°C	$p < 0.01$	ns	$p < 0.01$	ns	$p < 0.05$

5.2.3.2. BOND STRENGTH DETERMINATION

(a) GLASS POLYALKENOATE-DENTINE

Comparative tensile bond strength results for Ketac Fil, Ketac Bond and Coltene 018804 B glass polyalkenoate cements and one glass cermet cement Ketac Silver, to dentine, with or without dentine pretreatment with polyacrylic acid are shown in Table 5.46. Without pretreatment, the highest mean strength was achieved in descending ranking order by Coltene > Ketac Fil > Ketac Bond > Ketac Silver. There was a significant difference among these means ($p < 0.001$ ANOVA). A Tukey test comparison of means to localise significant differences revealed significant differences between all the means ($p < 0.01$ Tukey).

After pretreatment with polyacrylic acid, the highest mean strength was achieved in descending ranking order by Coltene > Ketac Silver > Ketac Fil > Ketac Bond. There was still a significant different among means ($p < 0.01$ ANOVA), but this was less significant than without pretreatment and there was now no significant difference between Ketac Fil and Ketac Bond (Table 5.47.).

Pretreatment of dentine with polyacrylic acid was found to significantly reduce mean bond strength values in terms of mean strength ($p < 0.05$ ANOVA) and Weibull Modulus ($p < 0.05$) for Ketac Fil, have no significant effect for Ketac Bond, significantly improve mean strength for Ketac Silver ($p < 0.01$ ANOVA) and significantly improve Weibull Modulus for Coltene 018804 B (Table 5.48.). Comparison of the variables for Weibull Modulus pre and post dentine treatment with polyacrylic acid, shown in Table 5.49. bear out the above comments.

Graphical representation of results (Fig. 5.52.) generated by the

TABLE 5.46

Quantitative analysis of tensile bond strength results to dentine for the glass polyalkenoate cements Ketac Fil, Ketac Bond and Coltene 018804 B and a glass cermet Ketac Silver, with and without dentine pretreatment with polyacrylic acid (P.A.A.). 30 specimens tested for each variable.

VARIABLE	MEAN STRENGTH (MPa)	STANDARD DEVIATION	CORRELATION COEFFICIENT	WEIBULL MODULUS	S. ERROR OF MODULUS
K. Fil - Dentine	4.51	2.37	0.97	1.98	0.13
K. Fil P.A.A.- Dentine	3.30	2.11	0.98	1.62	0.05
K. Bond - Dentine	3.40	1.11	0.81	2.19	0.20
K. Bond P.A.A.- Dentine	3.15	1.08	0.78	1.66	0.17
Coltene - Dentine	5.09	1.56	0.98	3.19	0.09
Coltene P.A.A.- Dentine	4.71	1.26	0.97	3.77	0.12
K. Silver - Dentine	2.82	1.67	0.96	1.44	0.06
K. Silver - P.A.A. Dentine	4.26	1.90	0.94	1.72	0.08

TABLE 5.47.

A Tukey Test Comparison of means.

VARIABLE CODE	K FIL P.A.A.	K. BOND P.A.A.	COLTENE P.A.A.	K. SILVER P.A.A.
K. Fil P.A.A.		ns	$p < 0.01$	$p < 0.01$
K. Bond P.A.A.	ns		$p < 0.01$	$p < 0.01$
Coltene P.A.A.	$p < 0.01$	$p < 0.01$		$p < 0.05$
K. Silver P.A.A.	$p < 0.01$	$p < 0.01$	$p < 0.05$	

Tukey Test Significance: ns if means differ by < 0.38

$p < 0.05$ if means differ by > 0.38

$p < 0.01$ if means differ by > 0.47

TABLE 5.48

Statistical analysis of tensile bond strength testing results to dentine (D) comparing each cement pre and post treatment with polyacrylic acid (P.A.A.). Mean strength significance was calculated by Students' t test and Weibull Modulus significance at 5% level from +/- 2 x S.E. of Modulus.

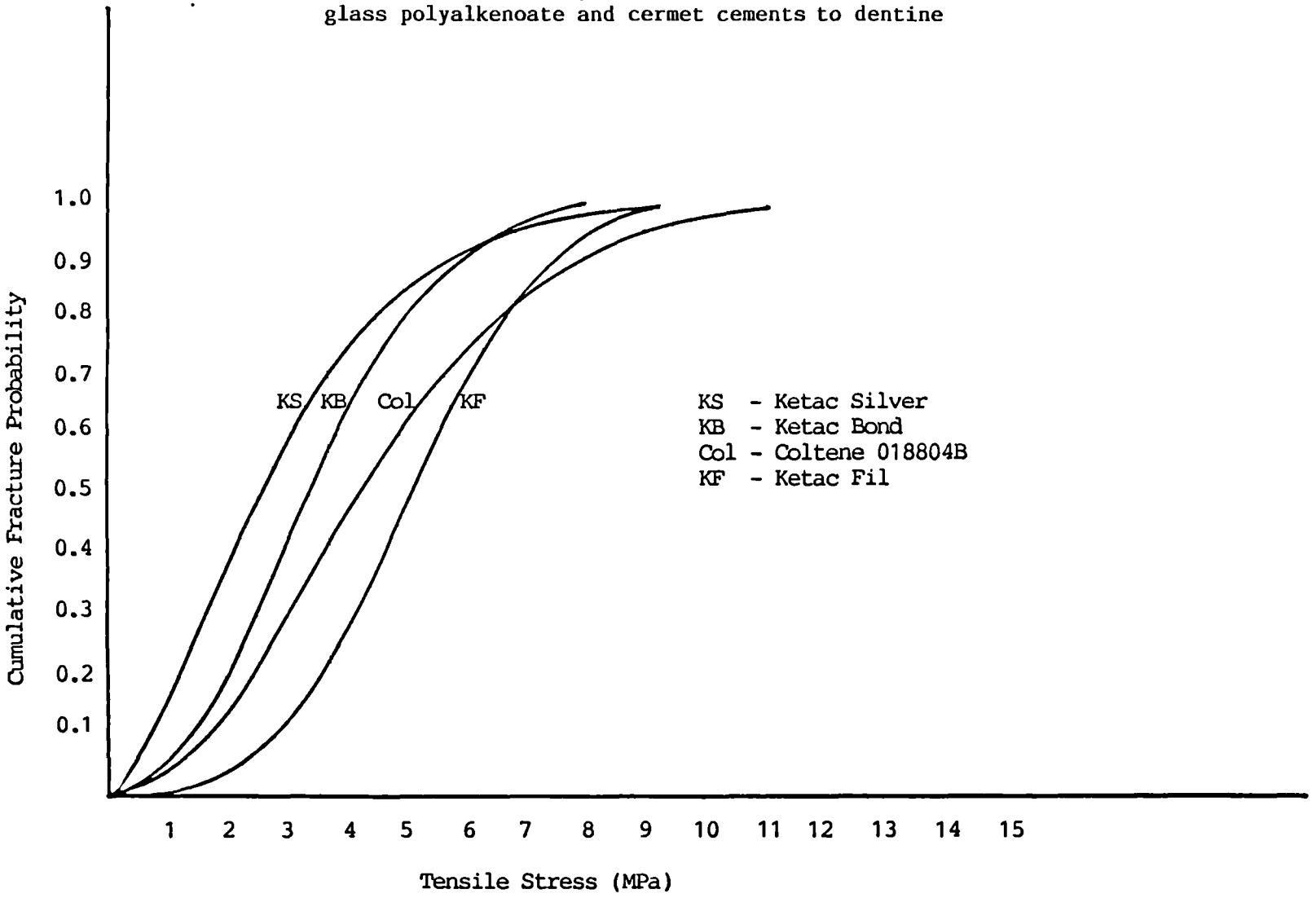
COMPARING	MEAN STRENGTH	WEIBULL MODULUS
K. Fil - D v. K. Fil - P.A.A. - D	p 0.05 Favours K.F. - D	p 0.05 Favours K.F. - D
K. Bond - D v. K. Bond - P.A.A. - D	ns	ns
Coltene - D v. Coltene - P.A.A. - D	ns	p 0.05 Favours Col. PAA-D
K. Silver - D v. K. Silver - P.A.A. - D	p 0.01 Favours KS - P.A.A.- D	ns

TABLE 5.49.

Statistical analysis of tensile bond strength testing results for Weibull Modulus. Significance at 5% level from +/- 2 x S Error of Modulus.

COMPARING	WEIBULL MODULUS
K. Fil - D v. K. Bond - D	ns
K. Fil - P.A.A. - D v. K. Bond - P.A.A. - D	ns
K. Fil - D v. K. Silver - D	$p < 0.05$ Favours K. Fil - D
K. Fil - P.A.A. - D v. K. Silver - P.A.A. - D	ns
K. Bond - D v. K. Silver - D	$p < 0.05$ Favours K. Bond - D
K. Bond - P.A.A. - D v. K. Silver P.A.A. -D	ns
K. Fil - D v. Col. - D	$p < 0.05$ Favours Col. - D
K. Fil - P.A.A. - D v. Col. - P.A.A. - D	$p < 0.05$ Favours Col. - P.A.A. - D
K. Silver - D v. Col. - D	$p < 0.05$ Favours Col - D
K. Silver - P.A.A. - D v. Col. - P.A.A. - D	$p < 0.05$ Favours Col. - P.A.A. - D
K. Bond - D v. Col. - D	$p < 0.05$ Favours Col. - D
K. Bond - P.A.A. - D v. Col. - P.A.A. - D	$p < 0.05$ Favours Col. - P.A.A. - D

Fig 5.52 Cumulative fracture probability versus tensilc stress for glass polyalkenoate and cermet cements to dentine



Weibull analysis shows the plot of cumulative probability of bond failure versus tensile stress for the cement - dentine bonds without dentine pretreatment with polyacrylic acid. Each of the lines is constructed from 30 test specimens and is typical of results generated by the Weibull analysis. Fig. 5.52. shows that there is a significant probability of bond failure at low stress values for Ketac Silver, Ketac Bond performs better than Ketac Silver, Coltene 018804 B better still, and Ketac Fil best of all. Although graphic representation helps us to predict cumulative failure probability ranking between cements, a more accurate impression is gained by comparing probability of bond failure calculations obtained from the Weibull equation (Table 5.50.). This shows that before dentine pretreatment with polyacrylic acid, at a stress value of 1 MPa, Ketac Fil and Ketac Bond have a very similar failure probability which is 10 - 12 times greater than Coltene 018804 B, but 3 - 4 times smaller than than of Ketac Silver. Ketac Silver has a 44 times greater failure probability than Coltene 018804 B. However, after dentine pretreatment with polyacrylic acid the performance of Ketac silver and Coltene improves while that of Ketac Fil and Ketac Bond is reduced.

Overall, comparing mean strength, Weibull Modulus and probability of failure, the performances of Ketac Fil and Ketac Bond are reduced and those of Coltene 018804 B and Ketac Silver enhanced by dentine pretreatment with polyacrylic acid.

The location of bond failures was predominantly adhesive at the cement-dentine junction in all cases except for Ketac Silver with polyacrylic acid dentine pretreatment where 40% of bond failure was a combination of adhesive/cohesive failure (Table 5.51.). There were no

TABLE 5.50.

Calculated probability of bond failure at stated stresses (MPa) for the cement-dentine bonds of Ketac Fil, Ketac Bond, Coltene 018804 B and Ketac Silver.

VARIABLE	PROBABILITY OF BOND FAILURE $x\ 10^{-3}$ at 1 MPa	
	Without P.A.A.	With P.A.A.
K. Fil - Dentine	38.9	113
K. Bond - Dentine	46.3	99.8
Coltene - Dentine	3.8	1.95
K. Silver - Dentine	168	61.2

TABLE 5.51.

Location of bond failure for the cement-dentine or cement-P.A.A.-dentine bonds under test. 30 specimens tested for each variable.

VARIABLE	LOCATION OF BOND FAILURE %		
	ADHESIVE	AD/CO	COHESIVE
K. Fil-	100		
K. Fil-P.A.A. Dentine	100		
K. Bond-Dentine	100		
K. Bond-P.A.A. Dentine	97	3	
Coltene-Dentine	100		
Coltene-P.A.A.-Dentine	93.4	6.6	
K. Silver-Dentine	100		
K. Silver-P.A.A. Dentine	60	40	

completely cohesive failures. The results in Table 5.51. suggest that in the cases of Ketac Bond, Coltene and especially Ketac Silver, some resistance to adhesive failure may be attained by pretreatment of dentine with polyacrylic acid.

(b) GLASS POLYALKNOATE-COMPOSITE RESIN

(i) TENSILE BOND STRENGTH AS A FUNCTION OF MATERIAL COMPOSITION

Comparative tensile bond strength results for Ketac Bond, Ketac Fil, Coltene 018804 B and Ketac Silver to Occlusin composite resin, all prepared according to manufacturers recommendations are shown in Table 5.52. There was a significant difference in mean bond strength values between the variables ($p < 0.001$ ANOVA) with a ranking order in decreasing order of magnitude of $KS\ 60_5 > KF\ 60_{15} > Col\ 60_4 > KB\ 60_4$. A Tukey comparison of means to localise significant differences (Table 5.53.) showed the mean strength of $KB\ 60_4$ to be poorer than all other variables ($p < 0.01$ Tukey) and $Col\ 60_4$ to be poorer than $KS\ 60_5$ ($p < 0.01$ Tukey). Comparison of the variables for Weibull Modulus (Table 5.54.) showed that $KB\ 60_4$ and $KB\ 60_{15}$ to be more dependable than each of the other variables ($p < 0.05$).

Graphical representation of results (Fig. 5.53.) generated by the Weibull analysis shows the plot of cumulative probability of bond failure versus tensile stress for the cement-composite resin bonds. The graph shows that there is a significant probability of bond failure at low stress values for Ketac Bond, Coltene 018804 B performs better than Ketac Bond, Ketac Fil better still and Ketac Silver best of all. Although graphic representation helps to predict cumulative probability failure ranking between cements a more accurate impression is gained by comparing probability of failure calculations obtained from the Weibull Equation (Table 5.55.). This shows that at a stress value of 1 MPa Ketac Bond has a 25 times greater failure probability than Ketac Fil, a 4 times greater failure probability than Ketac Silver and twice the failure probability of Coltene. Ketac Fil has the lowest failure probability at all 3 stresses shown.

TABLE 5.52.

Quantitative analysis of tensile bond strength results for glass polyalkenoate-Occlusin variables as described in Table 4.1. 30 specimens tested for each variable. Variable codes are explained in Section 4.2.1.3.2.

VARIABLE	MEAN STRENGTH (MPa)	STANDARD DEVIATION	CORRELATION COEFFICIENT	WEIBULL MODULUS	S. ERROR OF MODULUS
KB 60 4	2.45	0.62	0.86	4.21	0.32
KF 60 15	5.38	1.39	0.96	4.21	0.16
Col 60 4	4.43	1.57	0.92	3.24	0.18
KS 60 5	5.72	2.12	0.93	3.05	0.16

Tukey Test Significance: ns if means differ by < 1.04

$p < 0.05$ if means differ by > 1.04

$p < 0.01$ if means differ by > 1.27

TABLE 5.53.

Tukey Test paired comparisons of variable means. Significance at 1% level where stated.

VARIABLE CODE	KB 60 4	KF 60 15	Col 60 4	KS 60 5
KB 60 4		$p < 0.01$	$p < 0.01$	$p < 0.01$
KF 60 15	$p < 0.01$		ns	ns
Col 60 4	$p < 0.01$	ns		$p < 0.01$
KS 60 5	$p < 0.01$	ns	$p < 0.01$	

TABLE 5.54.

Statistical analysis of tensile bond strength results shown in Table 5.52. Weibull Modulus significance at 5% level from +/- 2 x S. Error of Modulus.

COMPARING	WEIBULL MODULUS
KB 60 v. 4 KF 60 15	ns
KB 60 v. 4 Col 60 4	$p < 0.05$ Favours KB
KB 60 v. 4 KS 60 5	$p < 0.05$ Favours KB
KF 60 v. 15 Col 60 4	$p < 0.05$ Favours KF
KF 60 v. 15 KS 60 5	$p < 0.05$ Favours KF
Col 60 v. 4 KS 60 5	ns

Fig 5.53 Cumulative fracture probability versus stress for glass polyalkenoate and cermet cements to composite resin

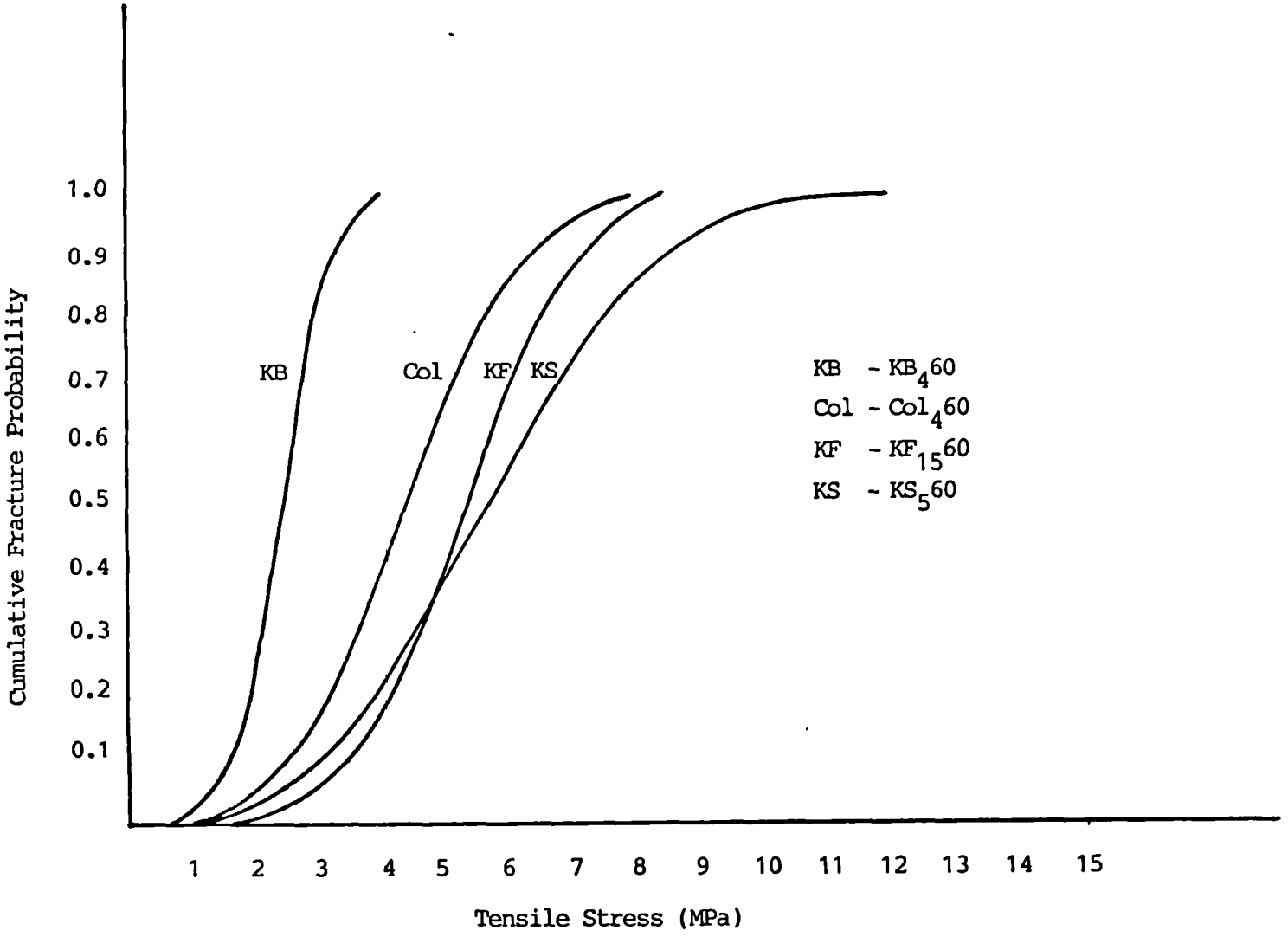


TABLE 5.55.

Calculated probability of bond failure at stated stresses (MPa) for the variables in Table 4.1.

VARIABLE CODE	PROBABILITY OF BOND FAILURE x 10^{-3}		
	1MPa	2MPa	3MPa
KB 60 4	15.2	2.47	791
KF 60 15	0.6	10.4	56
Col 60 4	5.7	52	180
KS 60 5	3.5	28	94

Overall in terms of bond strength, Weibull Modulus and probability of failure, KF 60 performs better than the other variables.
15

The location of bond failures in the tensile bond strength tests are shown in Table 5.56., and differed for the variables under test. A high proportion of cohesive failures was seen in KB 60 and Col 60, whereas KF 60 and KS 60 had around 40% adhesive failures. Cohesive failure when it occurred usually took place about 1 mm. from the cement-occlusin junction.
4 4
15 5

TABLE 5.56.

Location of bond failures for the variables in Table 4.1.

VARIABLE CODE	LOCATION OF BOND FAILURE %		
	ADHESIVE	AD/CO	COHESIVE
KB 60 4	0	0	100
KF 60 15	37	0	63
Col 60 4	3	3	94
KS 60 5	40	6.6	53.3

(ii) T.B.S. FOR KETAC BOND-OCCLUSIN AS A FUNCTION OF THE POWDER: LIQUID RATIO OF KETAC BOND.

Comparative tensile bond strength results for the variables under test are shown in Table 5.57. There was a significant difference among mean bond strength values between the variables ($p < 0.001$ ANOVA) with a ranking order in decreasing order of magnitude of $3.83 > 4.26 > 2.97 > 2.55 > 3.4$ (recommended). A Tukey comparison of means to localise significant differences, found differences between KB 3.4 v. KB 3.83 and KB 3.4 v. KB 4.26 ($p < 0.01$ Tukey). However, statistical comparison of variables against the manufacturers recommended ratio (3.4:1) for Weibull Modulus (Table 5.58.) showed the 3.4:1 ratio to be more dependable than the 2 lower powder:liquid ratios, and not statistically different from the 2 higher ratios.

Overall, increasing the powder:liquid ratio of Ketac Bond glass polyalkenoate cement above the recommended ratio , increases the resultant tensile bond strength without jeopardising the Weibull Modulus (dependability).

Graphical representation of results (Fig. 5.54.) generated by the Weibull analysis shows the plot of cumulative probability of bond failure versus tensile stress for the differing powder:liquid ratios of Ketac Bond. The graph shows that there is a significant probability of bond failure at low stress values for all powder:liquid ratios of Ketac Bond, but cumulative probability failure ranking between cements is difficult due to the close grouping of the 5 lines. A more accurate impression of ranking can be gained by comparing probability of failure calculations obtained from the Weibull Equation (Table 5.59.). This shows that at a stress value of 1MPa, Ketac Bond mixed with lower powder:liquid ratios has a greater failure probability than Ketac Bond mixed with higher powder:liquid ratios.

