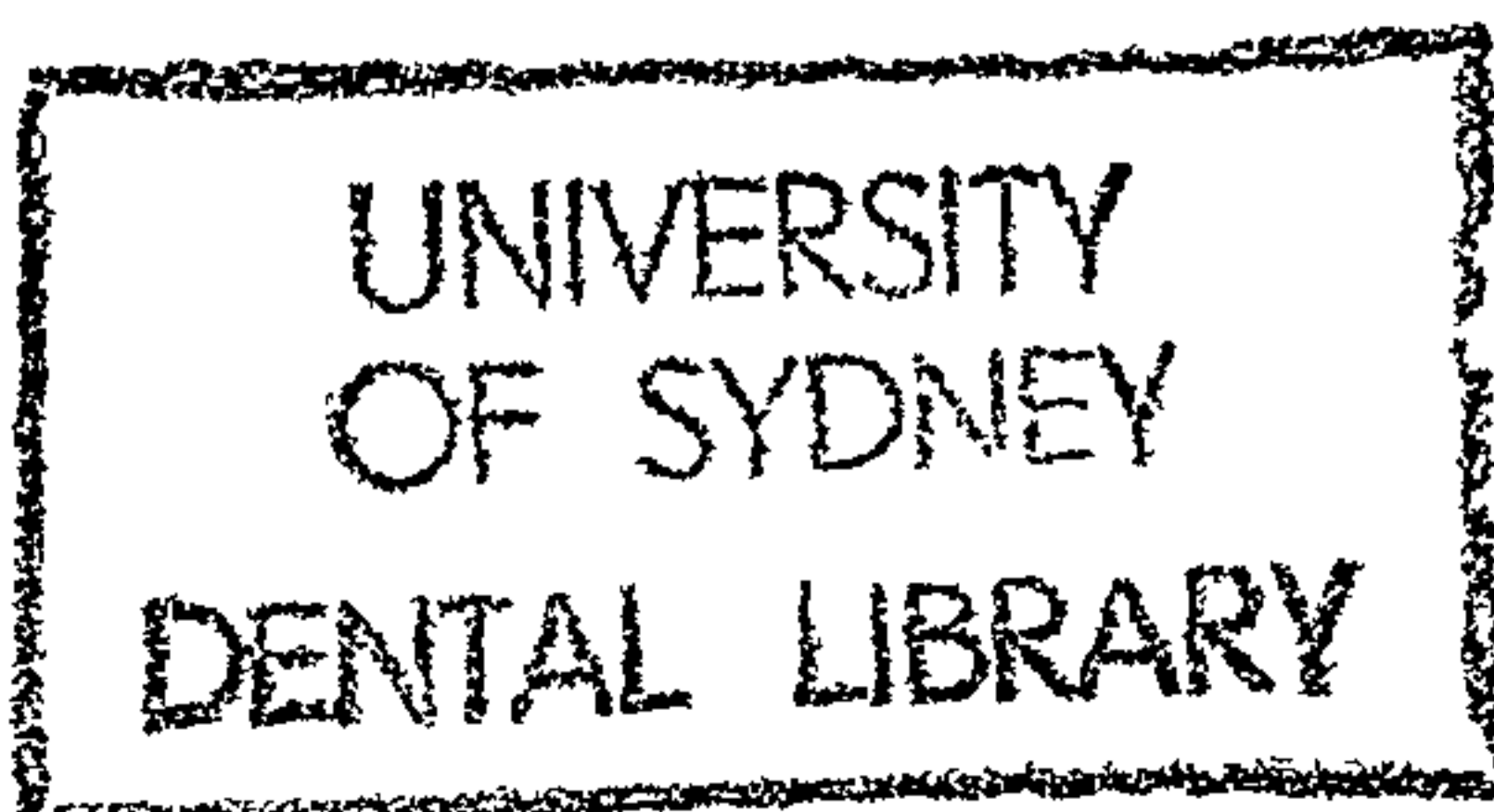


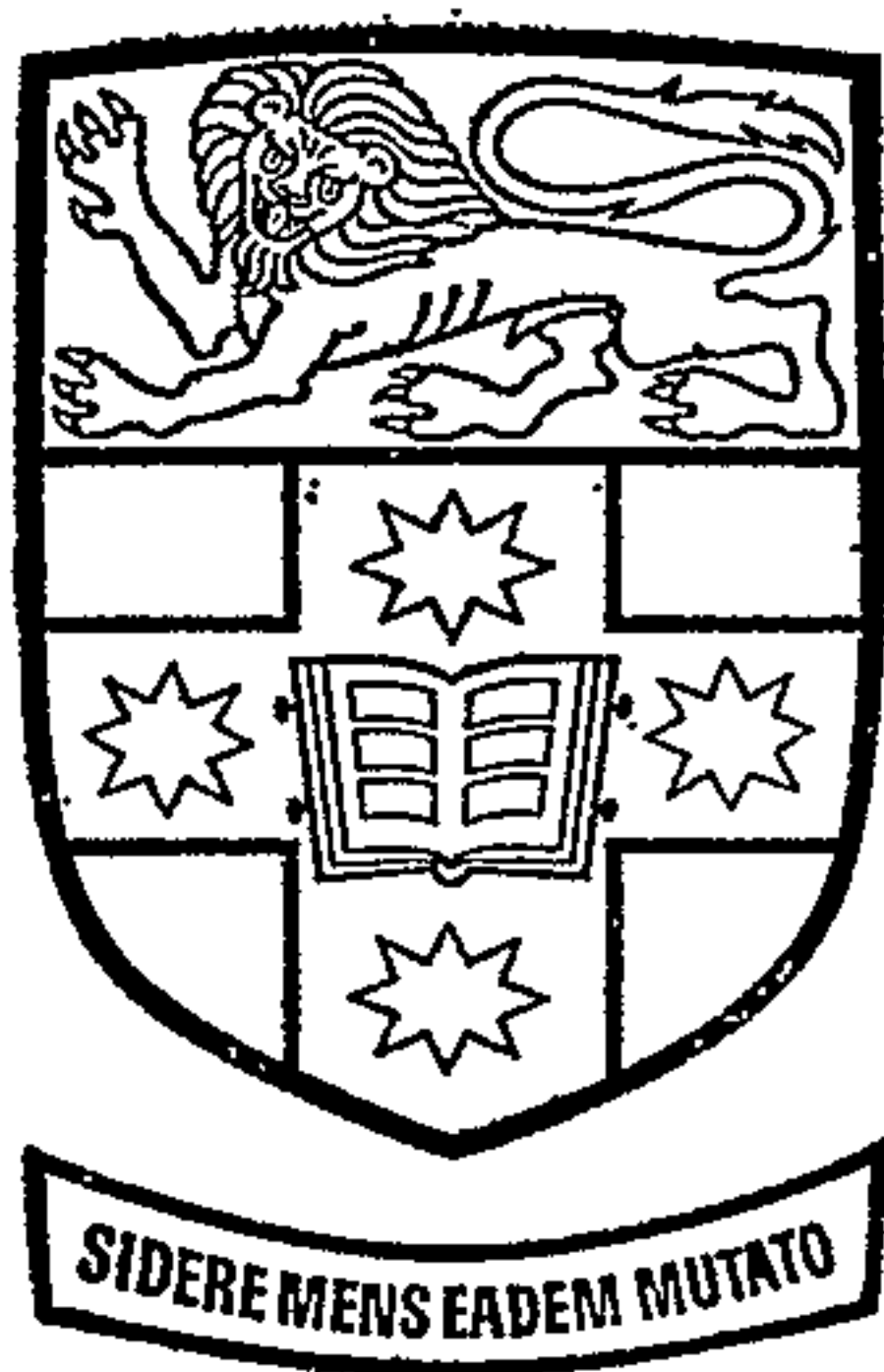
ORTHODONTIC ADHESIVE RESIDUE FOLLOWING DEBONDING

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## INTRODUCTION

Bonding orthodontic appliances directly to teeth is now a widely accepted practice. A recent survey of 2000 American specialist orthodontists showed that 93% of respondents were using such techniques (Gorelick, 1979).

One disadvantage noted in the survey was that debonding is more time-consuming and uncomfortable than debanding. By definition debonding implies the total removal of adhesives and appliances and the restitution of the tooth surfaces to pretreatment normal. Clinical and laboratory studies have shown this to be a problem area in orthodontics.

This study was designed to compare the debonding residue of three different types of orthodontic adhesives and to investigate the relationship between this and the different physical and handling properties of these adhesives.