TABLE 5.57.

Quantitative analysis of tensile bond strength results for different powder:liquid ratios of Ketac Bond-Occlusin as described in Table 4.2.

30 specimens tested for each variable.

VARIABLE CODE + P/L ratio	MEAN STRENGTH (MPa)	STANDARD DEVIATION	CORRELATION COEFFICIENT	WEIBULL MODULUS	STANDARD ERROR OF
KB 60 (2.55) 4	3.09	1.31	0.97	2.51	0.08
KB 60 (2.97) 4	3.17	1.15	0.93	3.11	0.16
KB 60 (3.4) 4	2.45	0.62	0.86	4.21	0.32
KB 60 (3.83) 4	3.74	1.07	0.98	3.65	0.11
KB 60 (4.26) 4	3.47	1.21	0.82	3.50	0.31

Tukey Test significance: ns if means differ by < 0.75

$p < 0.05$ if means differ by > 0.75

$p < 0.01$ if means differ by > 0.92

TABLE 5.58.

Statistical analysis of Tensile Bond Strength results shown in Table 5. Weibull Modulus significance at 5% level was calculated from +/- 2 x S. Error of Modulus.

COMPARING	WEIBULL MODULUS
KB 60 v. $\frac{4}{4}$ KB 60 2.55	$p < 0.05$ Favours KB 60 $\frac{4}{4}$
KB 60 v. $\frac{4}{4}$ KB 60 2.97	$p < 0.05$ Favours KB 60 $\frac{4}{4}$
KB 60 v. $\frac{4}{4}$ KB 60 3.83	ns
KB 60 v. $\frac{4}{4}$ KB 60 4.26	ns

Fig 5.54 Cumulative fracture probability versus tensile stress for varying powder liquid ratios of Ketac Bond

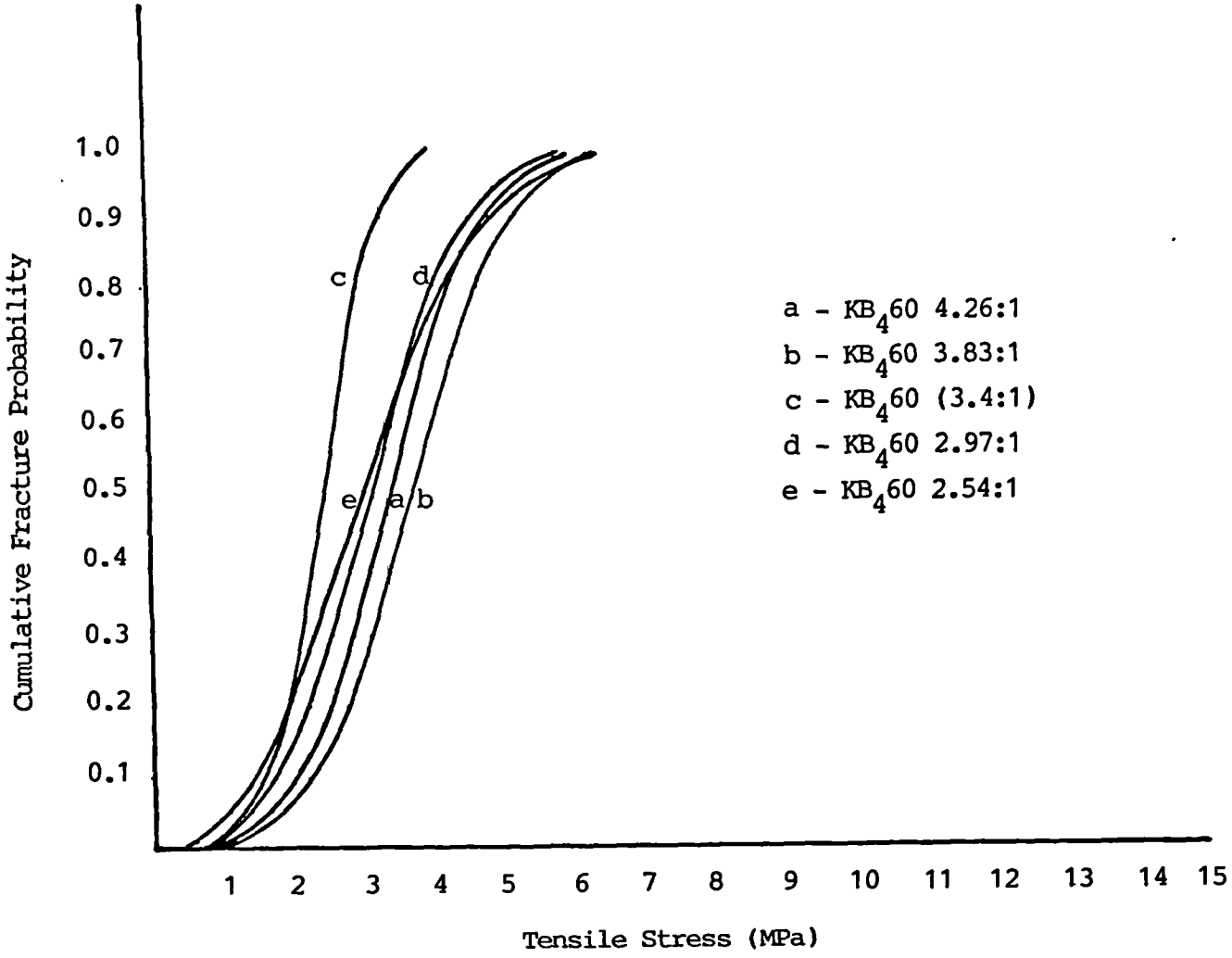


TABLE 5.59.

Calculated probability of bond failure at stated stressed (MPa) for the variables in Table 4.2.

VARIABLE CODE	PROBABILITY OF BOND FAILURE x 10^{-3}		
	1MPa	2MPa	3MPa
KB 60 2.55 4	42.7	220	496
KB 60 2.97 4	19.4	155	448
KB 60 (3.4) 4	15.2	247	791
KB 60 3.83 4	5.5	67.2	264
KB 60 4.26 4	8.8	95.3	339

Increasing the powder:liquid ratio of Ketac Bond above the recommended (3.4:1) value would appear to reduce the failure probability at low stress values.

The location of bond failures for these experimental variables were almost exclusively cohesive(within the cement) and occurred about 1 mm. from the cement-occlusin junction (Table 5.60.). There is a suggestion that lower powder:liquid ratios may fail in an increasingly adhesive manner.

TABLE 5.60.

Location of bond failures for the variables in Table 4.2.

VARIABLE CODE	LOCATION OF BOND FAILURE %		
	Adhesive	Ad/Co	Cohesive
KB 60 2.55 4	7	0	93
KB 60 2.97 4	3	0	97
KB 60 (3.4) 4	0	0	100
KB 60 3.83 4	1	1	98
KB 60 4.26 4	0	0	100

(iii) T.B.S. for Ketac Bond-Occlusin as a function of the length of time after commencement of mix prior to etching, the type and duration of etch and the presence of an unfilled intermediate resin layer.

Comparative tensile bond strength results for the variables under test are shown in Table 5.61. There was a significant difference among mean strength values between the variables ($p < 0.001$ ANOVA) with a ranking order in decreasing order of magnitude of $KB_{60} > KB_{60}^{ne} > KB_{4}^{30} > KB_{4}^{60} > KB_{4}^{ne} > KB_{4}^{new} > KB_{3}^{60} > KB_{4}^{60\ nr}$. A Tukey comparison of means to localise significant differences is shown in Fig. 5.62. All specimens that were bonded after the recommended 4 minutes from commencement of mix, regardless of etching or washing procedure and using intermediate resin performed similarly with regard to mean bond strength.

Statistical comparison of variables against the manufacturers recommended clinical regime (KB_{4}^{60}) for Weibull Modulus (Table 5.63.) showed KB_{4}^{60} to be more dependable than KB_{4}^{new}, $KB_{4}^{60\ nr}$, KB_{3}^{60} and KB_{60}^{ne} ($p < 0.05$), but there was no statistical difference compared to KB_{4}^{ne}, KB_{4}^{30} and KB_{60}^{60}.

Three other facts are obvious from Table 5.61.: $KB_{4}^{60\ nr}$ and KB_{3}^{60} have the 2 lowest mean strengths, by far the lowest Weibull Moduli, and a percentage of the prepared specimens also fractured prematurely before bond strength testing could be done. This highlights them as being inferior when compared to the other variables under test.

Graphical representation of results (Fig. 5.55.) generated by the Weibull analysis shows the plot of cumulative probability of bond

TABLE 5.61.

Quantitative analysis of tensile bond strength results for Ketac Bond-Occlusin variables as described in Table 4.3. Variable codes are explained in section 4.2.1.3.2.

30 specimens tested for each variable.

VARIABLE CODE	MEAN STRENGTH (MPa)	STANDARD DEVIATION	CORRELATION COEFFICIENT	WEIBULL MODULUS	S. ERROR OF MODULUS	BONDS FRACTURING PREMATURELY %
KB new 4	2.70	1.22	0.77	1.64	0.17	
KB ne 4	2.71	0.75	0.93	3.94	0.20	
KB 30 4	2.93	1.01	0.93	3.27	0.17	
KB 60 4	2.45	0.62	0.86	4.21	0.32	
KB 60nr 4	0.97	0.77	0.73	0.30	0.04	13
KB 60 3	1.87	1.14	0.68	0.23	0.03	20
KB ne 60	2.95	1.13	0.93	3.08	0.11	
KB 60 60	3.43	1.09	0.97	3.49	0.08	

Tukey Test Significance: ns if means differ by < 0.81

$p < 0.05$ if means differ by > 0.81

$p < 0.01$ if means differ by > 0.97

TABLE 5.62.

Tukey Test paired comparisons of variable means. Significance at 1% and 5% level where stated.

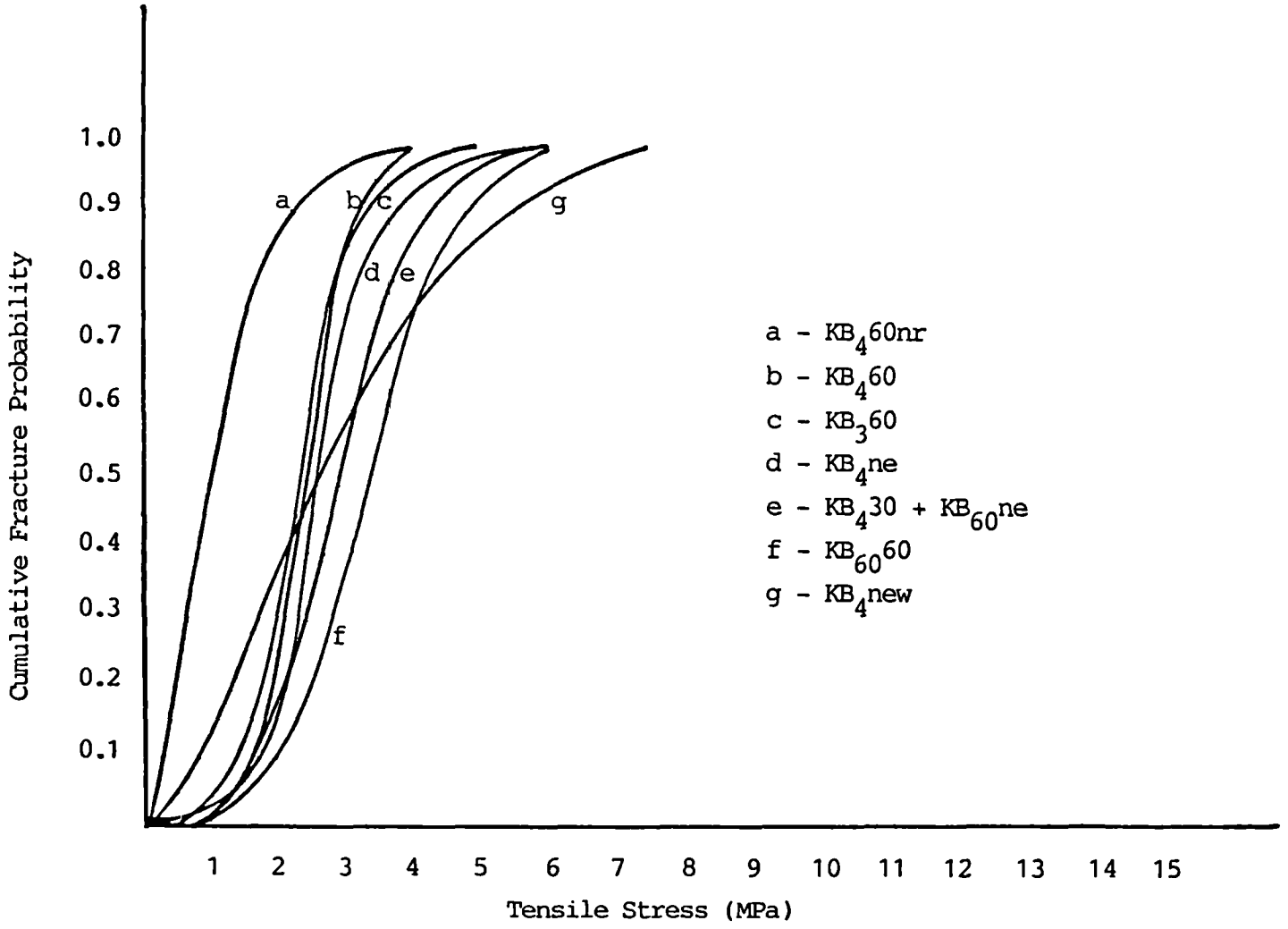
VARIABLE CODE	KB new 4	KB ne 4	KB 30 4	KB 60 4	KB 60nr 4	KB 60 3	KB ne 60	KB 60 60
KB new 4		ns	ns	ns	$p < 0.01$	$p < 0.05$	ns	ns
KB ne 4	ns		ns	ns	$p < 0.01$	$p < 0.05$	ns	ns
KB 30 4	ns	ns		ns	$p < 0.01$	$p < 0.01$	ns	ns
KB 60 4	ns	ns	ns		$p < 0.01$	ns	ns	$p < 0.05$
KB 60nr 4	$p < 0.01$	$p < 0.01$	$p < 0.01$	$p < 0.01$		$p < 0.05$	$p < 0.01$	$p < 0.01$
KB 60 3	$p < 0.05$	$p < 0.05$	$p < 0.01$	ns	$p < 0.05$		$p < 0.01$	$p < 0.01$
KB ne 60	ns	ns	ns	ns	$p < 0.01$	$p < 0.01$		ns
KB 60 60	ns	ns	ns	$p < 0.05$	$p < 0.01$	$p < 0.01$	ns	

TABLE 5.63.

Statistical analysis of tensile bond strength results shown in Table 5.61. Weibull Modulus significance was calculated at 5% level from +- 2 x S. Error of Modulus.

COMPARING	WEIBULL MODULUS
KB 60 v. 4 KB new 4	$p < 0.05$ Favours KB 60 4
KB 60 v. 4 KB ne 4	ns
KB 60 v. 4 KB 30 4	ns
KB 60 v. 4 KB 60nr 4	$p < 0.05$ Favours KB 60 4
KB 60 v. 4 KB 60 3	$p < 0.05$ Favours KB 60 4
KB 60 v. 4 KB 60 60	ns
KB 60 v. 4 KB ne 60	$p < 0.05$ Favours KB 60 4

Fig 5.55 Cumulative fracture probability versus tensile stress for the experimental variables of Ketac Bond to Occlusin



failure versus tensile stress for the experimental variables. The graph shows that there is a significant probability of bond failure at low stress values for KB^{4} 60 nr, the specimens that received no intermediate resin layer and for KB^{4} new the specimens that were neither etched or washed. Further cumulative probability failure ranking between variables is difficult due to the close grouping of the other 6 lines. A more accurate impression of ranking can be gained by comparing probability of failure calculations obtained from the Weibull equation (Table 5.64.). This shows that at a stress value of 1 MPa, KB^{4} 60 nr specimens have a 33 times, KB^{3} 60 specimens have a 15 times, KB^{4} new specimens have a 9 times and KB^{4} 30 and KB^{60} ne specimens have a slightly greater probability of failure than KB^{4} 60 specimens. KB^{4} ne the specimens that were washed only after 4 mins and KB^{60} 60 the specimens that were etched for 60 seconds after 60 minutes have a slightly reduced probability of failure compared to KB^{4} 60 specimens.

Overall, comparing mean bond stength, Weibull Modulus and probability of failure calculations, the specimens that were washed only after 4 minutes (KB^{4} ne) and those that were etched for 60 seconds after 60 minutes (KB^{60} 60) perform slightly better than KB^{4} 60 the manufacturers recommended clinical regime.

The location of bond failures for the experimental variables in these investigations was almost exclusively cohesive (within the cement) apart from the 2 cases where fracture was predominantly adhesive, KB^{4} 60 nr where adhesive failure was 97.7% and KB^{3} 60 where adhesive failure was 26.3%. When cohesive failure occurred it took place about 1 mm. from the cement-occlusin junction (Table 5.65.)

TABLE 5.64.

Calculated probability of bond failure at stated stresses (MPa) for the variables in Table 4.3.

VARIABLE CODE	PROBABILITY OF BOND FAILURE x 10^{-3}		
	1MPa	2MPa	3MPa
KB new 4	132	356	576
KB ne 4	13.4	187	639
KB 30 4	20.7	183	532
KB 60 4	15.2	247	791
KB 60nr 4	510	852	968
KB 60 3	230	318	788
KB ne 60	24.9	193	526
KB 60 60	9.3	100	352

TABLE 5.65.

Location of bond failures for the variables in Table 4.3.

VARIABLE CODE	LOCATION OF BOND FAILURE %		
	Adhesive	AD/CO	Cohesive
KB new 4	60	0	40
KB ne 4	1.7	1.7	96.6
KB 30 4	10	0	90
KB 60 4	0	0	100
KB 60nr 4	97.7	0	3.3
KB 60 3	26.3	0	73.7
KB ne 60	1.5	0	98.5
KB 60 60	3	0	97

(iv) T.B.S. for Ketac Silver-Occlusin as a function of the length of time prior to etching, the type and duration of etch and of mechanical preparation of the cement surface prior to etching.

Comparative tensile bond strength results for the variables under test are shown in Table 5.66. There was a significant difference among mean strength values between the variables ($p < 0.05$ ANOVA) with a ranking order in decreasing order of magnitude of $KS\ 60 = Ks\ 60 > KS\ ne > KS\ 60M > KS\ ne$. However, paired comparisons of the means found no significant difference at the 1% and 5% level between any comparison (Tukey Test). Statistical comparison of variables against the manufacturers recommended clinical regime ($KS\ 60$) for Weibull Modulus (Table 5.67.) showed there to be no significant difference compared to the specimens left to set for 60 minutes ($KS\ ne$, $KS\ 60$, $KS\ 60M$), but that the specimen treated after 5 minutes by washing was more dependable ($p < 0.05$).

TABLE 5.66.

Quantitative analysis of tensile bond strength results for Ketac Silver-Occlusin variables as described in Table 4.4. Variable codes are explained in section 4.2.1.3.2.

30 specimens tested for each variable.

VARIABLE CODE	MEAN STRENGTH (MPa)	STANDARD DEVIATION	CORRELATION COEFFICIENT	WEIBULL MODULUS	S. ERROR OF MODULUS
KS ne 5	5.05	1.37	0.96	3.93	0.16
KS 60 5	5.72	2.12	0.93	3.05	0.16
KS ne 60	4.66	1.65	0.92	3.48	0.14
KS 60 60	5.72	2.71	0.88	2.70	0.13
KS 60M 60	4.86	1.71	0.91	3.44	0.14

Tukey Test Significance: ns if means differ by < 1.36

$p < 0.05$ if means differ by > 1.36

$p < 0.01$ if means differ by > 1.66

TABLE 5.67.

Statistical analysis of tensile bond strength results. Weibull Modulus Significance at 5% level was calculated from +/- 2 x S. Error of Modulus.

COMPARING	WEIBULL MODULUS
KS 60 v. 5 KS ne 5	$p < 0.05$ Favours KS ne 5
KS 60 v. 5 KS ne 60	ns
KS 60 v. 5 KS 60 60	ns
KS 60 v. 5 KS 60M 60	$p < 0.05$ Favours KS 60M 60

Graphical representation of results (Fig.5.56) generated by the Weibull analysis shows the plot of cumulative probability of bond failure versus tensile stress for the experimental variables. It is impossible to rank specimens concerning probability of failure at low stress values due to the very close grouping of the 5 lines. A more accurate impression can be gained by comparing probability of failure calculations obtained from the Weibull equation (Table 5.68.). This shows that at a stress value of 1MPa the specimens that were only washed after 5 minutes (KS ne) have a 3 times lesser probability of failure than the other specimens.

Overall, comparing mean bond strength, Weibull Modulus and probability of failure calculations:

1. the specimens that were washed only after 5 minutes (KS ne) performed better than KS 60, the manufacturers recommended clinical regime.
2. An increase in the time after mixing prior to bonding offered no advantages.

The location of bond failures for the experimental variables are shown in Table 5.69. The specimens that were washed only after 5 minutes (KS ne) failed almost exclusively in a cohesive manner whilst those etched after 5 minutes failed almost equally cohesively and adhesively. The specimens that were left for 60 minutes prior to preparation and bonding, failed in about 90% of cases in a cohesive manner.

Fig 5.56 Cumulative fracture probability versus tensile stress for the experimental variables of Ketac Silver to Occlusin

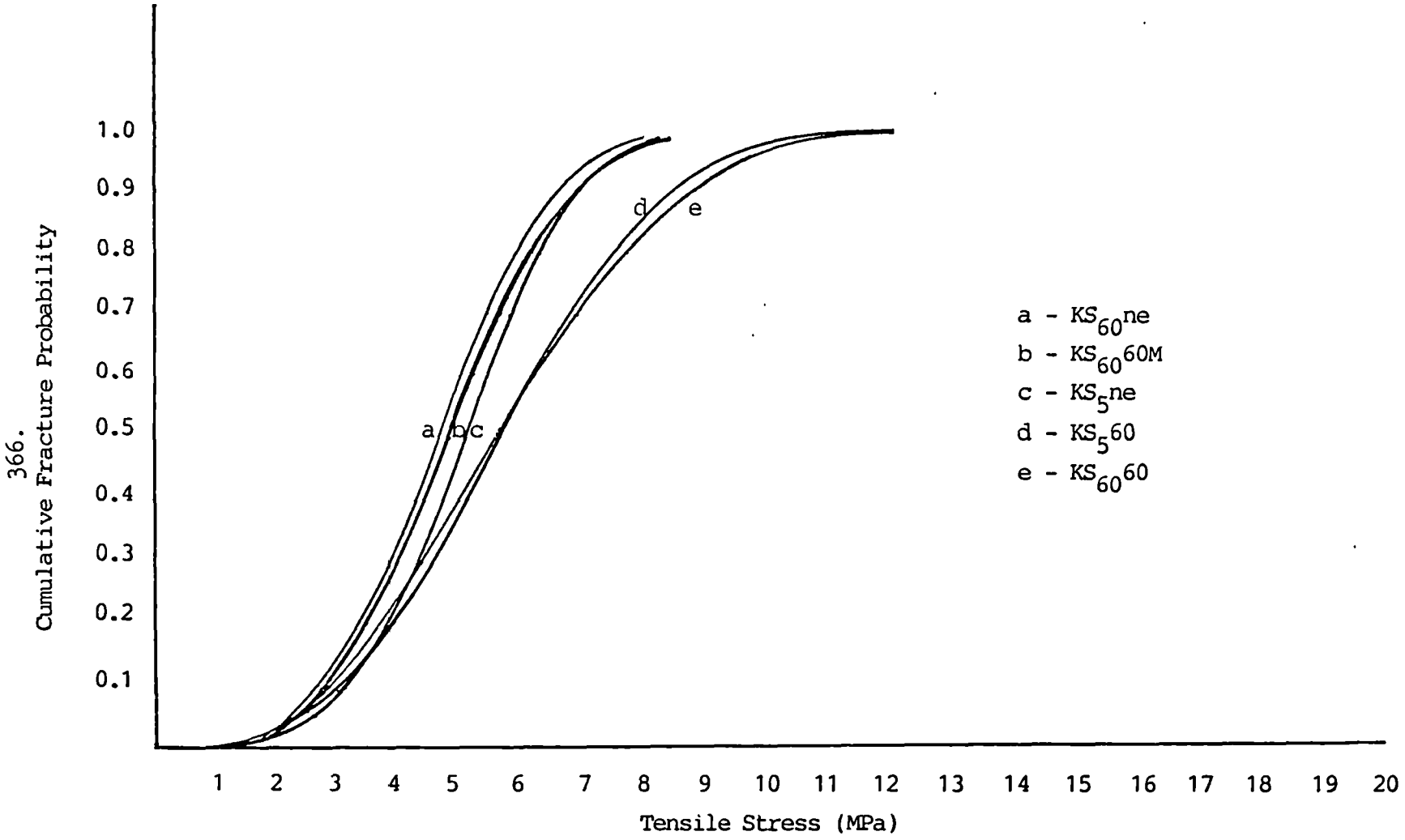


TABLE 5.68.

Calculated probability of bond failure at stated stresses (MPa) for the variables in Table 4.4.

VARIABLE CODE	PROBABILITY OF BOND FAILURE x 10^{-3}		
	1MPa	2MPa	3MPa
KS ne 5	1.2	17.6	83.8
KS 60 5	3.5	28.3	94.3
KS ne 60	3.3	36.0	139
KS 60 60	6.4	41.4	120
KS 60M 60	3.0	32.3	124

TABLE 5.69.

Location of bond failures for the variables in Table 4.4.

VARIABLE CODE	LOCATION OF BOND FAILURE %		
	ADHESIVE	AD/CO	COHESIVE
KS ne 5	0	3	97
KS 60 5	40	6.6	53.3
KS ne 60	13	0	87
KS 60 60	7	0	93
KS 60M 60	11	0	89

(v) T.B.S. for Ketac Fil-Occlusin as a function of the length of set prior to etching.

Comparative tensile bond strength results for the 2 variables under test are shown in Table 5.70. and statistical comparison of the pair in Table 5.71. The specimens that were etched after 8 minutes (KF_{8}^{60}) had a significantly greater mean strength ($p < 0.001$), but a significantly poorer Weibull Modulus ($p < 0.05$) than the specimens that were etched after 15 minutes (KF_{15}^{60}).

Graphical representation of results (Fig. 5.57.) generated by the Weibull analysis shows the plot of cumulative probability of bond failure versus tensile stress. Ranking the 2 at low stress values is not possible due to the very close grouping of the lines at low values. However, probability of failure calculations (Table 5.72.) at 1MPa show KF_{8}^{60} to have 2 times the probability of failure of KF_{15}^{60} but both values are very low.

Overall, comparing mean bond strength, Weibull Modulus and probability of failure calculations, a reduction in the recommended 15 minutes after commencement of mix prior to etching, to 8 minutes, does not appear to significantly reduce the quality of bond achieved to composite resin.

The location of bond failure in the specimens that were etched after 8 minutes was entirely cohesive, while in those specimens etched after 15 minutes it was 63% cohesive and 37% adhesive (Table 5.73).

TABLE 5.70.

Quantitative analysis of tensile bond strength results for Ketac Fil-Occlusin as described in Table 4.5. Variable codes are explained in section 4.2.1.3.2.

30 specimens test for each variable.

VARIABLE CODE	MEAN STRENGTH (MPa)	STANDARD DEVIATION	CORRELATION COEFFICIENT	WEIBULL MODULUS	S.ERROR OF MODULUS
KF 60 8	8.82	2.98	0.99	2.97	0.07
KF 60 15	5.38	1.39	0.96	4.21	0.16

TABLE 5.71.

Statistical analysis of tensile bond strength results shown in Table 5.70. Mean Strength significance was calculated by students' T. Test and Weibull Modulus significance at 5% level from +/- 2 x S. Error of Modulus.

COMPARING	MEAN STRENGTH	WEIBULL MODULUS
KF 60 v. 8 KF 60 15	$p < 0.001$ Favours KF 8	$p < 0.05$ Favours KF 15

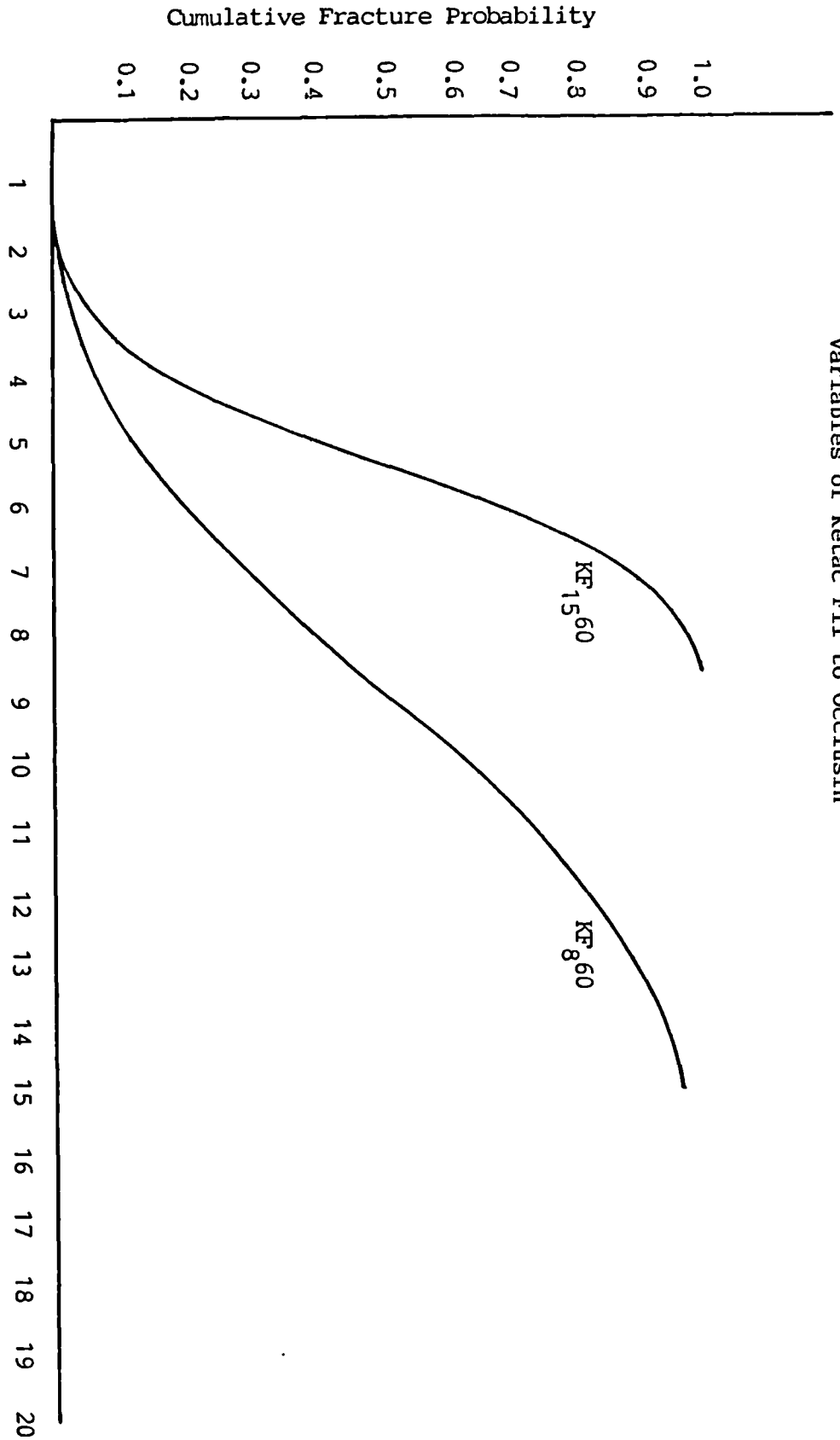


Fig 5.57 Cumulative fracture probability versus tensile stress for the experimental variables of Ketac Fil to Occlusin

TABLE 5.72.

Calculated probability of bond failure at stated stresses (MPa) for the variables in Table 4.5.

VARIABLE CODE	PROBABILITY OF BOND FAILURE x 10^{-3}		
	1MPa	2MPa	3MPa
KF 60 8	1.1	8.6	28.5
KF 60 15	0.6	10.4	60

TABLE 5.73.

Location of bond failures for the variables in Table 4.5.

VARIABLE CODE	LOCATION OF BOND FAILURE %		
	ADHESIVE	AD/CO	COHESIVE
KF 60 8	0	0	100
KF 60 15	37	0	63

(vi) T.B.S. for Coltene-Occlusin as a function of the type of etch employed.

Comparative tensile bond strength results for the 2 variables under test are shown in Table 5.74. and statistical comparison of the pair in Table 5.75. There was no significant difference in mean bond strength, but the specimens that were only washed (Col $_4$ ne) had a significantly greater Weibull Modulus ($p < 0.05$) and may, therefore, produce a more dependable bond.

Graphical representation of results (Fig. 5.58.) shows the plot of cumulative probability of bond failure versus tensile stress. At 1 MPa Col $_4$ 60 has a 5 times greater probability of failure than Col $_4$ ne. (Fig. 5.76).

Overall, comparing mear bond strength, Weibull Modulus and probability of failure calculations, the specimens that were just washed (Col $_4$ ne) performed better than those that were etched and washed (Col $_4$ 60).

The location of bond failure in both variables was almost exclusively cohesive (Table 5.77.).

TABLE 5.74.

Quantitative analysis of tensile bond strength results for Coltene-Occlusin as described in Table 4.6. Variable codes are explained in section 4.2.1.3.2.

30 specimens tested for each variable.

VARIABLE CODE	MEAN STRENGTH (MPa)	STANDARD DEVIATION	CORRELATION COEFFICIENT	WEIBULL MODULUS	S. ERROR OF MODULUS
Col ne 4	4.15	1.0	0.95	4.51	0.19
Col 60 4	4.43	1.57	0.92	3.24	0.18

TABLE 5.75.

Statistical analysis of tensile bond strength results shown in Table 5.74. Mean strength significance was calculated by Students T. Test and Weibull Modulus significance at 5% level from +/- 2 x S. Error of Modulus.

COMPARING	MEAN STRENGTH	WEIBULL MODULUS
Col ne v. 4 Col 60 4	ns	$p < 0.05$ Favours Col ne 4

Fig 5.58 Cumulative fracture probability versus tensile stress for the experimental variables of Coltene to occlusin

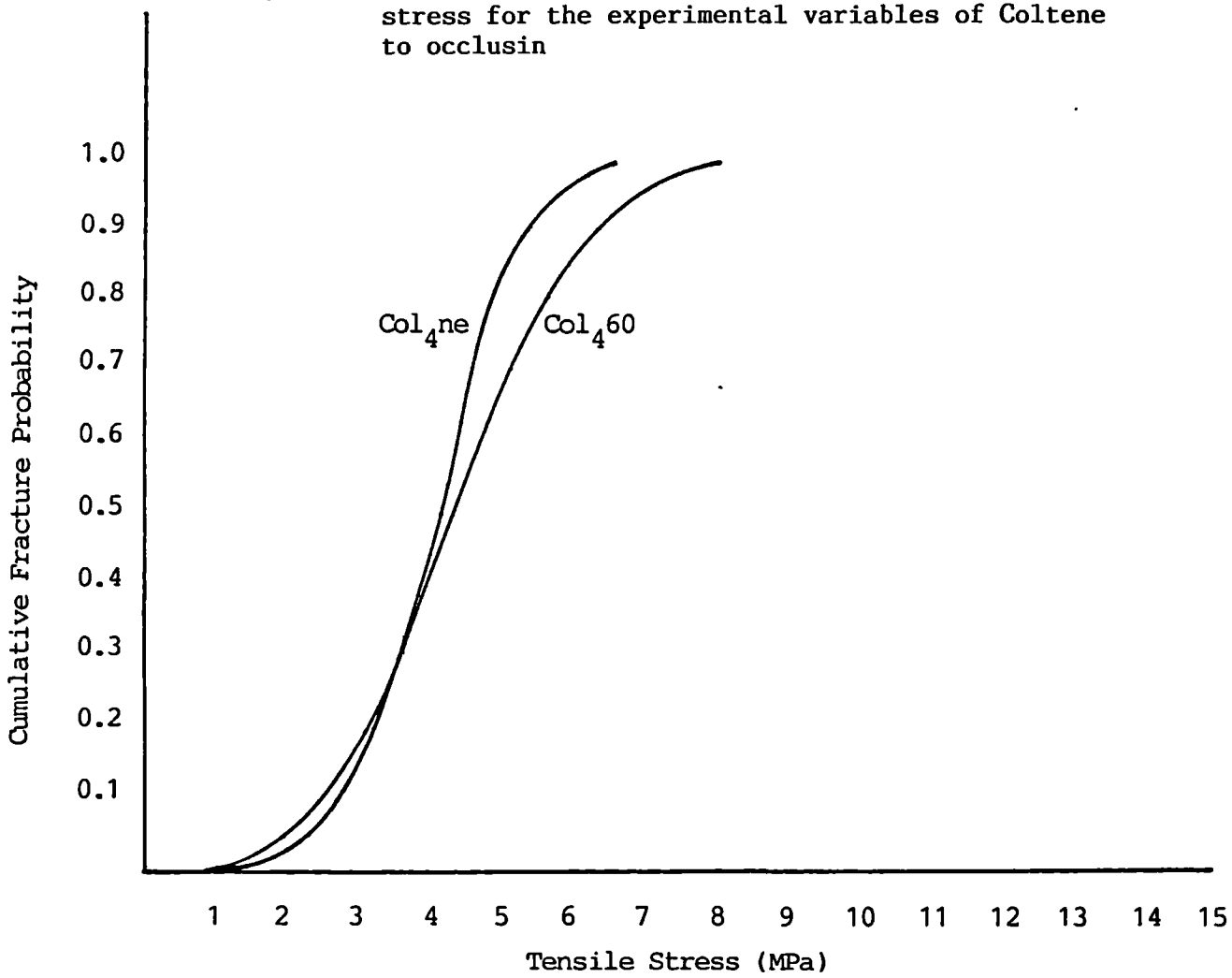


TABLE 5.76.

Calculated probability of bond failure at stated stresses (MPa) for the variables in Table 4.6.

VARIABLE CODE	PROBABILITY OF BOND FAILURE x 10^{-3}		
	1MPa	2MPa	3MPa
Col ne 4	1.08	24.3	142
Col 60 4	5.65	52.1	180

TABLE 5.77.

Location of bond failures for the variables in Table 4.6.

VARIABLE CODE	LOCATION OF BOND FAILURE%		
	ADHESIVE	AD/CO	COHESIVE
Col ne 4	0	6	94
Col 60 4	3	3	94

5.2.3.3. DEPTH OF ETCH DETERMINATION

(i) The variation in depth of etch with material composition: Ketac Bond and Coltene 018804 B.

There was a significant difference in the performance of these 2 materials over the 3 experimental conditions ($p < 0.001$ ANOVA) and between the experimental conditions ($p < 0.001$ ANOVA) (Table 5.78.). A Tukey comparison of means to localise significant differences found no difference between the 2 materials with wash only, but significant differences at the other conditions ($p < 0.01$ Tukey). For Ketac Bond significantly less cement was lost by washing for 60 seconds, compared to etching for either 30 or 60 seconds prior to washing ($p < 0.01$ Tukey), and less cement was lost by etching for only 30 seconds, compared to 60 seconds ($p < 0.01$ Tukey). For Coltene 018804 B significantly less cement was lost by washing for 60 seconds only ($p < 0.01$ Tukey) compared to etching for either 30 or 60 seconds. There was no significant difference between etching for 30 seconds compared to 60 seconds.

(ii) The variation in depth of etch for Ketac Bond with earlier etching and washing of the specimen.

There was no significant difference in the performance of these 2 variables over the 3 experimental conditions (ANOVA), but there was a significant difference between experimental conditions ($p < 0.001$ ANOVA). A Tukey comparison of means revealed significantly less cement was loss by washing only ($p < 0.01$ Tukey) and there was no significant difference between the 30 seconds compared to the 60 seconds etch. (Table 5.79)

TABLE 5.78.

Comparative results for depth of etch investigations under the 3 experimental variables for Ketac Bond and Coltene 018804 B. The cements were subjected to the variables 4 minutes after commencement of mix.

MATERIAL	0 ETCH, WASH ONLY (60 secs.)		30 SECS. ETCH AND WASH (60 secs)		60 SECS. ETCH AND WASH (60 secs)	
	Depth Loss (μm.)	S. Deviation	Depth Loss (μm.)	S. Deviation	Dept Loss (μm.)	S. Deviation
Ketac Bond	16.35	10.14	60.78	12.45	76.86	13.26
Coltene 018804B	9.28	4.79	36.19	9.31	45.3	7.06

Tukey Test Significance: ns if means differ by < 13.26

$p < 0.05$ if means differ by > 13.26

$p < 0.01$ if means differ by > 16.01

TABLE 5.79.

Comparative results for depth of etch investigations for Ketac Bond subjected to the 3 experimental variables after 3 and 4 minutes from mix commencement.

12 specimens tested for each cement at each variable.

MATERIAL	0 ETCH WASH ONLY (60 secs)		30 SECS. ETCH AND WASH (60 secs)		60 SECS. ETCH AND WASH (60 secs
	Depth Loss (μm.)	S. Deviation	Depth Loss (μm.)	S. Deviation	Depth Loss (μm)	S. Deviation
KB_3	19.97	10.36	67.55	17.71	66.23	10.87
KB_4	16.35	10.14	60.78	12.45	76.86	13.26

KB_3 - Ketac Bond subjected to the experimental variables 3 minutes after commencement of mix.

KB_4 - Ketac Bond subjected to the experimental variables 4 minutes after commencement of mix.

Tukey Test Significance: ns if means differ by < 17.19

$p < 0.05$ if means differ by > 17.19

$p < 0.01$ if means differ by > 20.77

(iii) The variation in depth of etch with differing powder:liquid ratio mixes of Ketac Bond: 2.55:1. 2.97:1, 3.4:1. 3.83:1, 4.26:1.

The average depth loss (Microns) and standard deviations for the powder:liquid ratios under the 3 experimental conditions as outlined in section 4.2.1.3.3. are shown in Table 5.80. There was a significant difference in performance between the different powder:liquid ratios ($p < 0.001$ ANOVA), between the experimental conditions ($p < 0.001$ ANOVA), and between the different variables at different times ($p < 0.001$ ANOVA).

After just a wash and a 30 seconds etch, the recommended powder:liquid ratio 3.4:1 and the greater powder:liquid ratios 3.83:1 and 4.21 performed significantly better ($p < 0.01$ Tukey) than the reduced powder:liquid ratios. After 60 seconds etch, there was a significant difference in performance between the recommended ratio and the lowest powder:liquid ratio 2.55:1 ($p < 0.05$ Tukey).

The trend was for less cement to be lost at each of the 3 experimental conditions for those specimens with a higher powder:liquid ratio. 2 exceptions to this were the 4.26:1 ratio, where more cement was lost at wash only and at 30 seconds etch than lower powder:liquid ratios (Table 5.80.). However, removal of the 4.26:1 ratio from ANOVA calculations did not alter the overall results.

TABLE 5.80.

Comparative results for depth of etch investigations for differing powder:liquid ratios of Ketac Bond subjected to the 3 experiemental variables 4 minutes after commencement of mix.

12 specimens tested for each cement at each variable.

K. BOND P:L RATIO	0 ETCH WASH ONLY (60 secs)		30 SECOND ETCH AND WASH (60 secs)		60 SECOND ETCH AND WASH (60 secs)	
	Depth Loss (μm.)	S. Deviation	Depth Loss (μm.)	S. Deviation	Depth Loss (μm.)	S. Deviation
2.55:1	119.06	48.21	112.17	37.89	107.45	16.94
2.97:1	69.17	28.17	95.13	22.94	86.95	9.22
3.4:1	16.35	10.14	60.78	12.45	76.86	13.26
3.83:1	17.99	4.64	39.79	19.10	71.17	6.06
4.26:1	23.75	5.88	55.20	5.72	59.45	5.51

Tukey Test Significance: ns if means differ by < 30.3

$p < 0.05$ if means differ by > 30.3

$p < 0.01$ if means differ by > 34.7

5.2.3.4. MORPHOLOGY OF ETCHED SURFACES

(a) The study of glass polyalkenoate cement surface.

(i) The surface of Ketac Bond, acid etched for 15 seconds, 30 seconds or 60 seconds 4 minutes after mix commencement, and then washed for 60 seconds and dried is shown in Fig. 5.59. at 3 different magnifications, 200 x, 1,000 x, and 5,000 x.

(ii) The surface of Ketac Fil subjected to the same regime as above 8 minutes after mix commencement is shown in Fig. 5.60.

(iii) The surface of Ketac Silver subjected to the same regime as above 5 minutes after mix commencement is shown in Fig. 5.61.