## REVIEW OF LITERATURE

### 1. ADVANTAGES OF BONDING

The bonding of orthodontic attachments directly to tooth enamel eliminates the necessity of circumferential stainless steel bands. The advantages of such "bandless orthodontics" have been often propounded (Newman, 1965; Retief, Dreyer and Gavron, 1970; Lee, Orłowski, Enabe and Rogers, 1974; Brandt, Servoss and Wolfson, 1975; Barnard, 1976; Moser, Dowling, Greener and Marshall, 1976; et al.), and can be summarised as:

1. Improved aesthetics.
2. Facilitation of oral hygiene procedures.
3. Elimination of the danger of decalcification under loose or poorly fitted bands.
4. Reduced gingival irritation.
5. Reduced discomfort during appliance placement.
6. Reduced time for placing appliances.
7. Elimination of the need to separate teeth before banding, or close spaces after debanding.
8. Facilitation of interproximal stripping during treatment.
9. Simplification of attachment procedures to unerupted or partially erupted teeth.

## 2. APPROACHES TO BONDING

Bonding to enamel involves factors of adhesion and micromechanical interlocking. These mechanisms have been discussed by Brauer and Huget (1972), Phillips (1973), Lee and Orłowski (1973), Buonocore (1975), Driessens (1977), Glantz (1977) and Retief (1978).

The three major avenues explored to determine the ideal bonding method have been:

1. The development of adhesive cements.
2. The use of thin, intermediary layers of coupling agents to effect adhesion between enamel and bracket cement.
3. Modification of the enamel surface to render it amenable to adhesion.

### ADHESIVE CEMENTS

Docking (1973) reviewed attempts to bond orthodontic attachments directly to teeth. The most promising materials for use on unmodified enamel were the polycarboxylates developed by Smith (1968).

The properties of these cements have been enthusiastically presented by Smith (1969) and Mizrahi and Smith (1969;1971). However, Phillips, Swartz and Rhodes (1970) and Sadowsky and Retief (1976) found tensile bond strengths too low to be clinically satisfactory.

### COUPLING AGENTS BETWEEN RESINS AND ENAMEL

Bowen (1965) synthesised the addition-reaction product of N-phenylglycine and glycidyl methacrylate (NPG-GMA) for use as a coupling agent. He showed a 200% improvement in bond strength of direct filling resins to disced human enamel. Retief (1975a), using polished human enamel, found that nine of his specimens failed to bond at all. The remaining six produced a

mean tensile adhesive strength of only  $0.8 \text{ N/mm}^2$  compared with Bowen's (1965) claim of  $51.3 \text{ kg/cm}^2$  ( $5.0 \text{ N/mm}^2$ ).

#### ENAMEL PRETREATMENT

Buonocore (1955) described how the application of 85% phosphoric acid to enamel, prior to the placement of acrylic resin, greatly improved retention. He suggested five possible factors for this increased adhesion:

1. Greatly increased surface area, due to increased roughness.
2. Exposure of organic matrix to which resins can adhere.
3. Creation of spaces along interprismatic areas, into which resins can penetrate.
4. Removal of old, fully reacted, inert enamel surface and exposure of a fresh, reactive surface more favourable for adhesion.
5. Adsorption onto the enamel of highly polar phosphate groups, derived from the acid used, which may enhance adhesion and wettability.

This system of enamel modification for adhesion has been called the "acid-etch technique" and involves penetration of the enamel by "tags" of adhesive resin (Buonocore, Matsui and Gwinnett, 1968).

The length of such tags has been variously reported as 5-10 microns (Brandt et al., 1975), about 25 microns (Buonocore et al., 1968; Newman, 1973), or 50-60 microns (Retief, 1973; 1974; Silverstone, 1975).