(b) The study of composite resin tag morphology.

The morphology of composite resin tags found in the variables for Ketac Bond specimens [(i) a - e] as described in section 4.2.1.3.4. are shown in Fig. 5.62., while the morphology for Ketac Bond specimens [(i)f, (ii)a and (iii)a] are shown in Fig. 5.63. The morphology of composite resin tags found in the variables for Ketac Silver [(i)a, b] and Ketac Fil [(i) + (ii)] are shown in Fig. 5.64.

Fig 5.59 Morphology of the etched surface of Ketac Bond

a) Etched for 15 secs 4 mins after mix commencement
magnification 200x, 1000x, 5000x

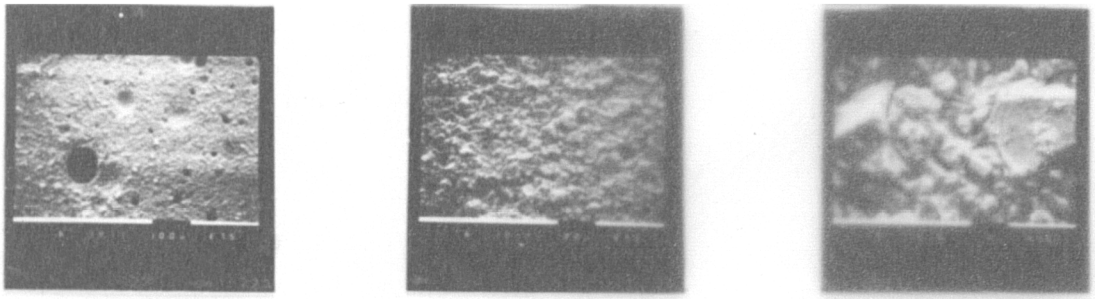
b) Etched for 30 secs 4 mins after mix commencement
magnification 200x, 1000x, 5000x

c) Etched for 60 secs 4 mins after mix commencement
magnification 200x, 1000x, 5000x

Fig 5.59 Morphology of the etched surface of Ketac Bond

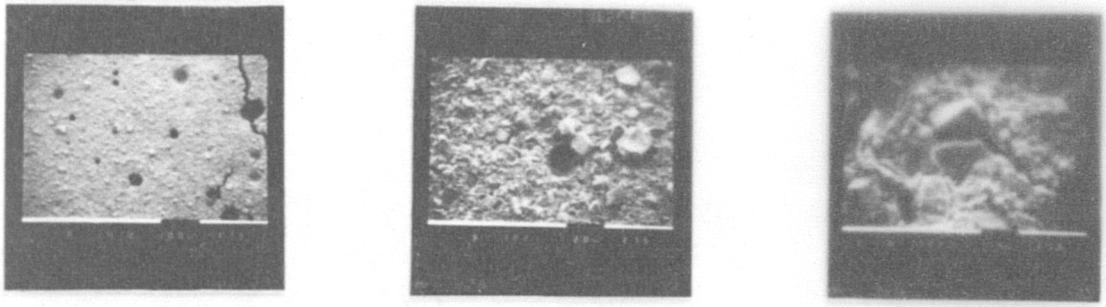
a) Etched for 15 secs 4 mins after mix commencement

magnification 200x, 1000x, 5000x



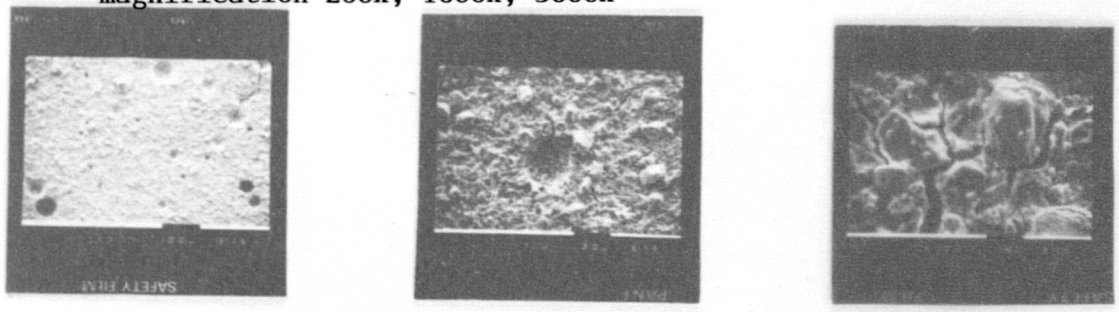
b) Etched for 30 secs 4 mins after mix commencement

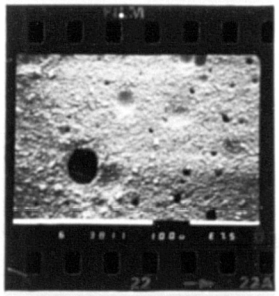
magnification 200x, 1000x, 5000x

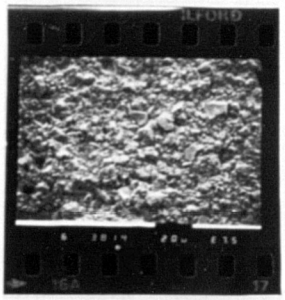


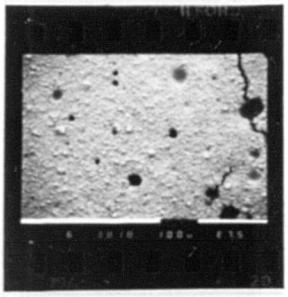
c) Etched for 60 secs 4 mins after mix commencement

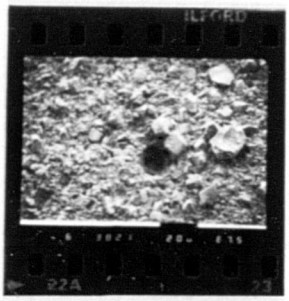
magnification 200x, 1000x, 5000x

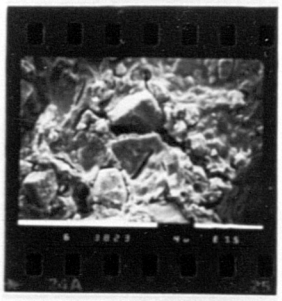


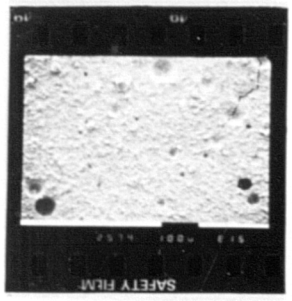


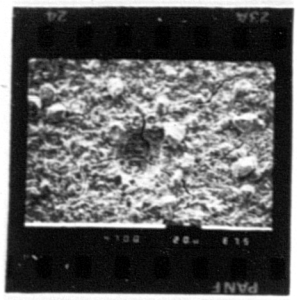









SAFETY FILM



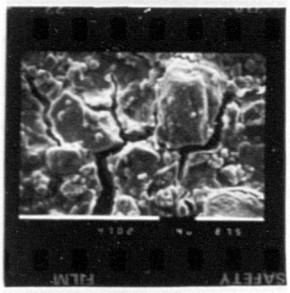


Fig 5.60 Morphology of the etched surface of Ketac Fil

a) Etched for 15 secs, 8 mins after mix commencement
magnification 200x, 1000x, 5000x

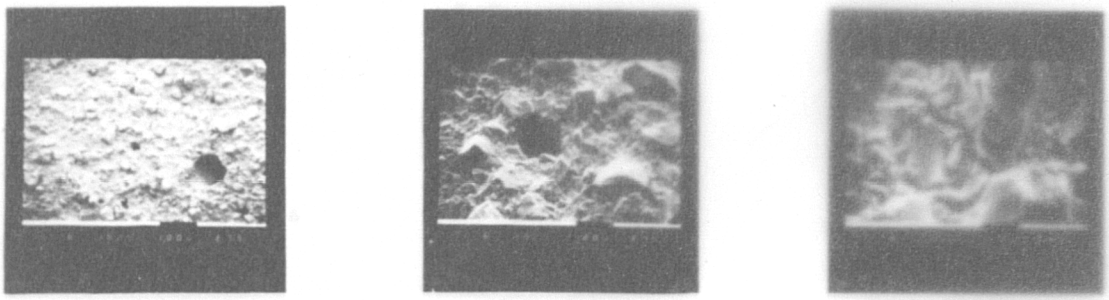
b) Etched for 30 secs, 8 mins after mix commencement
magnification 200x, 1000x, 5000x

c) Etched for 60 secs, 8 mins after mix commencement
magnification 200x, 1000x, 5000x

Fig 5.60 Morphology of the etched surface of Ketac Fil

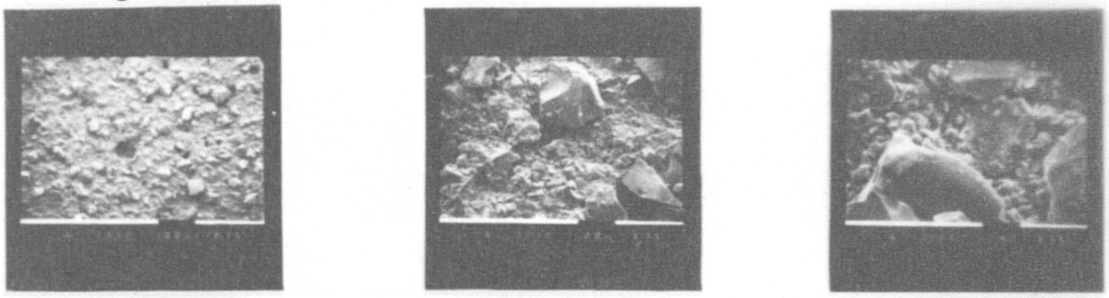
a) Etched for 15 secs, 8 mins after mix commencement

magnification 200x, 1000x, 5000x



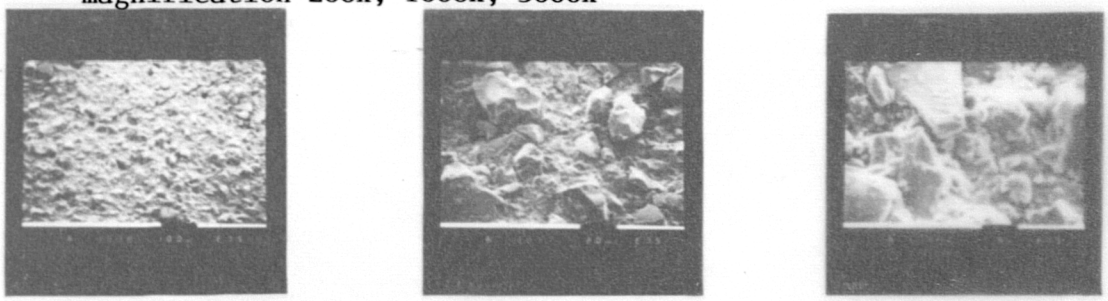
b) Etched for 30 secs, 8 mins after mix commencement

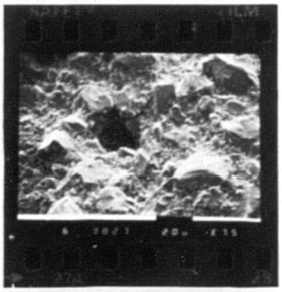
magnification 200x, 1000x, 5000x

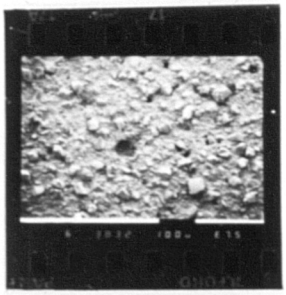


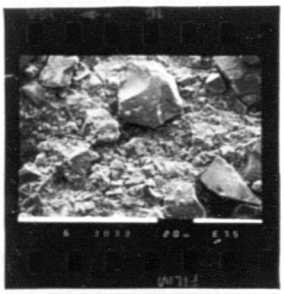
c) Etched for 60 secs, 8 mins after mix commencement

magnification 200x, 1000x, 5000x









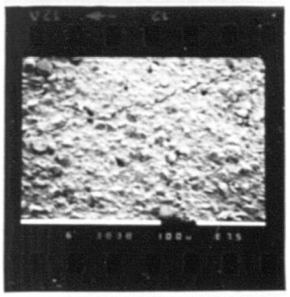


Fig 5.61 Morphology of the etched surface of Ketac Silver

a) Etched for 15 secs, 5 mins after mix commencement
magnification 200x, 1000x, 5000x

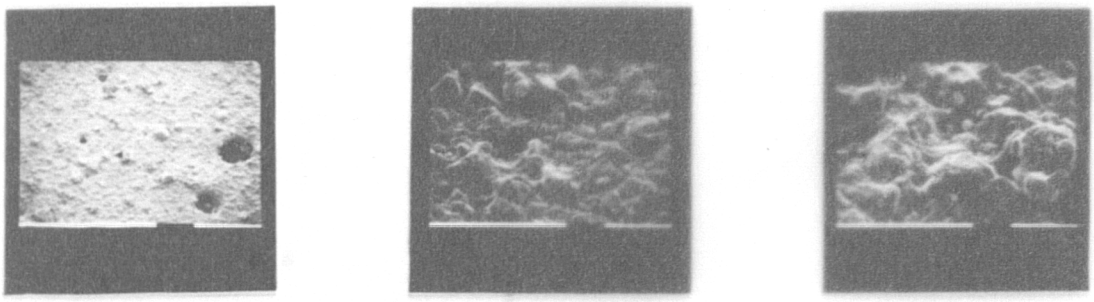
b) Etched for 30 secs, 5 mins after mix commencement
magnification 200x, 1000x, 5000x

c) Etched for 60 secs, 5 mins after mix commencement
magnification 200x, 1000x, 5000x

Fig 5.61 Morphology of the etched surface of Ketac Silver

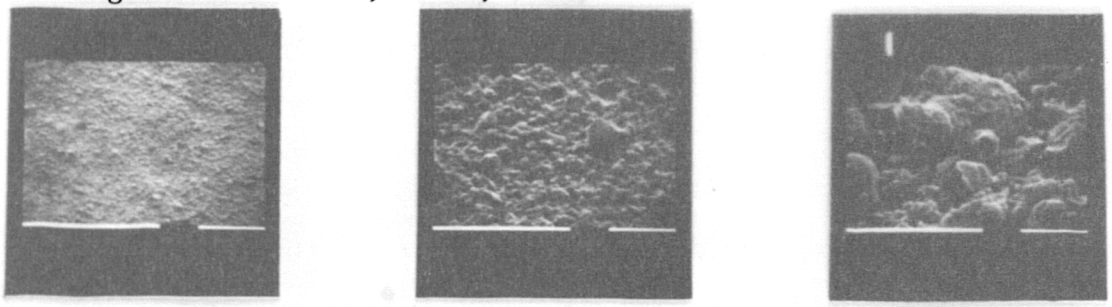
a) Etched for 15 secs, 5 mins after mix commencement

magnification 200x, 1000x, 5000x



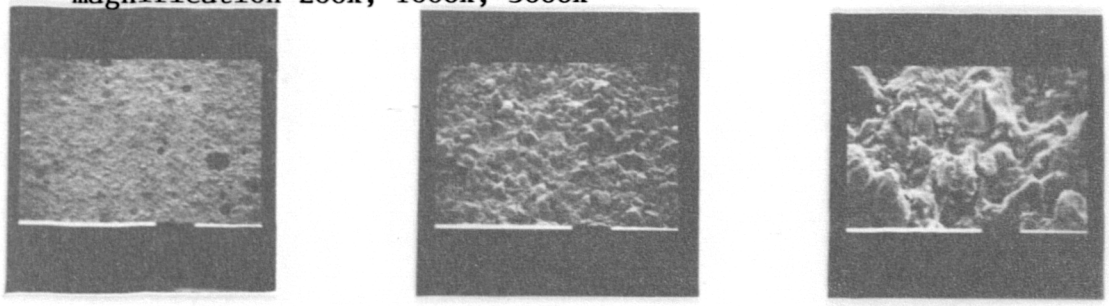
b) Etched for 30 secs, 5 mins after mix commencement

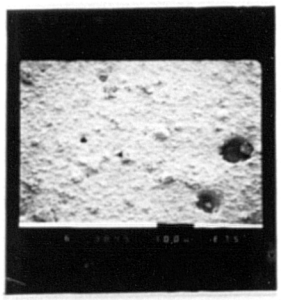
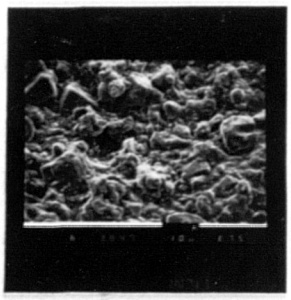
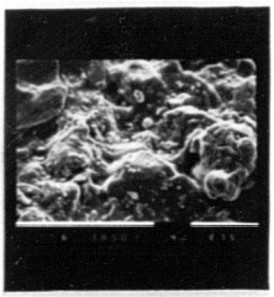
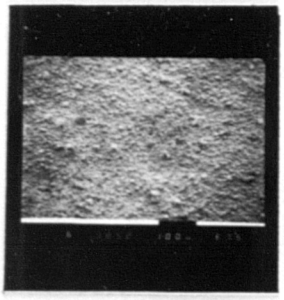
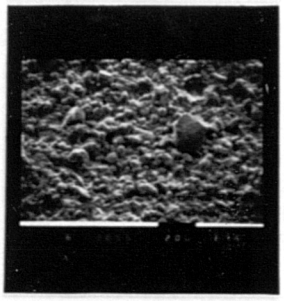
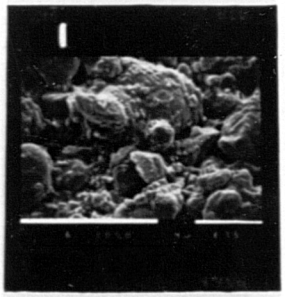
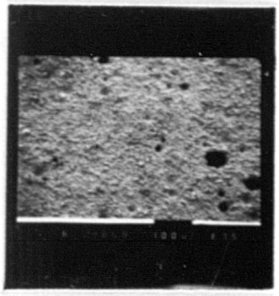
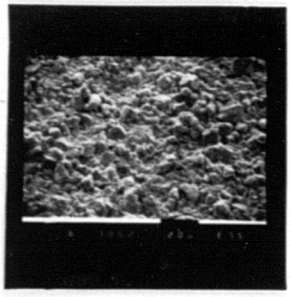
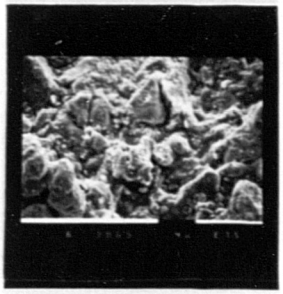
magnification 200x, 1000x, 5000x



c) Etched for 60 secs, 5 mins after mix commencement

magnification 200x, 1000x, 5000x



. Fig 5.62 Composite resin tag morphology. Ketac Bond.

a) KB_4new Ketac Bond no etch or wash, after 4 mins
magnification 200x, 1000x, 5000x

b) KB_4ne Ketac Bond washed for 60 secs and dried, after 4 mins
magnification 200x, 1000x, 5000x

c) $KB_4$15 Ketac Bond etched 15 secs, washed 60 and dried, after 4 mins
magnification 200x, 1000x, 5000x

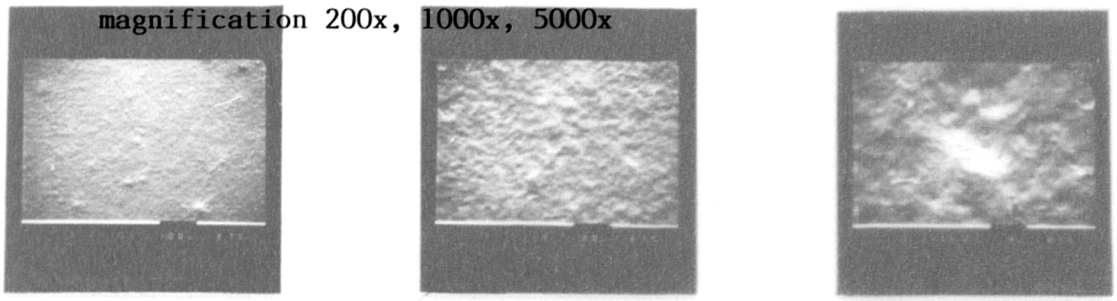
d) $KB_4$30 Ketac Bond etched 30 secs, washed 60 and dried, after 4 mins
magnification 200x, 1000x, 5000x

. e) $KB_4$60 Ketac Bond etched 60 secs, washed 60 and dried, after 4 mins
magnification 200x, 1000x, 5000x

Fig 5.62 Composite resin tag morphology. Ketac Bond.

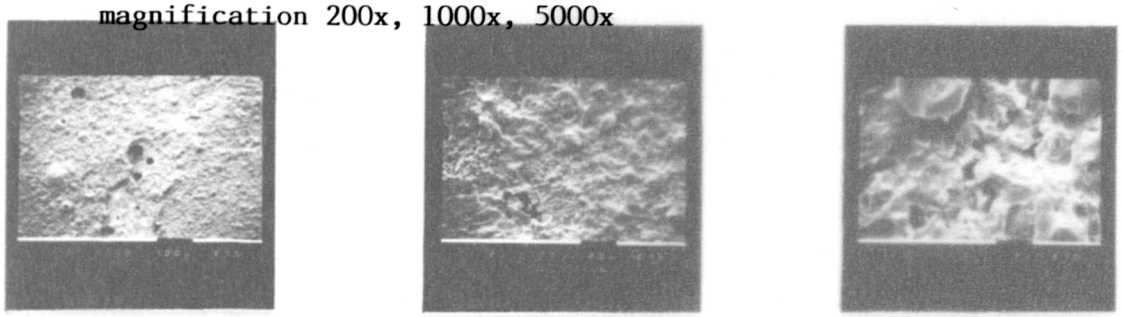
a) KB_4new Ketac Bond no etch or wash, after 4 mins

magnification 200x, 1000x, 5000x



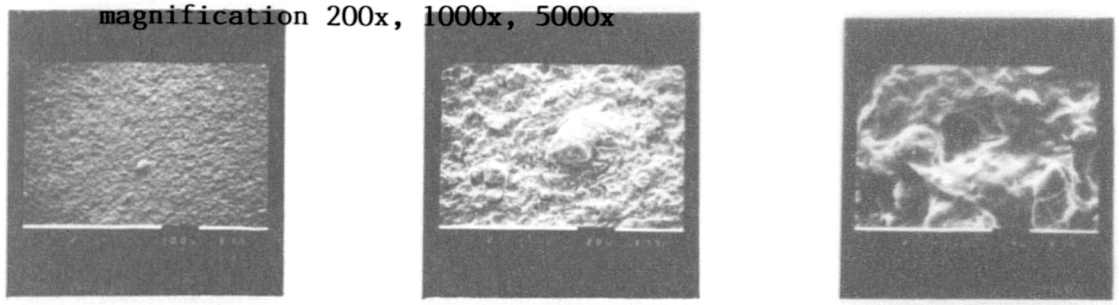
b) KB_4ne Ketac Bond washed for 60 secs and dried, after 4 mins

magnification 200x, 1000x, 5000x



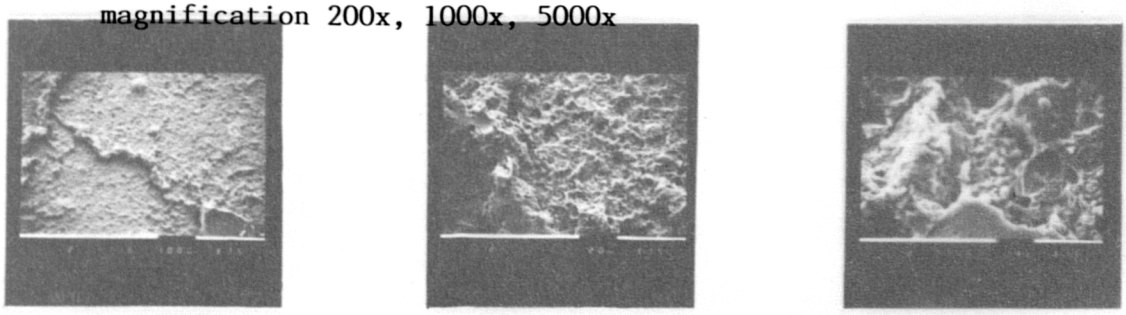
c) $KB_4$15 Ketac Bond etched 15 secs, washed 60 and dried, after 4 mins

magnification 200x, 1000x, 5000x



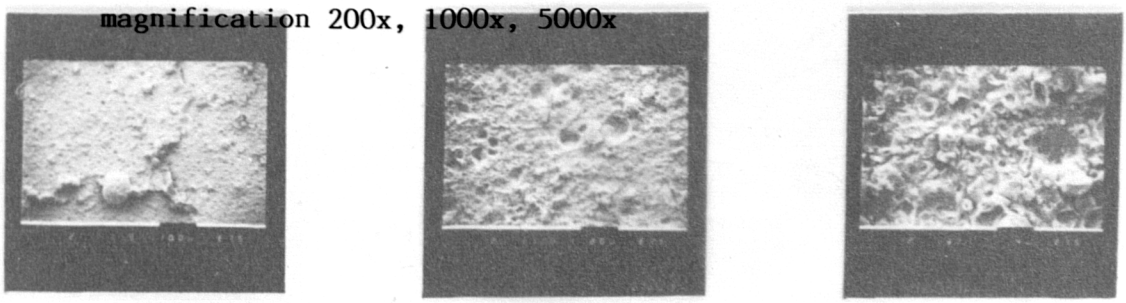
d) $KB_4$30 Ketac Bond etched 30 secs, washed 60 and dried, after 4 mins

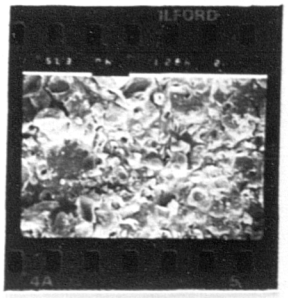
magnification 200x, 1000x, 5000x



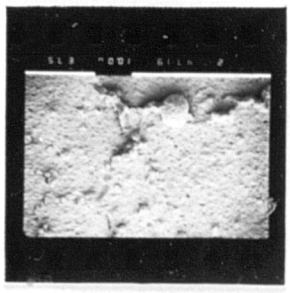
e) $KB_4$60 Ketac Bond etched 60 secs, washed 60 and dried, after 4 mins

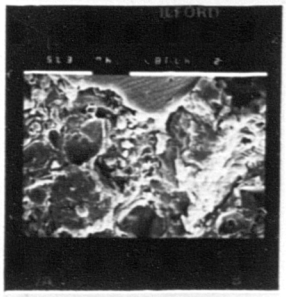
magnification 200x, 1000x, 5000x




ILFORD


PAN F

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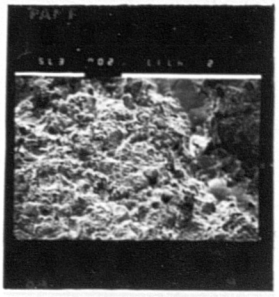
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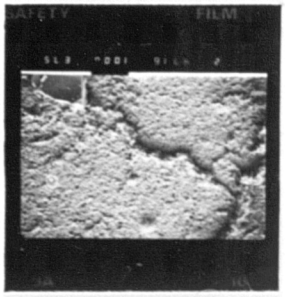
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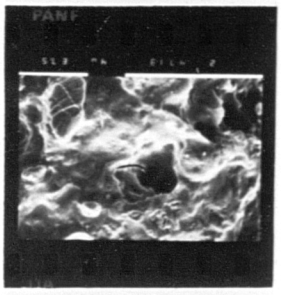
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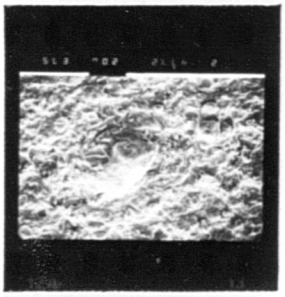

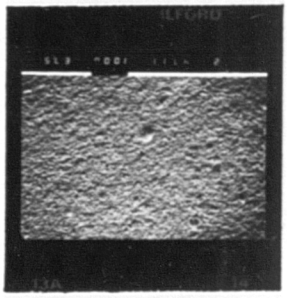
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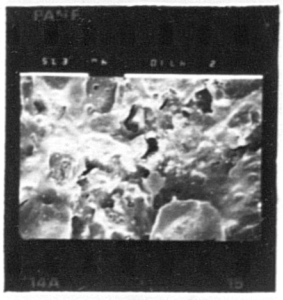
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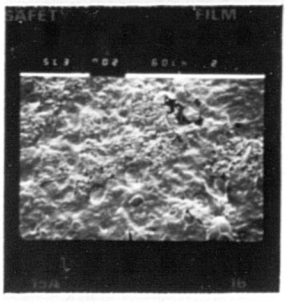
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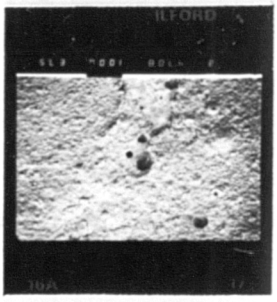
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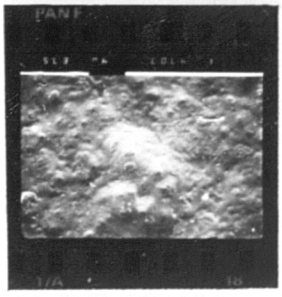
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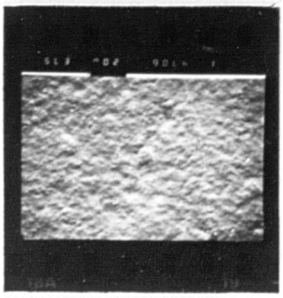


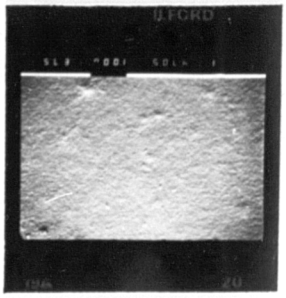

ILFORD

Fig 5.63 Composite resin tag morphology. Ketac Bond.

a) $KB_4$60nr Ketac Bond etched 60 sec, washed 60 and dried, after 4 mins but no intermediate unfilled resin

magnification 200x, 1000x, 5000x

b) $KB_3$60 Ketac Bond etched 60 secs, washed 60 and dried, after 3 mins

magnification 200x, 1000x, 5000x

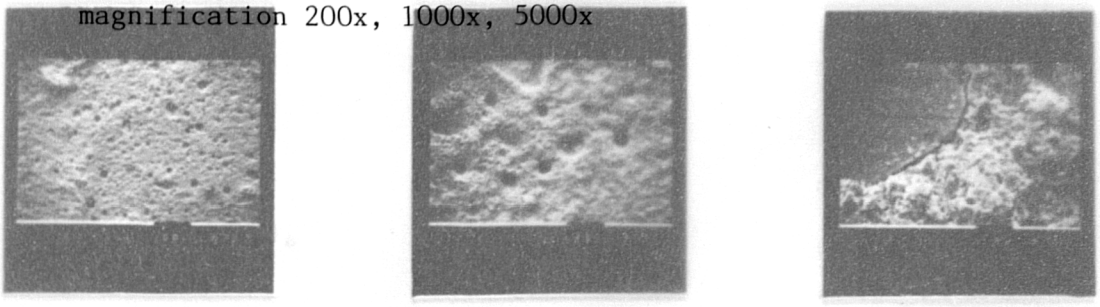
c) $KB_5$30 Ketac Bond etched 30 secs, washed 60 and dried, after 5 mins

magnification 200x, 1000x, 5000x

Fig 5.63 Composite resin tag morphology. Ketac Bond.

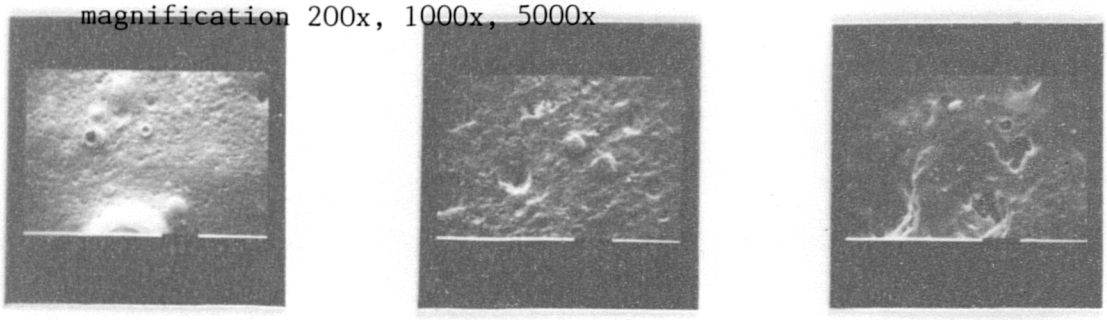
a) $KB_4$60nr Ketac Bond etched 60 sec, washed 60 and dried, after 4 mins but no intermediate unfilled resin

magnification 200x, 1000x, 5000x



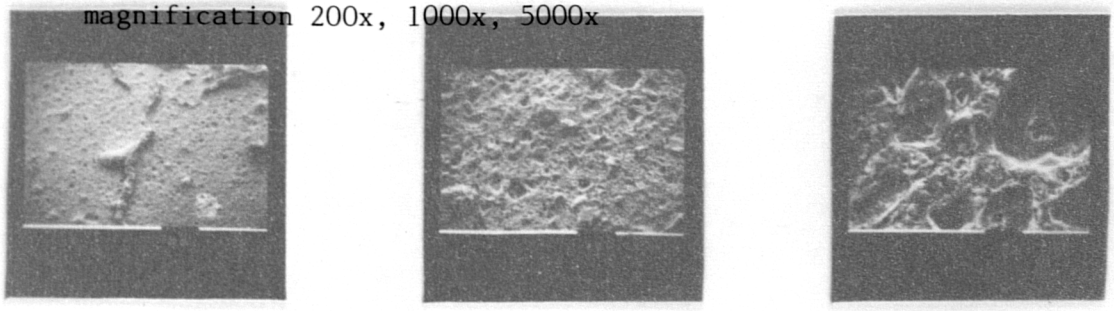
b) $KB_3$60 Ketac Bond etched 60 secs, washed 60 and dried, after 3 mins

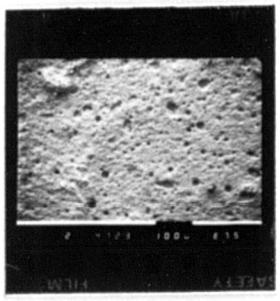
magnification 200x, 1000x, 5000x

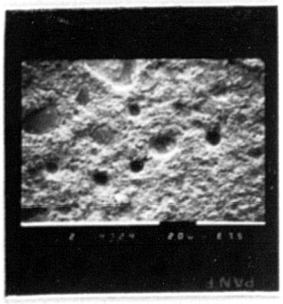


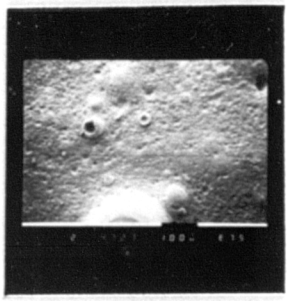
c) $KB_5$30 Ketac Bond etched 30 secs, washed 60 and dried, after 5 mins

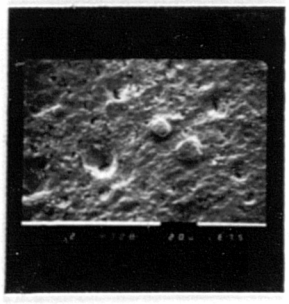
magnification 200x, 1000x, 5000x

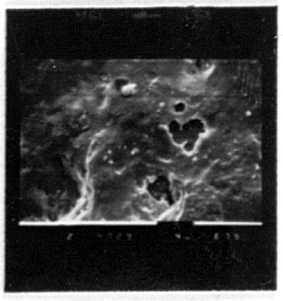


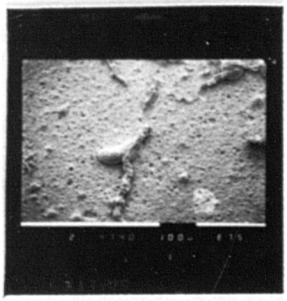


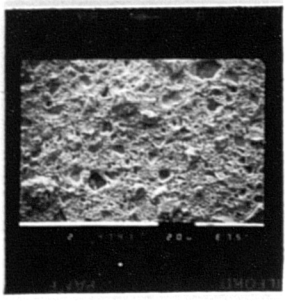












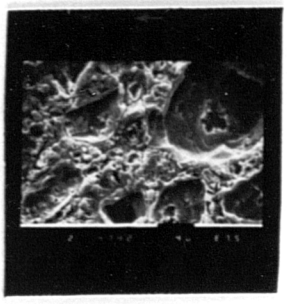


Fig 5.64 Composite resin tag morphology. Ketac Silver and Ketac Fil

a) KS_5ne Ketac Silver washed 60 and dried, after 5 mins
magnification 200x, 1000x, 5000x

b) $KS_5$60 Ketac Silver etched 60, washed 60 and dried, after 5 mins
magnification 200x, 1000x, 5000x

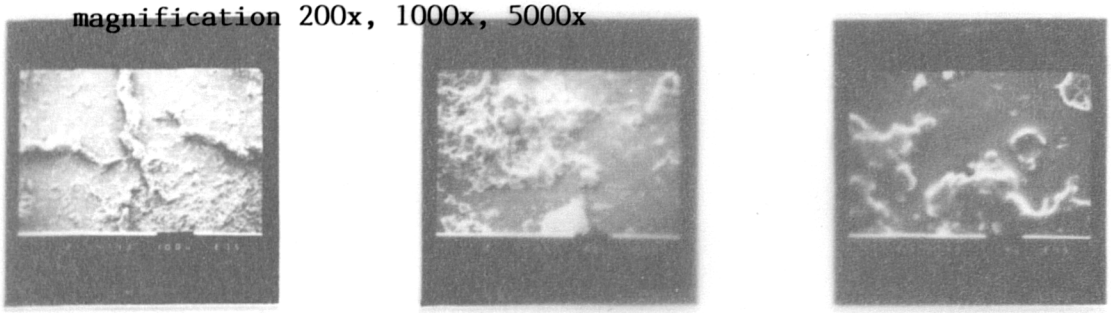
c) $KF_8$60 Ketac Fil, etched 60, washed 60 and dried, after 8 mins
magnification 200x, 1000x, 5000x

d) KF_{15}60 Ketac Fil, etched 60, washed 60 and dried, after 15 mins
magnification 200x, 1000x, 5000x

Fig 5.64 Composite resin tag morphology. Ketac Silver and Ketac Fil

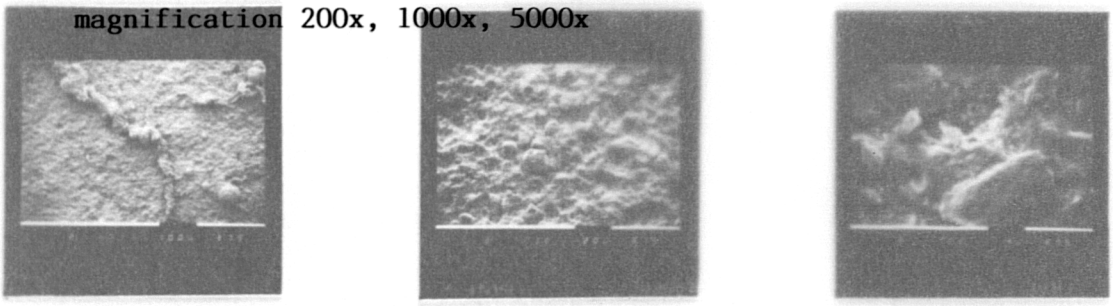
a) KS_5ne Ketac Silver washed 60 and dried, after 5 mins

magnification 200x, 1000x, 5000x



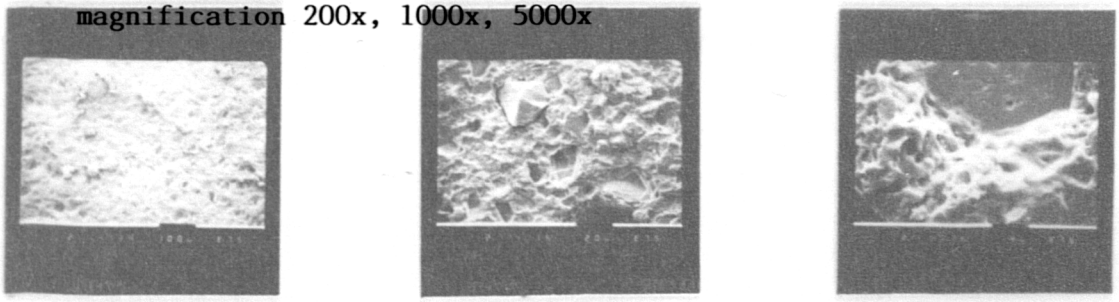
b) KS_560 Ketac Silver etched 60, washed 60 and dried, after 5 mins

magnification 200x, 1000x, 5000x



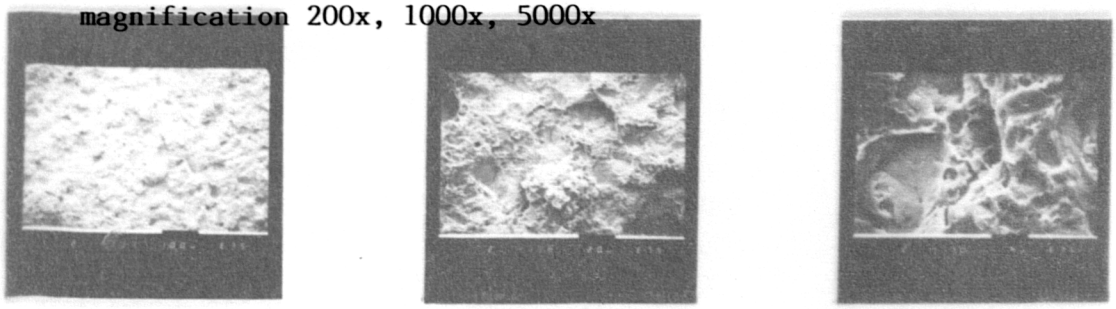
c) KF_860 Ketac Fil, etched 60, washed 60 and dried, after 8 mins

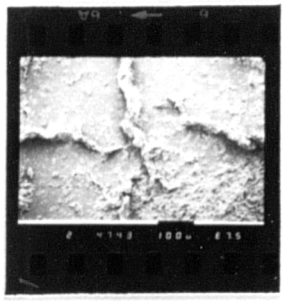
magnification 200x, 1000x, 5000x

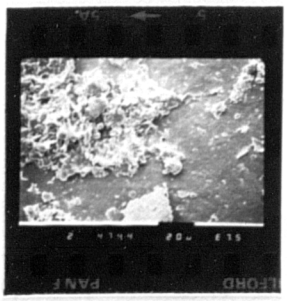


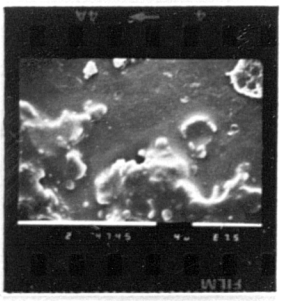
d) $KF_{15}60$ Ketac Fil, etched 60, washed 60 and dried, after 15 mins

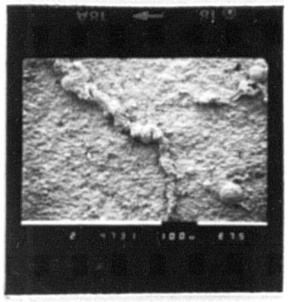
magnification 200x, 1000x, 5000x

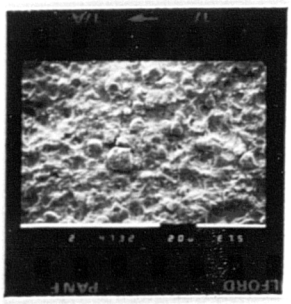


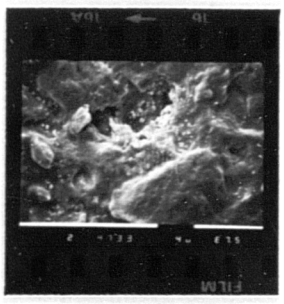


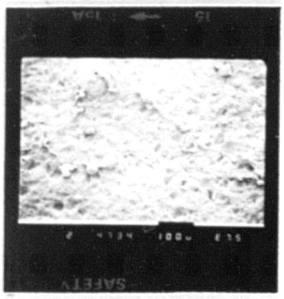


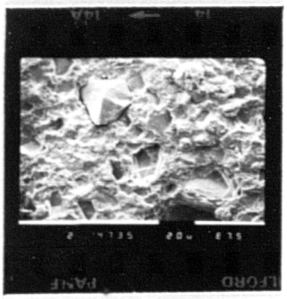


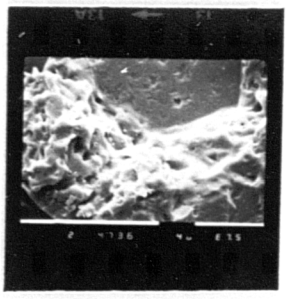


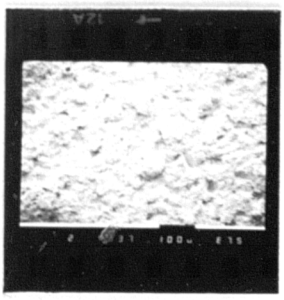


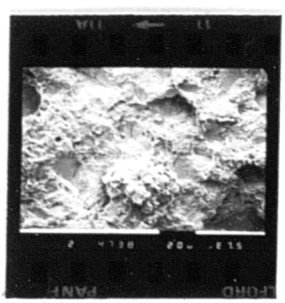


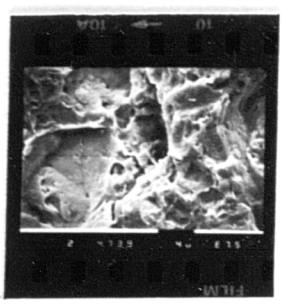












5.3. IN VITRO STUDIES (HELIOCOLOR MICROFILLED COMPOSITE RESIN)

5.3.1. FATIGUE WEAR

The fatigue wear (2 body abrasive wear with some element of fatigue of Heliocolor (Heliosit shade 20) and Adaptic were determined following 1 week of storage in distilled water. A full description of the method is contained in Section 4.2.2.1.1.