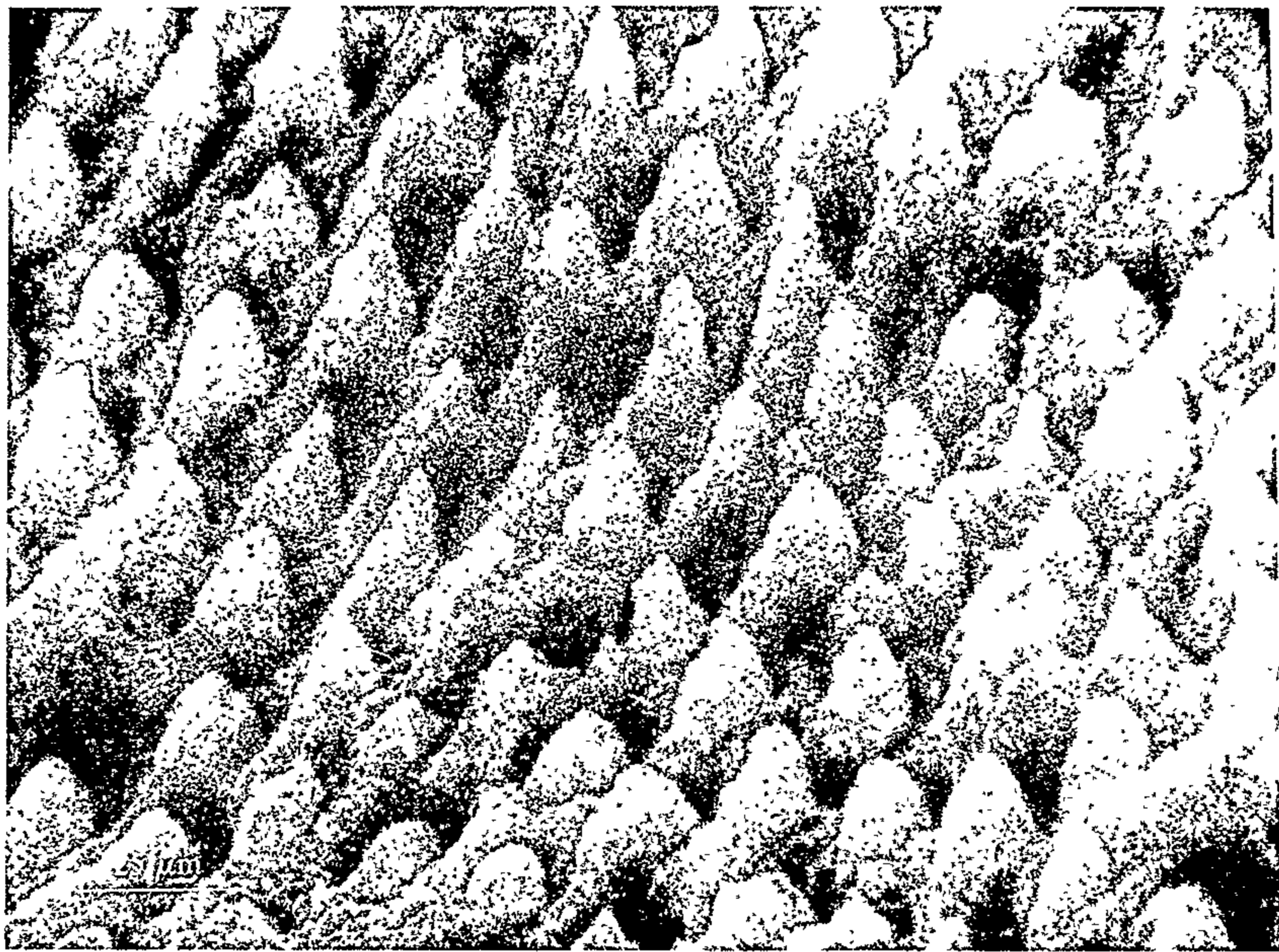


Fig.1: Resin replica of etched enamel showing "tags".  
(From : Silverstone and Dogon, 1975.)

### 3. ACID ETCHING

#### EFFECTS ON ENAMEL

Microscopic examination of the roughened surface of acid-etched enamel shows three patterns (Silverstone, Saxton, Dogon and Fejerskov, 1975):

type 1 : prism cores preferentially dissolved.

type 2 : prism peripheries dissolved.

type 3 : no normal prism morphology evident.