The wear rate of the specimens of Heliocolor and Adaptic were compared to those of Occlusin (Chadwick 1988) and expressed as wear factors relative to amalgam (Amalcap) (Table 5.81.). These were obtained by recording the weight loss of specimens vibrated at 43Hz for a total of 320 minutes in vials lined with silicon carbide abrasive paper. The specimens were weighed initially and at 80 minute intervals. At these intervals, the silicon carbide abrasive paper was also changed. The weight loss was converted to the volume lost and its rate calculated. This was then divided by the original specimen weight to give the wear rate of the material. This was expressed as a wear factor relative to amalgam.

There was a significant difference in wear factors between Heliocolor, Adaptic and Occlusin ($p < 0.001$ ANOVA). Tukey Test comparison of wear factors revealed no significant difference between Occlusin and Adaptic, but significant differences between Heliocolor and Occlusin ($p < 0.01$) and Heliocolor and Adaptic ($p < 0.01$). The microfilled resin Heliocolor had a larger wear factor indicating less resistance to abrasion.

TABLE 5.81.

Mean fatigue wear values following 1 week of storage in distilled water. Bracketed figures are standard deviations.

6 specimens tested for each resin.

MATERIAL	WEAR FACTORS
Heliocolor (Heliosit)	2.26 (0.18)
Adaptic	1.84 (0.11)
Occlusin	1.88 (0.14)

Tukey Test significance: ns if means differ by < 0.14

$p < 0.05$ if means differ by > 0.14

$p < 0.01$ if means differ by > 0.18

5.3.2. ABRASIVE WEAR

The 3-body abrasion resistance of a microfilled composite resin (Heliocolor - Heliosit), a hybrid composite resin (Occlusin), a larger particle macrofilled 2 paste chemically activated composite resin (Adaptic) and a lathe cut conventional amalgam alloy (Amalcap) were assessed after 50,000 brush strokes. A full description of the method is contained in section 4.2.2.1.2.

The mean depth loss was obtained from the profile traces by the same method as outlined in section 4.2.1.1. and results are shown in Table 5.82. There was no significant differences between the materials for abrasive wear (ANOVA), and no significant differences comparing paired means (Tukey Test).

5.3.3. ROUGHNESS AVERAGE (Ra)

The roughness average figure is obtained by processing a continuously integrated signal which is then displayed on the meter of the profilometer. The readout obtained is not necessarily a constant value, but a statistical average over a given length of time.

Ra values for the 4 materials tested in the abrasive wear experiment (above) are shown in Table 5.83. Highly significant differences ($p < 0.001$ ANOVA) were detected between the Ra values of the materials. A Tukey comparison of means was performed to localise the differences and this revealed Heliocolor, Occlusin and Amalcap to be not significantly different, but Adaptic to be significantly different (rougher) from all the other test materials ($p < 0.01$).

TABLE 5.82.

Average depth loss (μm.) from 4 profile readings (2 specimens with 2 profiles each). Bracketed figures are standard deviations.

MATERIAL	AVERAGE DEPTH LOSS (μm.)
Heliocolor (Heliosit)	1.49 (1.01)
Occlusin	1.58 (0.56)
Adaptic	2.65 (0.7)
Amalcap	1.66 (0.86)

Tukey Test significance: ns if means differ by < 2.28

$p < 0.05$ if means differ by > 2.28

$p < 0.01$ if means differ by > 2.99

TABLE 5.83.

Roughness average values obtained from 10 profile readings (2 specimens with 5 profiles each). Bracketed figures are standard deviations.

MATERIAL	ROUGHNESS AVERAGE Ra
Heliocolor (Heliosit)	0.49 (0.25)
Occlusin	0.68 (0.14)
Adaptic	1.89 (0.64)
Amalcap	0.75 (0.39

5.3.4. SURFACE HARDNESS

Hardness discs of Heliocolor (Heliosit) were stored in distilled water for 1 hour prior to indentation by a Vickers diamond under a load of 200g. for 20 seconds, as described in Section 4.2.2.1.4. 2 specimens underwent 4 indentations each and the mean Vickers hardness value obtained was 23.5 with a standard deviation of 2.1. Occlusin hardness values at 1 hour, after storage in distilled water (Chadwick 1988), were 60.3 (19.7) for the upper surface and 65.7 (9.5) for the lower surface of the specimens. The Vickers hardness value for the microfilled composite Heliocolor was significantly less than that of the hybrid composite Occlusin ($p < 0.001$ ANOVA).

5.3.5. FLEXURAL STRENGTH

Comparative results of Heliocolor (Heliosit), and Occlusin (Chadwick 1988) tested as described in Section 4.2.2.1.5. are shown in Table 5.84. Highly significant differences in mean strength values were found between the test materials ($p < 0.001$ ANOVA). The test materials were also significantly different for Weibull Modulus ($p < 0.05$) values.

Graphical representation of results (Fig. 5.65.) generated by the Weibull analysis shows the plot of cumulative probability of bond failure versus flexural stress and demonstrates the difficulty of predicting which material might perform better at lower stresses. However, probability of failure calculations obtained by computer analysis of the Weibull equation reveal that at a stress of 13 MPa, the probability of failure is at least for Heliocolor and greatest for Occlusin (Table 5.85.). 13 MPa was the lowest stress that the

computer was able to calculate a probability of failure for both materials.

TABLE 5.84.

Quantitative test values from Flexural strength testing for Heliocolor (Heliosit), and Occlusin following 1 week of storage in distilled water.

30 specimens of each material tested.

	MEAN FLEXURAL STRENGTH (MPa)	STANDARD DEVIATION	WEIBULL MODULUS	S.E. OF MODULUS
Heliocolor	68.56	5.76	12.65	0.32
Occlusin	115.08	21.71	5.14	0.13

TABLE 5.85.

Probability of failure values for the test materials at a Flexural stress of 13MPa.

Heliocolor 4.7×10^{-10}

Occlusin 1.4×10^{-5}

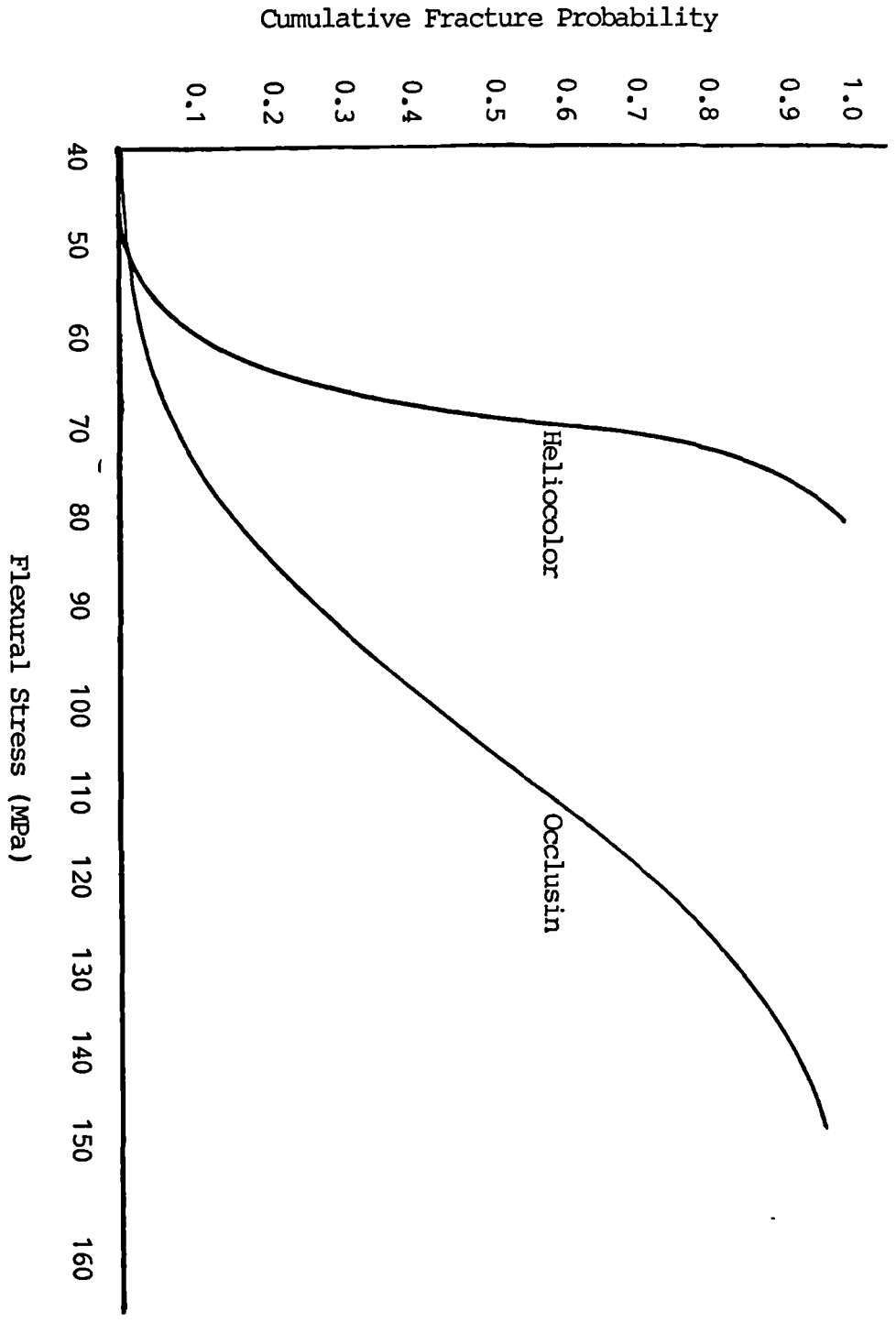


Fig 5.65 Cumulative fracture probability versus flexural stress for 2 composite resins

5.4. IN VITRO STUDIES (THE DEPTH OF ENAMEL REMOVED BY HCI-PUMICE)

The mean amount of enamel loss in microns for the variables detailed in Section 4.2.3. are shown in Table 5.86.

High significant differences were found between the experimental variables ($p < 0.001$ ANOVA). A Tukey comparison of means was performed to localise the differences and this revealed significant differences between the 5 x 5 seconds and the 10 x 5 seconds ($p < 0.05$), between the 5 x 5 seconds and the 15 x 5 seconds ($p < 0.01$), but no significant difference between the 10 x 5 seconds and the 15 x 5 seconds variables.

TABLE 5.86

The amount of enamel loss (μm.) for the 3 experimental variables in the hydrochloric acid-pumice experiment.

6 specimens were tested for each variable.

VARIABLES	DEPTH LOSS (μm.)	STANDARD DEVIATION
5 x 5 seconds	45.38	3.71
10 x 5 seconds	73.90	15.63
15 x 5 seconds	100.13	21.81

6.

DISCUSSION

6.1. IN VIVO STUDIES

6.1.1. GLASS POLYALKENOATE CEMENTS

The requirements for a restorative material in the deciduous dentition are different from those in the permanent dentition. Deciduous teeth in terms of human lifespan are after all only temporary, having a maximum normal life of 8 to 9 years. Consequently, a restoration will only have to last a limited time in function in the oral environment. Previous authors have postulated that glass polyalkenoate cements are capable of fulfilling this requirement (McLean and Wilson 1977b; Saito 1979: Plant et al 1977; Vliestra et al 1978; Knibbs et al 1986; Walls et al 1988). In addition, there are other potential advantages associated with the use of glass polyalkenoate cement as a restorative material in children. The adhesive nature of the material would allow less destructive cavity preparation, this in tern would reduce treatment time, and may mean that local analgesia would not be necessary. Also of importance is the longterm fluoride release from the cement which if in therepeutic amounts, would lead to a local cariostatic environment involving the tooth itself and any adjacent tooth surface for a Class II restoration. However, before these potentially beneficial materials are used it must be demonstrated that they will do at least as good a job as the alternative material (amalgam). This trial was designed to compare the efficacy of a glass polyalkenoate cement with an amalgam as restorative materials in the deciduous dentition.

The results of this study were analysed using survival analysis techniques (Peto et al 1977). This method of analysis allows accurate comparison of the two techniques/materials during the whole of the

follow up period rather than at specific time intervals. Comparison of the two materials is performed by calculating the significance of the differences between the two survival curves, using the Log Rank Test, over the whole of their length. This proviudes an accurate picture of the relative performance of the compared materials over the study period.

The glass polyalkenoate cement underwent a significantly greater loss of anatomical form compared to amalgam both in the early and the latter stages of the trial. This is shown in Figs. 5.3. and 5.4. by the continued divergence of the survival curves with time. This was to be expected in view of the brittle nature of the cement.

The marginal integrity of glass polyalkenoate restorations for scores of 2 or more was significantly better than amalgam. However, for marginal integrity scores 3 or more there was no significant difference, and for scores of 4 or more and 5, the amalgam performed significantly better. The superiority of glass polyalkenoate at lower scores of marginal integrity and the superiority of amalgam at higher scores can be explained by the fact that while amalgam retorations quickly attained a marginal integrity score of 2 they tended to maintain this score for a long period. However, a lot of the glass polyalkenoate restorations while initially maintaining marginal integrity scores of 1, progressively deteriorated to achieve higher marginal integrity scores than amalgam at comparable lengths of service.

Results at levels of failure, for anatomical form (3) and marginal integrity (4 or 5) were combined with those for the development of caries, to determine the overall failure rate of the restorations. There was a significant difference in performance

between the two materials, favouring amalgam, both in the early and the latter stages of the trial. This can be seen by the early and sustained divergence of the respective survival curves in Fig. 5.9. The median survival time for amalgam restorations was 41.4 (S.E. 2.24.) months and that of polyalkenoate restorations was 33.4 (S.E. 2.2.6.) months.

The survival of amalgam restorations was found to be dependant upon the age of the patient at the time of placement of the restoration, while the survival of glass polyalkenoates was not. This can be explained by the fact that adequate operating conditions for amalgam restorations involving local anaesthetic, more extensive cavity preparations and longer treatment time are more difficult in the younger patient. The short treatment times often requiring no local anaesthetic for the placement of glass polyalkenoate restorations are tolerated equally well by younger and older age groups.

The survival of respective types of restoration was found to be independent of tooth type or dental arch. This was slightly surprising regarding the survival of glass polyalkenoate restorations in the lower arch where isolation from saliva is considerably more difficult than the upper arch.

There have been 3 other studies on the performance of glass polyalkenoate cements in the deciduous dentition (Plant et al 1977; Vleistra et al 1978: Knibbs et al 1986b). The results of these trials are difficult to interpret, but approximately 75% of the restorations examined were 'intact' - that is had no gross loss of material - 1 year after placement, and 90% had 'fair to good' marginal adaptation.

The initial report of the 2 year results of this study (Walls et al 1988) suggested that Ketac Fil may be more resistant to gross material loss than ASPA used by Plant et al 1977 and Vliestra et al 1978. The 5 year results presented and discussed above have not endorsed this early finding. Over the longer time span, the marginal integrity was shown to progressively deteriorate.

The median survival time of amalgam restorations in this study 41.4 (S.E. 2.24.) months, was compatible with the longevity of low copper amalgam restoration in occlusal cavities of deciduous molars reported by Holland et al 1986.

The original Null Hypothesis stated that 'amalgam and glass polyalkenoate restorations last the same length of time in deciduous teeth'. The conclusions to be drawn from this study are that when amalgam is placed in a conventional cavity (approximately 28% of occlusal surface) and glass polyalkenoate in a minimally prepared cavity (approximately 16% of occlusal surface) the amalgam restoration is more durable in terms of anatomical form, marginal integrity and overall failure. However, the glass polyalkenoates were found to have a median survival time of around 2½ years, this after having been placed in a relatively atraumatic fashion, often requiring no local analgesia, a shorter treatment time and occupying only 16% of the occlusal tooth surface. Glass polyalkenoate cement is, therefore, a valuable material in paediatric restorative dentistry where treatment involves not only 'plugging holes in teeth', but an awareness that apprehension, fear and pain in the younger patient can mould their dental psyche for life.

6.1.2. MINIMAL COMPOSITE RESTORATIONS

The amalgam used in this study was a conventional, lathe-cut material. Whilst it is probable that the rate of breakdown of anatomical form and marginal integrity would have been less if a high copper alloy had been chosen, there is some evidence that these factors have little relevance in relation to the prevention of recurrent decay and consequently failure of the restoration (Hamilton et al 1983; Letzel et al 1984). In addition, the use of this material allows direct comparison with the published results for the longevity of occlusal restorations in first permanent molars using this material (Walls et al 1985). The composite resin used was a small particle size macrofilled visible light activated material, designed for anterior and premolar use. As such, its properties when used as a posterior restorative material, are somwehat difficult to predict. However, at the commencement of the trial, it was the only visible light activated material available with a compatible visible light activated fissure sealant, thus allowing simultaneous cure of the restoration and the sealant. This system was chosen to avoid any possibility of disruption of the sealant-composite interface as a result of the sealant contracting during polymerisation on top of a set composite surface.

The scoring criteria used for amalgam and minimal composite restorations were dissimilar. Consequently, a direct comparison between the two study groups at any level other than failure is difficult. There was no difference between the two groups in terms of failure of the restorations. The median survival time of amalgam restorations when placed in younger children was considerably better

than that reported by Walls et al (1985). Unlike the study of Walls et al (1985), there was no significant difference in median survival times with age at placement. The rate of failure for minimal composite restorations was greater than that reported by both Simonsen (1980) and Houpt et al (1984).

10 minimal composite restorations exhibited detectable loss of anatomical form or marginal integrity during the study period. The performance of the chosen composite material as a posterior restoration in conventional cavity preparations has not been reported. However, its properties and in vivo wear resistance will probably be better than the macrofilled chemically activated composites due to its method of initiation and lack of porosity (McCabe 1985; McCabe and Ogden 1987). The very low rate of wear encountered in this study may be due to the minimal nature of cavity preparation serving to protect the composite from in vivo wear. The 10 composites that were detected as having a discrepancy in anatomical form occupied approximately 13% of the occlusal surface of the tooth compared to the average 5% value.

50% of the minimal composite restorations underwent partial loss of fissure sealant material. This is a greater loss than that reported by Houpt et al (1984) for similar restorations, but one that falls within the rates of 5% to 81% reported by Bagramian et al (1979) and Isler et al (1980) for fissure sealants alone in a paediatric population. There was no significant difference in loss of fissure sealants between upper and lower arches.

It was not surprising to find that minimal composite restorations, involved much less of the occlusal tooth surface (5%) than either a contiguous amalgam restoration in a permanent molar (25%) or a pit restoration in the mesial portion of the occlusal

surface of an upper first or second molar (15%). This is a reflection of two factors. Firstly, the cavities for the minimal composite restorations were not extended into deep, stained fissures adjacent to the carious lesion (these were sealed with the sealant material), whereas the amalgam restorations were extended into the stained fissure pattern. Secondly, in 10 cases, the amalgam contol replaced an existing amalgam restoration whose extent was outside the control of the investigation. The reduction in the amount of natural teeth tissue removed in the more conservative cavity preparation can only be beneficial to the patient in the future when fresh cavity preparation may be necessary due to recurrent or approximal decay.

Minimal composite restorations compare well with occlusal amalgam restorations after 5 years. There was no significant difference between the median survival times of amalgam [61.48 (1.64)] and composite resin (63.25 (1.36)]. This parity of minimal composite with amalgam restorations was achieved with significantly less destruction of tooth tissue.

6.1.3. GLASS POLYALKENOATE CEMENT - COMPOSITE RESIN SANDWICH TECHNIQUE

Meticulous attention to moisture control and the manufacturers recommended instructions for the materials involved, was followed in this trial. Nevertheless, 11 restorations (22%) had to be replaced within 14 months due to a failure of Ketac Bond glass polyalkenoate cement at the base of the approximal box. This despite the fact that no box extended below the cemento enamel junction. Failure universally took the form of progressive loss of the glass polyalkenoate material , and was always suspected by adjacent erythema

and swelling of the interdental papilla before being confirmed by dental probe. No other reports exist of this application of the glass polyalkenoate composite resin sandwich restoration. 6 restorations of the original 49 had to be replaced due to 'Occlusin' only failures and this figure is very similar to the failure rate after 2 years reported by Wilson et al (1986). Scores for anatomical form, marginal adaptation and surface roughness on the occlusal surface only were also very similar to Wilson et al (1986) although in the sandwich technique, there was slightly more cavomarginal discolouration, but a better colour match and no reported temperature sensitivity. However, in drawing comparisons between the 'Occlusin' restored occlusal surfaces of the sandwich trial after 2 years and the 2 year results of Wilson et al (1986), one should be aware of the small number of patients who completed the 2 year review in the sandwich trial (11) compared to the langer number in Wilson's report (52).

Nevertheless, regardless of the performance of Occlusin composite resin in the more coronal part of the cavities, this trial was designed to investigate whether a sandwich restoration incorporating 1 - 2 mm. of glass polyalkenoate cement at the base of the finished approximal surface in Class II boxes would overcome the problem of cervical contraction gaps in Class II composite resin restorations. It has failed to achieve this aim with the materials used and cannot be adcovated as an alternative method of restoration in the approximal box situation.

6.1.4. MICROFILLED COMPOSITE RESIN VENEERS

The failure rate of 14.5% for the microfilled composite resin veneers compared most favourably with the failure rate of 80% for Mastique laminate veneers found by Walls (1985) in an almost identical population involving a comparable number of veneers over a similar time span. A better retention rate for composite veneers has been reported by Jordan (1981) over a 5 year period, but he reported problems with colour stability and abrasive wear.

The incidence of marginal staining associated with the microfilled composite veneers was very low (6.2%) compared to over 50% with the Mastique veneers (Walls 1985). Colour stability was good with the composite veneers and patient acceptability was high with only 3 veneers being replaced for aesthetic reasons.

In marked contrast to the progressive deterioration in gingival health seen with the Mastique laminate veneers (Walls 1985) the gingival health associated with the microfilled composite veneers was universally maintained at the pretreatment level. This highlights the probable significance of buccal enamel reduction prior to veneer placement, especially in an adolescent age group where oral hygiene habits may be suboptimal.

The hypothesis 'Microfilled composite resin veneers perform better than Mastique veneers in the adolescent and young adult patient' has been proven to be true.

6.1.5. CONTROLLED ENAMEL REMOVAL BY THE HCI-PUMICE ABRASION TECHNIQUE

The aesthetically pleasing results of this technique are self evident, and patient satisfaction has been universal. The technique is quick, painless and easy to perform. Even in cases where stain removal was subtotal the original stain often became unobtrusive to the patient.

On the basis of the results of this study, it seems appropriate not only to endorse the hypothesis 'A method for removing enamel stains by acid abrasion, first practised 70 years ago, still has a place in the armamentarium of modern dental techniques', but also the clinical practice of Croll (1986a) who suggests that all enamel discolourations should be subjected to HCI-Pumice prior to considering any other treatment.

6.2. IN VITRO STUDIES (GLASS POLYALKENOATE-CERMET CEMENTS)

6.2.1. EROSION RESISTANCE

This method for in vitro erosion testing utilises the margins of the specimen holder as fixed datum points to permit direct measurement of the quantity of material lost at the single exposed cement surface. The gentle washing action induced by the repeated immersion and removal of the specimens from their eroding medium removes any loosely bound surface debris at each cycle, thus exposing a fresh cement surface throughout the test sequence, without any possible abrasive action from a brush or tissue.

(a) The susceptibility of the glass polyalkenoate and glass cermet cement to erosion cycling is affected by the age of the cement and the cement type. Ketac Fil and Chelon are identical in composition, the only variations in presentation are that polyalkenoic acid is in an aqueous solution in Ketac Fil, and is in a vacuum dried powder mixed with the ion leachable glass in Chelon, and that Ketac Fil is a mechanically mixed encapsulated material and Chelon is a hand mixed product mixed with a 15% aqueous solution of tartaric acid. It came as no surpise, therefore, that the Ketac Fil and Chelon specimens behaved very similarly in terms of susceptibility to erosion, apart from at 15 minutes where Ketac Fil was statistically superior and after 28 days when the converse was true.

Ketac Bond is a 'fast setting' material which is hand mixed from an aqueous solution of 85% water and 15% tartaric acid, and an ion leachable glass powder that has incorporated into it freeze dried polyacrylic and polymaleic powders. It is

considerably less susceptible to erosion than either Ketac Fil or Chelon at any of the times tested. The reason for this is unclear. Susceptibility to erosion is dependant upon the stability of the polysalt matrix which will be influenced by: the composition of the ion leachable glass and its fusion temperature (Crisp and Wilson 1974b; Barry et al 1979); the nature and molecular weight of the polyalkenoic acid (Crisp et al 1980); and the presence and proportion of a suitable chelating agent in the cement mix (Crisp and Wilson 1976). The nature and molecular weight of the polyalkenoic acid is very similar for Ketac Fil, Chelon and Ketac Bond all manufactured by ESPE. Watts et al (1981) have reported marked variation in the formation of the glasses used in commercially available cements, and it may be that this, in association with an accelerated setting reaction, is responsible for the improved erosion resistance of Ketac Bond. Ketac Silver a glass cermet cement containing sintered metallic particles performed similarly to Ketac Bond with no significant difference between the two materials at any time. It is possible that the sintered metal particles are confering improved erosion resistance compared to other glass polyalkenoates.

The experimental cement, Coltene 018804 B, of which little is known of its composition underwent erosion that was independent of the cements age and which did not improve with increasing time. This suggests that after 15 minutes, this cement was set as completely as at 28 days, and this was further investigated in the differential thermal analysis investigations.

(b) Erosion as a function of varying powder:liquid ratios of Chelon and Ketac Bond showed the same dependence upon specimen age no matter what p:l was employed. Those specimens allowed to set for longer period underwent less erosion. However, the response of the two cements to varying the p:l ratio away from the manufacturers recommended ratio was different. Increasing the p:l ratio for Chelon from 6.7:1 to 7.54:1 did not significantly improve erosion resistance except for the 24 hour result. Increasing the p:l ratio to 8.38:1 resulted in an improved erosion resistance at all times, except the 24 hour result, where there was no significant difference. Conversely reducing the p:l ratio resulted in ambivalent results for the 15 and 60 minute specimens, but for the 24 hour, 7 day and 28 day specimens resulted in a lowered resistance to erosion. The common clinical practice of increasing the p:l ratio would appear from these results to be beneficial in terms of an improved resistance to erosion for Chelon cement. However, increasing the p:l ratio for Ketac Bond cement was found to be generally detrimental in terms of erosion resistance while reducing p:l ratio produced results that were no poorer than the manufacturers' recommended ratio of 3.4:1. This highlights the appropriate recommendations of the manufacturers for Ketac Bond, and the common clinical practice of increasing the p:l ratio to quicken set and improve the strength of the cement is not to be recommended in view of the likelihood of a reduced resistance to erosion. Why these two cements should react differently to variation in p:l ratio is unclear.

The objective of any in vitro test method is to attempt to

reproduce the type of erosion encountered in vivo, but over a reduced time period. Sensitive chemical analyses have been suggested to provide a total estimation of the decomposition products, both soluble and insoluble, of dental cements (Wilson 1976), but variations between cements in structure and composition would mean that each cement type would require its own specific analysis (Walls et al 1985). Studies of erosion of glass ionomer cement in both neutral (demineralised water) (Crisp et al 1976, 1980) and acidic media (lactic acid - sodium lactate buffer 0.01M) (Crisp et al 1980) have been reported. Chemical analysis of the eluates and gravimetric weighing of the sample discs (both pre and post erosion cycling) were undertaken in these studies, and the rate of elution was found to increase as the powder liquid ratio was decreased.
Crisp et al (1980) used a wet toothbrush to remove loosely bound surface debris from erosion cycled specimens. This does not reflect the action of oral fluids and asperities exposing a fresh cement surface during oral function. A flask/shaker (McCabe 1982) and a falling column of liquid (the jet test) (Beech and Bandyopadhyay 1983, Oilo 1984, Setchell et al 1985) have also been employed to remove debris during cycling. The amount of erosion may be determined by weight loss (McCabe 1982), Beech and Bandyopadhyay 1983, Oilo 1984) or by direct measurement such as depth loss (Walls et al 1985; Setchell et al 1985).
However, the method for erosion testing used in this work was that employed by Walls et al (1985), where the specimens

rotate around a series of beakers containing alternately pH4 lactic acid eroding solution and pH7 distilled water buffer. This method has proved an accurate and reproducible method of comparing erosion between different cements and is independent of their structure and composition. The use of alternate beakers of pH4 and pH7, and the gentle washing effect gives a more realistic appraisal of cement performance in terms of likely in vivo erosion.

6.2.2. DIAMETRAL COMPRESSIVE TENSILE STRESS

(a) The variation in mechanical properties with material composition. Ketac Bond and Coltene performed significantly worse than all the other materials in terms of mean compressive tensile stress and probability of failure, and Coltene also performed worse than all other materials in terms of Weibull Modulus. Why Ketac Bond should perform so much worse than Ketac Fil is not clear unless it be the presence of polymaleic acid in the Ketac Bond cements. The glass cermet Ketac Silver incorporating sintered metal particles is significantly stronger than Ketac Bond and Coltene but not superior to Ketac Fil 8 and Ketac Fil 15. The stength of Ketac Silver may be a manifestation of the incorporation of metallic particles into the material, or it could be related to the glass used in its manufacture. The latter point could also be relevant to the superior properties of Ketac Fil.

(b) The variation in mechanical properties with variation in the powder:liquid ratio of Ketac Bond specimens. Changing the clinical handling properties of Ketac Bond cement by adding or subtracting powder to achieve a stiffer or more runny mix will result in detrimental changes in terms of mean compressive tensile stress, probability of failure and Weibull Modulus. The manufacturers' recommended p:l ratio (3.4:1) performed superiorly to all others and should be adhered to in order to achieve the materials full potential with regard to this particular property.

A statistical approach to material properties may explain many

practical observations on dental materials. It is known that many materials perform well in most cases, but occasionally fail for no apparent reason. The Weibull analysis offers a means of being able to predict the dependability of a material, and simple calculations allow the prediction of failure probability at any selected level of stress of vice versa. In dentistry, if it was known exactly what stresses had to be withstood in various situations, the probability of failure at these stresses would then be the important material property, and could be calculated readily using the Weibull equation. Bates et al (1975) and McCabe and Carrick (1987) have suggested that the likely overall mean chewing pressure experienced by any tooth surface or restoration would be lower than 1MPa, although they acknowledge there would be a wide variation for many reasons. Therefore, overall reliability of a material is related to both mean strength and Weibull Modulus considered together, e.g., probability of failure. A material with a very high Weibull Modulus but a low mean strength would not be very reliable. An example of this is shown in the diametral compressive tensile stress experiments. Ketac Bond has a low mean strength, a high value for Weibull Modulus, but an overall poor reliability indicated by its high probability of failure at 1MPa. Coltene in addition has a low mean strength, a low Weibull Modulus, and the highest probability of failure at 1MPa.

6.2.3. BIOMECHANICAL PROPERTIES

6.2.3.1. THERMAL ANALYSIS (REACTION KINETICS)

Differential thermal analysis has proved to be a convenient and reproducible method of evaluating setting characteristics (Walls et al 1988c). The time required for the temperature of the specimen to fall to 5% of Tmax gives an indication of the extent of reaction still occurring within the specimen, after the apparent 'setting time'. It is probable that the materials will still be adversely affected by moisture contamination during this period. Other methods of monitoring the setting reaction would probably not be able to distinguish this characteristic, as the material will appear rigid at the time corresponding to Tmax.

(a) There are significant differences between the materials under test in the rate of their setting reaction. As might be expected, the 'fast setting' lining material Ketac Bond exhibited the quickest temperature rise and time to 5% of Tmax compared to Coltene at both 23°C and 37°C. For both cements at both parameters the 37°C times were faster than the 23°C times. Ketac Bond is a radiopaque lining material manufactured specifically for use beneath composite resins and as such, it would need to set rapidly. It fulfils this latter criteria admirably compared to Coltene 018804 B, but some thought should be given to the magnitude of the exotherm that would be produced in relatively close proximity to the pulp. The magnitude of the exotherm represented by 3 different parameters: Peak exotherm °C, Rise °C per mg. wt., and Area under exotherm curve (cm^2) per mg. wt. (equivalent to heat of

reaction), all significantly favour Coltene at 37°C (i.e., it has a lower exotherm).

The rapid setting reaction of Ketac Bond is probably associated with altered structure and composition of the glass. Alteration in the composition of these glasses can result in acceleration of the setting reaction, but this is usually associated with deterioration in the appearance of the set cement which would not be so important in these two materials.

(b) Varying the powder liquid ratio of Ketac Bond produced no significant change in any of the 3 exothermic parameters at 23°C, but resulted in an increased exotherm at 37°C for higher p:l ratios and a reduced exotherm for lower p:l ratios. This highlights the clinical significance of carrying out laboratory investigations at temperatures that can be equated with oral temperature. Contrary to the recommendations of Comley (1987) and the laboratory findings of Walls et al (1988) at 23°C increasing the p:l ratio did not result in an accelerated setting reaction, but one in which there was a delay in reaching the maximum temperature rise, and also a retardation of the cooling process. However, at 37°C, an increase in p:l ratio did not delay the attainment to Tmax, but there was a statistically significant retardation of the cooling process. The effect of such variation in setting upon the properties of the cement are difficult to predict. However, it would seem likely that they would be susceptible to moisture contamination in vivo for a longer time after mixing than those mixed at the correct p:l ratio.

6.2.3.2. BOND STRENGTH DETERMINATION

(a) GLASS POLYALKENOATE - DENTINE

2 major problems are associated with the measurement of bond strengths of any material to tooth tissue. The first problem is one of specimen preparation and alignment, and the second is the use of a natural tissue as adherent.

Taking the former problem first, the bond strength of one material to another can be measured in tension or in shear, and practical difficulties exist with both. A shear force is usually applied by aligning the specimen beneath a testing jig and applying a load parallel to the bond interface, with the point of application of the load as close to the bond as possible. A misalignment of the specimen within the test rig would mean that the applied load would not solely be in shear, and secondly with odd specimen geometry it is not always practicable to apply shear load at the bond interface and there will always be an element of leverage in the applied force giving additional tensile and compressive loadings at different sites across the surface of the bond. In tensile measurements the bond interface should be perpendicular to the direction of the applied force. Inaccuracies occur when there is malalignment of the specimen in its holder due to preparatory inaccuracies. If there is misalignment, then the distracting force will not be solely tensile and can be resolved into its tensile and compressive elements. It is also important to ensure that the specimen holder and the testing machine does not impart any element of torsional load onto the system.

The use of a natural tissue dentine as adhered poses problems due to the variable mineralisation of dentine according to the age of the patient at the time of extraction and the level that the section was prepared at. As the patient gets older, there is progressive deposition of peritubular and secondary dentine. The peritubular dentine is deposited initially in the areas close to the amelo-dentinal junction, producing progressive occlusion of the dentinal tubules from amelo-dentinal junction to the pulp. The overall effect of these changes is to increase the thickness of the dentine and render the peripheral tissue hypermineralised relative to central tissue. There is also a progressive reduction in the frequency and area of dentinal tubules from the centre to the periphery. Dentine is also a vital tissue, the presence of tubular fluid ensures that a cut dentinal surface is wet and has an organic component to its surface. After extraction the tooth tissues are subject to post mortem change. Causton and Johnson (1979b) found that post mortem change significantly altered the measured bond strength of glass polyalkenoate cements to dentine and also recognised that the conditions under which a tooth is stored after extraction may affect the bond strength. Walls (1985) measured tensile bond strength after dentine storage in various media and concluded that the best sotrage media was Neutral Buffered Formulin.

To overcome problems of misalignment of specimens a series of accurate alignment jigs were constructed to minimise misalignment problems, thus allowing a tensile test method to

be used with the minimum potential for error. The alignment jigs were designed to allow the adhered surface to be lapped until flat and then to attach the specimen holder perpendicular to the prepared tooth surface. The bond strength testing jig was prepared with multiple universal joints, in an effort to eliminate any discrepancy in specimen alignment, and a freely rotating roller bearing to correct any tendency towards torsional loading at the bond interface. The method produces consistent bond strength measurements between teeth, and between replicate measurements on the same tooth.

Highest mean bond strengths and Weibull Moduli and lowest failure probabilities with or without pretreatment with polyacrylic acid were achieved by Coltene 018804 B. The composition of this material is unknown, and so it is not possible to speculate on its superiority. Before treatment with polyacrylic acid, Ketac Silver gave the poorest tensile bond strength. However, after polyacrylic acid pretreatment, the bond strength achieved rosse significantly. Conversely, the tensile bond strength of Ketac Fil to dentine was reduced after treatment with polyacrylic acid and those of Coltene and Ketac Bond remained statistically similar. The reason for these findings remains unclear, but it may be related to the nature and molecular weight of the polyalkenoic acid in the test materials. Certainly, these findings add fuel to both sides of the longstanding debate whether dentine pretreatment is beneficial or not.

It is normal practice in materials science when measuring mechanical properties such as strength to make a series of

measurements on a number of apparently identical specimens. Typically, the results show considerable variation, particularly when the fracture process is of a brittle nature, and tensile bond strength tests are notorious for producing results having a wide variation (Beech 1985). Variations may reflect the quality of the 'bond', but are also due to experimental variations involved in such tests, including improper alignment during bond rupture such that a degree of torsion or shear is introduced. However, the alignment jig used in the tensile bond strength measurements in this piece of work was designed to minimise any such problems.

The use of a normal distribution, on which mean and standard deviation calculations are based, assumes that the mean value is the 'true value' and that random variations around this true value are due to variations in test method, specimen preparation etc. Variations in test method in this case should be minimal and, therefore, most variation is probably due to specimen preparation. In a series of tests for strength, it is possible to explain low values by assuming specimen faults. It is impossible to explain extraordinary high values except by assuming that they are approaching the 'true strength' of the material. Traditionally, the method for presenting data from tensile bond strength tests is by quoting the number of tests, mean bond strength and standard deviation. Hence, when comparing systems considerable emphasis is placed on the mean value. The Weibull analysis relates probability of bond failure to tensile stress and takes into account both mean strength and

Weibull Modulus. It offers a means of being able to predict the dependability or reliability of a material and it is suggested that in future, less emphasis should be placed on the mean value of strength when evaluating mechanical properties. More value would be gained from giving the probability of failure at a selected and hopefully relevant level of stress or vice versa.

(b) GLASS POLYALKENOATE - COMPOSITE RESIN

(i) TENSILE BOND STRENGTH (T.B.S.) AS A FUNCTION OF MATERIAL COMPOSITION.

The merits of using the Weibull analysis for T.B.S. testing results has already been discussed. In terms of overall reliability, i.e., probability of failure, related to both mean bond strength and Weibull Modulus, the best performance at 1MPa was achieved by Ketac Fil (KF_{15}^{60}), while Ketac Silver (KS_{5}^{60}) and Coltene 018804 B (Col_{4}^{60}) had a 7 - 10 times greater, and Ketac Bond (KB_{4}^{60}) a 30 times greater probability of failure. The trial cement Coltene performed significantly better than its intended market competitor Ketac Bond.

The location of the bond failure differed for the variables under test. A high proportion of cohesive failures was seen in KB_{4}^{60} and Col_{4}^{60}, and a significant proportion of adhesive failure in KF_{15}^{60} (37%), and KS_{5}^{60} (40%). Adhesive failure suggests a poorer bond to composite resin. The reason why KS_{5}^{60} should have so many adhesive failures is not readily apparent, unless 5 minutes is too early to etch or the sintered silver particles make it more resistant to acid penetration. Results from section (v) of these tensile bond strength tests

where Ketac Fil etched for 60 seconds after only 8 minutes after mix commencement (KF 60) showed no adhesive failure suggest that the aged glass polyalkenoate KF^{8}_{15} 60 with 37% adhesive failure may be more resistant to acid etching. Almost all of the cohesive failures in the tensile bond strength testing of glass polyalkenoate cements to composite resin occurred more than 1 mm. from the etched bond. This could be due to a concentration of internal stresses at this level or the intermediate resin layer may have imparted an increased strength to the 1 mm. layer of cement next to the etched bond. However, this latter explanation suggests resin penetration to a depth of 1 mm., which is unlikely.

(ii) T.B.S. FOR KETAC BOND - OCCLUSIN AS A FUNCTION OF THE POWDER:LIQUID RATIO OF KETAC BOND.

Probability of failure calculations at a stress of 1MPa indicate that increasing the p:l ratio from 3.4:1 to 3.83:1 reduces failure probability 2 fold. Conversely reducing the p:l ratio from 3.4:1 to 2.55:1 will result in a 3 times greater failure probability. Therefore, in terms of tensile bond strength to composite, a thicker mix than recommended will be beneficial - notwithstanding potential clinical application difficulties.

(iii) T.B.S. FOR KETAC BOND - OCCLUSIN AS A FUNCTION OF THE LENGTH OF TIME AFTER COMMENCEMENT OF MIX PRIOR TO ETCHING, THE TYPE AND DURATION OF ETCH, AND THE PRESENCE OF AN UNFILLED INTERMEDIATE RESIN LAYER.

The probability of failure at a stress of 1MPa for the manufacturers recommended regime KB$^{60}_{4}$ was 15.2×10^{-3}. Failing to use an intermediate unfilled resin (KB$^{60nr}_{4}$) resulted in a 34 times greater failure probability, etching too soon (KB$^{60}_{3}$) resulted in a 15 times greater failure probability, and bonding without washing or etching the glass polyalkenoate cement (KB$^{new}_{4}$) resulted in a 9 times greater failure probability. These 3 experimental variables (KB$^{60nr}_{4}$, KB$^{60}_{3}$, KB$^{new}_{4}$) performed significantly worse than all others. The similar failure probabilities to the recommended KB$^{60}_{4}$ of the 2 other variables prepared after 4 minutes KB$^{ne}_{4}$ (washed only) and KB$^{30}_{4}$ (etched 30 seconds and washed) suggest that there are no advantages to be gained by etching with acid and a simple water wash will suffice. However, the probability of failure at a stress of 1MPa for the 2 specimens that were prepared 60 minutes after mix commencement (KB$^{ne}_{60}$ and KB$^{60}_{60}$) indicate that when bonding a composite resin to an older glass polyalkenoate cement the use of acid etching and washing will be required to produce the best bond. The older cement would appear to be more resistant to a simple water wash. The 3 experimental variables that performed significantly worse than all the others KB$^{new}_{4}$, KB$^{60nr}_{4}$ and KB$^{60}_{3}$ also had more adhesive failures confirming a weaker bond to composite resin.

(iv) T.B.S. FOR KETAC SILVER - OCCLUSIN AS A FUNCTION OF THE LENGTH OF TIME PRIOR TO ETCHING, THE TYPE AND DURATION OF ETCH, AND OF MECHANICAL PREPARATION OF THE CEMENT SURFACE PRIOR TO ETCHING.

The probability of failure at a stress of 1MPa for the manufacturers' recommended regime KS 60 was 3.5×10^{-3}. A simple wash only, after the same length of time (KS $_{5}^{ne}$) resulted in a reduction of failure probability by threefold. It is, therefore, advantageous not to etch Ketac Silver with acid prior to bonding it to composite resin, but merely to wash with water.

The 3 experimental variables that were prepared after 60 minutes KS $_{60}^{ne}$ (wash only), KS $_{60}$ (etch 60 and wash) and KS $_{60}^{60m}$ (mechanical preparation after etch and wash) showed that KS $_{60}^{ne}$ and KS $_{60}^{60m}$ performed better than KS $_{60}$. This indicates that when bonding composite resin to an older Ketac Silver cement, a mechanical preparation of the surface followed by a simple water wash will produce an adequate bond without needing to acid etch as well.

(v) T.B.S. FOR KETAC FIL-OCCLUSIN AS A FUNCTION OF THE LENGTH OF SET PRIOR TO ETCHING.

The probability of failure calculations indicate that although the manufacturer recommends that Ketac Fil cement is not etched until 15 minutes have elapsed from commencement of mix, a comparable bond will be achieved if the cement is etched after 8 minutes.