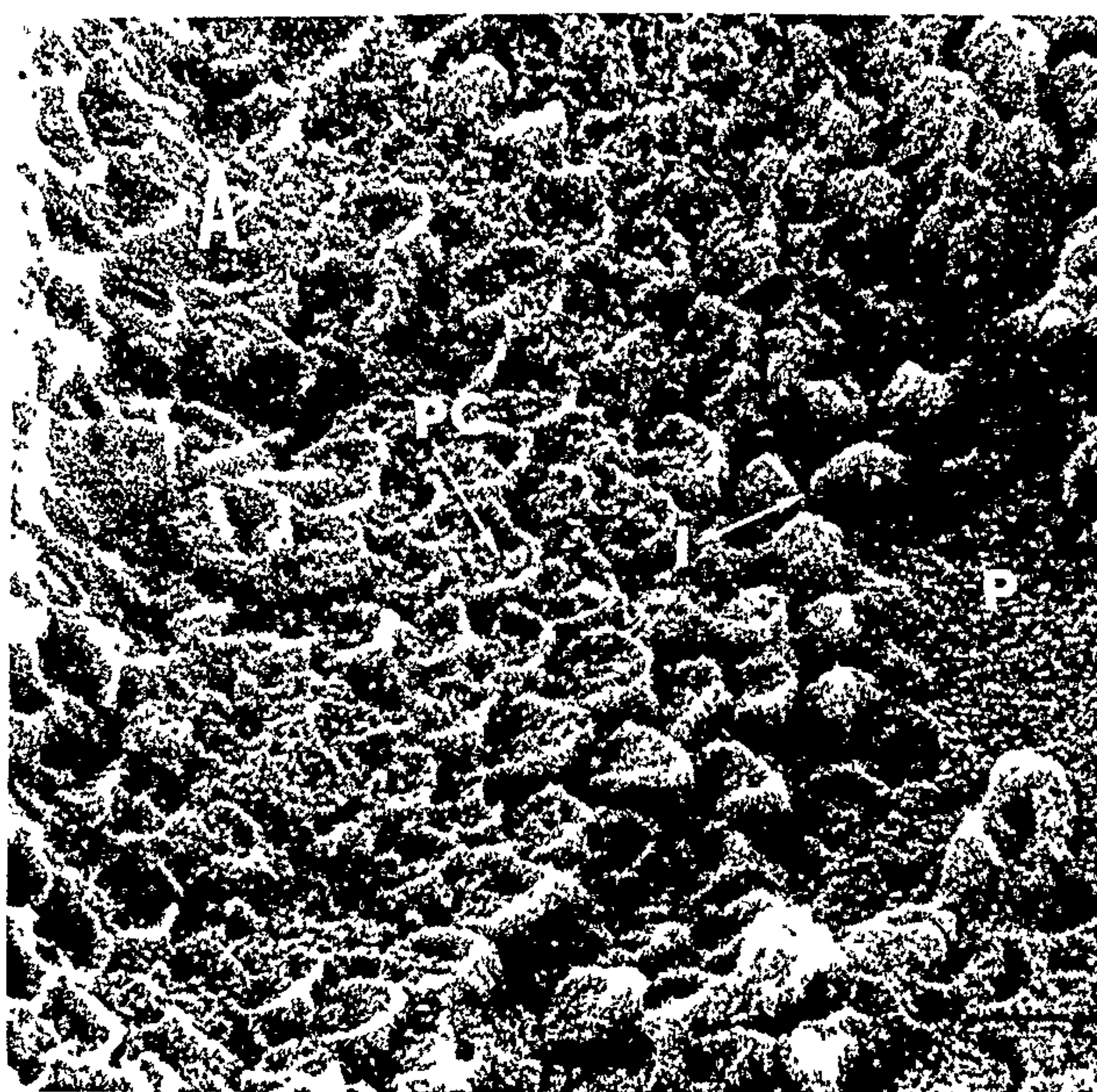


Fig.2: Photomicrograph of etched enamel, showing type 1, (PC), type 2. (I), and type 3 (P) zones.  
( From: Buonocore, 1975.)

Retief (1978) discussed the role of crystallite orientation in producing these patterns. The relationship of etching type to acid used was investigated by Poole and Johnson (1967), Gwinnett, Buonocore and Sheykhholeslam, (1972), Marshall, Olson and Lee (1975) and Bozalis and Marshall (1977).

Tyler (1976) found predominantly type 1 patterns when specimens were left static, and type 2 if they were agitated during etching. Maijer and Smith (1978) produced different patterns by using a gel preparation compared with the normal acid solutions.

Silverstone (1975) defined three zones shown in sections of acid-etched enamel:

1. "Etched" zone : totally dissolved or "lost" enamel.
2. "Qualitative porous" zone : microscopically visible porosity.
3. "Quantitative porous" zone : demonstrable by resin replica and birefringence techniques.

The depths of these two "porous" zones for different etchants and the etch patterns produced could affect adhesive bond strength initially, and ease of debonding subsequently.

#### ACIDS INVESTIGATED FOR ENAMEL ETCHING

The earliest report on acidic pretreatment for orthodontic bonding recommended 40% phosphoric acid, but it was noted that 10% hydrochloric or 50% sulphuric acid could also be used (Newman, 1965).