The increase in adhesive failures in the cement etched after 15

minutes suggests that the aged cement may be more resistant to acid etching.

(vi) T.B.S. FOR COLTENE-OCCLUSIN AS A FUNCTION OF THE TYPE OF ETCH EMPLOYED.

The probability of failure calculations at a stress of 1MPa show that a simple wash with water will produce a more reliable bond than that produced after acid etching and washing.
The location of bond failures was predominently cohesive and the same for the two experimental variables.

6.2.3.3. DEPTH OF ETCH DETERMINATION

(i) THE VARIATION IN DEPTH OF ETCH WITH MATERIAL COMPOSITION.

Significantly less cement was lost by washing only compared to etching and washing for both cements. This could be relevant in the clinical situation when the thickness of glass polyalkenoate cement is very thin.

(ii) THE VARIATION IN DEPTH OF ETCH FOR KETAC BOND WITH EARLIER ETCHING AND WASHING OF THE SPECIMEN.

Washing or acid etching Ketac Bond after only 3 minutes from commencement of mix instead of the recommended 4 minutes made no difference in terms of amount of cement loss.

(iii) THE VARIATION IN DEPTH OF ETCH WITH DIFFERING p:l RATIOS OF KETAC BOND.

Significantly more cement was lost with the lower p:l ratios of Ketac Bond. Increasing the p:l ratio from the manufacturers recommended value did not result in a reduced amount of cement loss, but one that was no different statistically from the recommended regime.

6.2.3.4. MORPHOLOGY OF ETCHED SURFACES

(a) THE STUDY OF GLASS POLYALKENOATE CEMENT SURFACE.

The series of SEM photographs demonstrates that there is little to be gained in terms of surface roughness of the glass polyalkenoate cement by a prolonged etch. Prolonged etching will merely result in removing sufficient polysalt matrix to expose and eventually lose the glass core particles. Thereupon, the whole cycle of loss of matrix and glass particles will start again.

(b) THE STUDY OF COMPOSITE RESIN TAG MORPHOLOGY.

The effectiveness of a wash with water alone is well demonstrated by the series of S.E.M. photographs in Fig. 5.62b. These show an almost identical morphology to specimens that were etched and washed.

The poor retention morphology of those specimens that were neither etched or washed (Fig. 5.62a.), bonded without using an unfilled intermediate resin (Fig. 5.63a.) and etched too soon (Fig. 5.63b) is clearly demonstrated.

These studies of composite resin tag morphology correlate very well with the results of the tensile bond strength experiments previously discussed.

6.3. IN VITRO STUDIES (HELIOCOLOR MICROFILLED COMPOSITE RESIN)

6.3.1. FATIGUE WEAR (2 body abrasive wear with some element of fatigue)

Adequate abrasion resistance is a necessary requirement of both posterior and anterior restorative materials. The technique of McCabe and Smith (1981) as used in this study, to assess the abrasion resistance of a number of dental restorative materials, may be described as a two body abrasion test with an element of fatigue, the wear rates of the test materials are expressed as wear factors relative to the control material, a conventional amalgam. It should be pointed out that although the test ranks materials according to their observed clinical abrasion resistance the test only involves abrasive wear with an element of fatigue whereas clinical wear is a more complex phenomenon.

Following one week of storage in distilled water, the wear factor of Heliocolor was significantly different from that of Adaptic and Occlusin, but there was no significant difference between Adaptic and Occlusin. The difference is probably a reflection of both the quantity and particle size distribution of the filler found in these materials (Draughn and Harrison 1978) with the microfilled material Heliocolor having the highest wear rate, and the hybrid resin Occlusin and the macrofilled resin Adaptic having a lower and almost identical wear rate. The materials with the lower wear rate, the hybrid resin Occlusin and the macrofilled resin bearing areas, i.e., posterior teeth. The microfilled composite resin with the highest wear rate will not be suitable in stress bearing areas, but in clinical situations where it will be protected from heavy stress, i.e., as an

anterior veneering agent.

6.3.2. ABRASIVE WEAR

The 3-body abrasion test involving 50,000 brush strokes found no significant difference between the 3 composite resins. It is probable that this test was not discriminative enough to highlight the differences found with the aforementioned 2 body abrasion test after a short storage period. Differences may become apparent after longer lengths of storage in distilled water prior to testing.

6.3.3. ROUGHNESS AVERAGE (Ra)

The roughness average figures obtained showed that the surface of the macrofilled resin Adaptic was significantly rougher than the hybrid resin Occlusin, the microfilled resin Heliocolor, and the lathe cut alloy Amalcap. This result correlates with the clinical 'polishability' of composite resins which is poorest with the macrofilled resins like Adaptic.

6.3.4. SURFACE HARDNESS

Occlusin has a superior surface hardness to Heliocolor due to the larger particle size of fillers and greater filler content in the hybrid resin. This relationship to filler size content was also found with abrasion resistance properties.

The magnitude of some of the physical properties of composite resins may be affected by the absorption of a small percentage of water. This is more likely to affect the surface of the material before the bulk (Braden et al 1976). This may have significant effects upon the surface hardness of the material with time (Hansen

1983). Further studies of these two materials with longer storage times in distilled water would allow such a comparison (e.g., Chadwick 1988).

6.3.5. FLEXURAL STRENGTH

The probability of failure at 13MPa (the lowest stress the computer analysis was able to predict a probability of failure for both materials) of Heliocolor the microfilled resin was much greater than that of Occlusin the hybrid resin. This can be explained by the larger particle size of fillers in the hybrid resin giving it increased strength. However, in gaining advantages in strength, the hybrid resin is not as 'polishable' as the microfilled resin and, therefore, inferior as an anterior veneering agent where high flexural strength values are not so important. Conversely, Heliocolor would not be as suitable a posterior restorative as Occlusin.

These results mirror the surface microhardness results for the two materials. This is perhaps not surprising as flexural strength may be influenced by the surface properties of the material.

When considering restoration of a tooth with a labial veneer that does not include incisal edge coverage a microfilled resin will be most suitable aesthetically and will be strong enough to withstand flexural stresses in this situation. However, when including incisal edge coverage in a veneer additional strength could be gained by using a combination of microfilled resin to cover the buccal surface and hybrid resin to cover the incisor tip. This would achieve a stronger restoration without unduly compromising the aesthetics (polishability).

6.4. THE DEPTH OF ENAMEL REMOVED BY HCI-PUMICE

The clinical regime employed for this technique was a maximum of 10 x 5 second applications. The laboratory investigations for this regime showed an average depth loss of 74μm. In terms of the overall enamel thickness, this is a small amount and acceptable for such a clinical procedure in view of the benefits achieved.

7.

PRINCIPAL FINDINGS

The principal findings of this research are:

1. A glass polyalkenoate cement was more susceptible to failure than an amalgam restoration when used as a posterior restorative material in the deciduous dentition, during a follow up period extending over 5½ years. The median survival time of glass polyalkenoate cement restorations was 33.4 months compared to 41.4 for amalgam restorations.
2. The marginal integrity of a glass polyalkenoate cement was better initially than amalgam, but while amalgam restorations remained relatively stable the glass polyalkenoate deteriorated more quickly.
3. A glass polyalkenoate cement underwent more rapid loss of anatomical form than amalgam when used as a posterior restorative material in the deciduous dentition.
4. The area of the occlusal surface of the teeth occupied by glass polyalkenoate cements was almost half that of amalgam restorations (16% compared to 28%).
5. The glass polyalkenoate restorations were not 'age dependent', whereas amalgam restorations in deciduous molars were 'age dependent' being less durable in younger age groups and more durable in the older age groups.
6. A minimal composite restoration, combined with a fissure sealant is no more susceptible to failure than an amalgam restoration for the treatment of occlusal caries in the permanent molar dentition after a 5½ year follow up period. The median survival time for the composite restorations was 63.25 months compared to 61.48 for amalgam restorations.

7. The minimal composite restorations occupied on average 5% of the occlusal surface of the tooth, compared with 25% for the amalgam restorations in this study.

8. The minimal composite restorations and the amalgam restorations in permanent molars were not 'age dependent' [cf No 5]. However, the number of overall failures in this trial was low and this should be taken into account when interpreting this result.

9. Minimal cavity preparations appear to offer an element of protection, to the composite material from wear in the oral environment.

10. The use of a glass polyalkenoate cement under a composite resin in Class II cavities in permanent molar and premolar teeth, where the glass polyalkenoate cement forms part of the finished approximal wall of the total restoration, was associated with a high failure rate. The failures usually occurred due to loss of glass polyalkenoate cement from the base of the box.

11. A microfilled composite resin veneer system exhibited a low level of failure rate and marginal staining over a follow up period extending to 2½ years.

12. The Hydrochloric Acid-Pumice abrasion technique for the removal of the intrinsic enamel stains proved quick and easy to perform and results were impressive for most stains of this nature.

13. Etching glass polyalkenoate cement with acid prior to bonding it to composite resin is not necessary and a simple wash with water will suffice.

14. Etching and washing a glass polyalkenoate cement too soon after commencement of mix will result in a poorer bond to composite

resin.

15. Failure to use an unfilled intermediate resin layer when bonding composite resin to glass polyalkenoate cement will result in a poorer bond.

16. Pretreatment of dentine with polyacrylic acid prior to bonding to glass polyalkenoate and cermet cements results in an improved bond with Ketac Silver, a poorer bond with Ketac Fil and made no significant difference with the two cements Ketac Bond and Coltene 018804 B.

17. Treatment of the surface of set glass polyalkenoate cement with water prior to bonding to composite resin resulted in less cement loss than a procedure involving both etching and washing.

18. The overall performance of Ketac Bond glass polyalkenoate cement over the Erosion, Compressive Tensile, Tensile, Differential Thermal Analysis, and Depth of Etch tests reported in this work was best at the manufacturers' recommended powder:liquid ratio of 3.4:1.

19. No single glass polyalkenoate material had properties which were better in every respect than those of other products. Properties varied and some materials performed better in some tests than others. Comparison of Coltene 018804 B and Ketac Bond, two cements intended for similar clinical applications, showed that while Coltene formed a superior bond to dentine and had a lower exothermic setting reaction, Ketac Bond had a superior erosion profile and achieved a quicker setting time.

20. Heliocolor, a microfilled resin system had a greater fatigue

wear factor, an inferior surface hardness, and a greater probability of failure at the same flexural stress than Occlusin a Hybrid resin.

21. The amount of enamel removed by the clinical regime employed in the HCI-Pumice abrasion technique was small.

22. Mechanical properties of dental materials are more meaningful when quoted in terms of failure probability at certain levels of stress.

8.

CONCLUSIONS

The Literature Review posed a number of hypotheses. To conclude this piece of work, these should be answered:

1. "Amalgam and glass polyalkenoate last the same length of time in deciduous teeth."

   Under the conditions of the clinical trial involving deciduous teeth the median survival time of amalgam was greater than glass polyalkneoate cement.

2. "Amalgam and minimal composite restorations last the same length of time in permanent molar teeth."

   Under the conditions of the clinical trail involving permanent teeth, this null hypothesis was upheld.

3. "The sandwich technique is a solution to cervical gap formation in Class II composite resin restorations."

   Under the conditions of the clinical trial involving the sandwich technique it was shown that the technique has severe limitations and cannot be recommended as a solution to cervical gap formation in Class II composite resin restorations.

4. "Microfilled composite resin veneers perform better than Mastique laminate veneers in the adolescent and young adult patient."

   Under the conditions of the clinical trial involving microfilled composite resin veneers, this hypothesis was upheld.

5. "A method for removing enamel stains by acid abrasion, first practised 70 years ago, still has a place in the armamentarium of modern dental techniques."

   This hypothesis was also upheld.

6. "Pretreatment of dentine with polyacrylic acid results in a stronger tensile bond to glass polyalkenoate cement."
   This hypothesis was not upheld. Different glass polyalkenoate cements behaved differently. Tensile bond strength was increased with one cement, decreased with another and showed no change with two cements after dentine pretreatment with polyacrylic acid.
7. "Etching of glass polyalkenoate cement is required to produce a satisfactory bond with composite resin."
   This hypothesis was not upheld and a simple water wash of the surface of the glass polyalkenoate cement resulted in as good a bond as that achieved after etching and washing.
8. "The tensile bond strength of the glass cermet cement Ketac Silver to composite resin is superior to that formed between conventional glass polyalkenoate cements and composite resins."
   This hypothesis was not upheld. The tensile bond strength of Ketac Silver to composite resin was superior to some glass polyalkenoates and composite resin, but not all.

APPENDIX I

This appendix contains details of the scoring criteria used during the clinical trials in this study

PART I Scoring criteria for Amalgam, Glass Polyalkenoate Cement and Minimal Composite resin restorations

Scoring criteria for Marginal Adaptation

1. The restoration appears to adapt closely to the tooth along its periphery, with no crevice formation. An explorer will not catch on being drawn across the margin, or if it will catch then only in one direction.

2. A sharp explorer will catch in both directions and there is visible evidence of early crevice formation into which the explorer will penetrate. Dentine and lining are not visible.

3. A blunted (0.4mm tip diameter) explorer will catch in both directions and there is visible evidence of early crevice formation into which the explorer will penetrate. Dentine and lining are not visible.

4. An explorer will penetrate into the crevice to sufficient depth that the dentine or lining is exposed. The restoration requires replacement.

5. The restoration is fractured or lost.

Scoring criteria for Anatomical Form

1. The restoration is continuous with the existing anatomy of the tooth.

2. The restoration is not in continuity with the existing anatomy of the tooth, but the discontinuity is insufficient to expose

dentine or lining material and hence the restoration is clinically acceptable.

3. The restoration is not in continuity with the existing anatomy of the tooth, the discontinuity is sufficient to expose dentine or lining, hence the restoration requires replacement.

Scoring criteria for Marginal Staining

0 No marginal stain visible

1 Marginal stain visible

Scoring criteria for Recurrent Decay

0 No recurrent decay detected

1 Recurrent decay detected, the restoration requires replacement

Scoring criteria for Minimal Composite Restorations

1. The restoration is intact, no treatment required.

2. There is partial loss of the fissure sealant portion of the restoration, the sealant requires 'topping up'.

3. There is complete loss of the fissure sealant portion of the restoration, the sealant requires replacement.

4. There is complete loss of both fissure sealant and composite restoration, the restoration does not expose dentine and is still clinically acceptable.

5. There is loss of fissure sealant and composite restoration with exposure of underlying dentine and/or lining. The restoration requires replacement.

6. Marginal staining.

7. Another. Specify eg caries.

PART II Scoring criteria for the Glass Polyalkenoate-Composite Resin sandwich restorations

Classification of Cavity Size

The size of the cavity was classified under the following scoring system.

Occlusal:

1. Cavity extends up the cuspal incline less than $\frac{1}{4}$ of the distance from depth of fissure to cusp tip.

2. Cavity extends between $\frac{1}{4}$-$\frac{1}{3}$ up the cuspal incline.

3. Cavity extends greater than $\frac{1}{3}$ of way up cuspal incline.

Interproximal:

1. Cavity just clearing contact point areas and into embrasures.

2. Cavity well into embrasure areas.

3. Cavity extending into the buccal and palatal/lingual walls.

Depth of Box:

1. Above cemento-enamel junction.

2. At cemento-enamel junction.

3. Below cemento-enamel junction.

Clinical Assessment Criteria

Anatomic Form:

A. The restoration is continuous with existing anatomic form.

B. The restoration is discontinuous with existing anatomic form, but the missing material is not sufficient to expose dentin or base.

C. Sufficient material lost to expose dentin or base.

Marginal Adaptation:

A. The restoration appears to adapt closely to the tooth along the periphery of the restoration. An explorer does not catch when drawn across the margins, or, if it does catch it will only catch in one direction and no crevice is visible.

B. The explorer catches and there is visible evidence of a crevice into which the explorer will penetrate. However neither dentin nor base is visible.

C. The explorer penetrates into a crevice that is of such depth that dentin or base is exposed.

D. The restoration is fractured, mobile or missing.

Surface Roughness:

A. Surface of restoration is smooth.

B. Surface of restoration is slightly rough or pitted, can be refinished.

C. Surface deeply pitted, irregular grooves (not related to anatomy) cannot be refinished.

D. Surface is fractured or flaking.

Marginal Discolouration:

A. No discolouration anywhere on the margin between restoration and the tooth structure.

B. The discolouration has not penetrated along the margin in a pulpal direction.

C. The discolouration has penetrated along the margin in a pulpal direction.

Colour Match:

A. The restoration matches in colour and translucency the adjacent tooth structure.

B. The mismatch in colour and translucency is within the acceptable range of tooth colour and translucency.

C. The mismatch in colour and translucency is outside the acceptable range of tooth colour and translucency.

Discomfort/Sensitivity:

A. None.

B. Mild.

C. Tolerable.

D. Severe.

PART 3 Scoring criteria for the Microfilled Composite Resin Veneer restorations

The Gingival Index (After Loe and Sillness 1963)

0	Absence of inflammation	
1	Mild inflammation	Slight change in the colour and little change in the texture of the gingival tissues.
2	Moderate inflammation	Moderate glazing, redness, oedema and hypertrophy. Bleeding on probing.
3	Severe inflammation	Marked redress and hypertrophy. Tendency to spontaneous bleeding. Ulceration.

APPENDIX 2

This appendix contains details of the composition of the buffer solutions and storage media used during this study

pH 4.0 Buffer solution:

69.4 ml of Analar grade Lactic Acid solution, made up to 8 litres with distilled water.

320 ml of 1:1 dilution of GPR grade sodium lactate. Checked against pH 4.0 buffer solution.

Storage Solutions

Neutral Buffered Formalin:

4.0 gm Sodium Dihydrogen Orthophosphate.

6.5 gm Anhydrous Disodium Hydrogen

Distilled Water:

Prepared using a commercial continuous still as required.

APPENDIX 3

This appendix contains details of the materials and devices used in this study

Part 1. Materials

ADAPTIC	Johnson and Johnson, East Windsor, New Jersey USA.
ALPINE MELINEX MATRIX STRIPS	De Trey Dentsply Ltd, Weybridge, Surrey England.
AMALCAP	Vivadent, Schaan, Lichtenstein.
CHELON	ESPE Gmbh, Seefeld/Oberbay BRD.
COPALITE	Cooley and Cooley Ltd, Houston, Texas, USA.
DURAFILL	Kulzer Gmbh, BRD.
HELIOCOLOR	Vivadent, Schaan, Lichtenstein.
KALZINOL	De Trey Dentsply Ltd, Weybridge, Surrey, England.
KETAC-BOND	ESPE Gmbh. Seefeld/Oberbay BRD.
KETAC-FIL	ESPE Gmbh. Seefeld/Oberbay BRD.
KETAC-SILVER	ESPE Gmbh. Seefeld/Oberbay BRD.
LIFE	Sybron Kerr Europe, Bassel, Switzerland.
MILINEX	Imperial Chemical Industries PLC, Welwyn Garden City.
OCCLUSIN	ICI, Macclesfield, England.
PERSPEX	Imperial Chemical Industries PLC, Welwyn Garden City.

PRISMA FIL	L.D. Caulk Co. Dentsply International Inc. Milford, Delaware, USA.
PRISMA SEAL	L.D. Caulk Co. Dentsply International Inc. Milford, Delaware, USA.
VARNISH	De Trey Dentsply Ltd, Weybridge, Surrey, England.

Part 2. Devices

ALPOLIT VUP 9157 (Polyester casting resin)
Resinous Products Ltd, Dunston, Tyne & Wear, England.

Ci ROBAL MICROFORCE BALANCE
CI Electronics Ltd, Salisbury, Wiltshire, England.

DIGITAL EQUIPMENT CORPORATION LS1-11/23
Digital Equipment Corporation, Manyard, Massachusetts, USA.

WITH

GICO DIGIPAD 5 GICO rockville, Maryland, USA.

HISTOKINETTE Shandon Southern Products Ltd, Cambridge, England.

INSTRON UNIVERSAL TESTING MACHINE Model 1195
Instron Ltd, High Wycombe, Buckingham, England.

KIPP AND ZONEN BD9 TWO CHANEL PEN RECORDERS
Kipp and Zonen, Delft, Holland.

KODACHROME 64 Eastman Kodak Inc., Rochester, New York, USA.

KONTRON MOP VIDEOPLAN DIGITAL ANALYSIS SYSTEM
Kontron Gmbh, Munich BRD.

METASERV ROTARY PREGRINDER and METSET MOULDS

Metallurgical Services Laboratories Ltd., Betchworth, Surrey, England.

MICROMETER — Mitutoyo Osaka, Japan.

MIKROKATOR — CEJ, Eskilstuna, Sweden.

MULTIBLITZ RING FLASH

Mannesman Gmbh, Porz-Westhoven, BRD.

NIKON F1 — Nippon Kogaku K.K., Marunouchi, Tokyo, Japan.

OERTLING TP 41 and U 40 BALANCES

Oertling Ltd., Orpington, Kent, England.

PVC TAPE — RS Components Ltd., Corby, Northants, England.

PYE Model 291 pH METER

Pye Unicam Ltd., Cambridge, England.

STANTON REDCROFT DTA 671 and TMA 691

Stanton Redcroft Ltd., London, England.

SURFOMETER TYPE SF101

Planer Products Ltd., Sunbury on Thames, England.

THERMAL CHILLER — Churchill Instrument Co. Ltd., Perivale, Middlesex, England.

Part 3. Chemicals

ANALAR GRADE — Lactic Acid, Sodium Hydroxide, Hydrochloric Acid and Sodium Dihydrogen Phosphate.

GPR GRADE — Sodium Lactate.

Standard Buffer Tablets for pH 4.0

ALL from — BDH Chemicals Ltd, Poole, England.

HYDROCHLORIC ACID - 17.7%

Boots the Chemist, England

CARBORUNDUM POWDER (400 GRIT)

The Carborundum Co. Ltd., Trafford Park, Manchester, England.

SILICON CARBIDE ABRASIVE PAPER (180, 400, 600 & 800 GRIT)

Wetordry TriMite, 3M United Kingdom Ltd., Bracknell, Berkshire.

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2) Typographic Errors.

Page 227, 2nd para, line 6, "fiven" to read "given".
Page 400, line 13 "tern" to read "turn".

Page 401, "proviudes" to read "provides".

Page 404, reference "Letzel et al 1984" read "Letzel and Vrijhoef 1984".

Page 407, line 15: "langer" to read "larger".

Page 407, penultimate line: "adcovated" to read "advocated".

Page 409, penultimate line: HCI" to read HCl". Error also repeated in subhead title on this page and on page 438 (2nd line, subsection 21).

Page 420, last line, 1st para "Formulin" to read "Formalin".