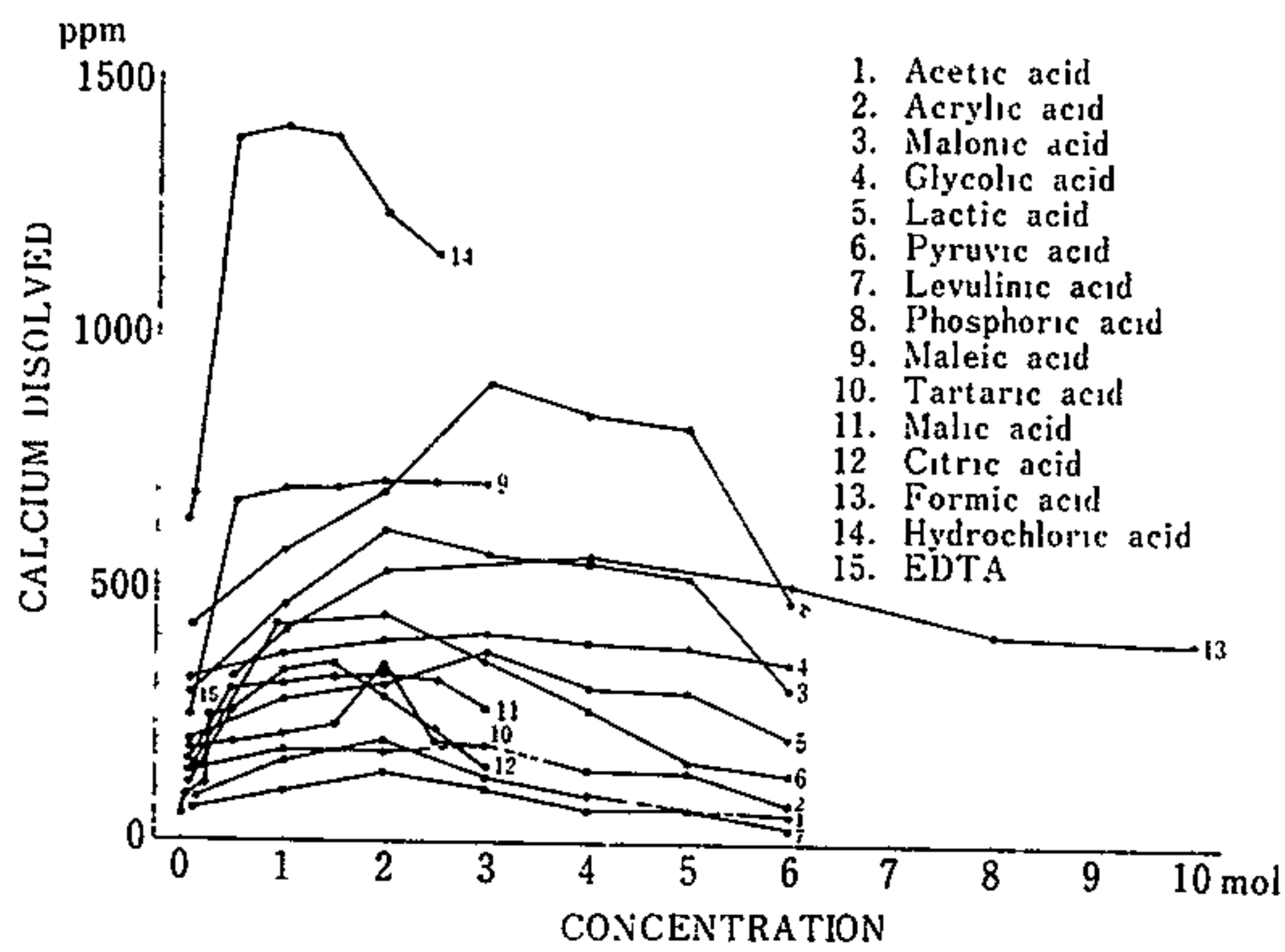
Numerous acids and etching routines have been investigated to attempt to determine the ideal techniques for particular adhesive systems (Gwinnett and Buonocore, 1965; Mulholland and de Shazer, 1968; Brauer and Termini, 1972; Retief, 1975c; Retief, Bischoff and van der Merwe, 1976).

Ohsawa (1972) examined 15 water soluble acids at seven different concentrations. He showed that:

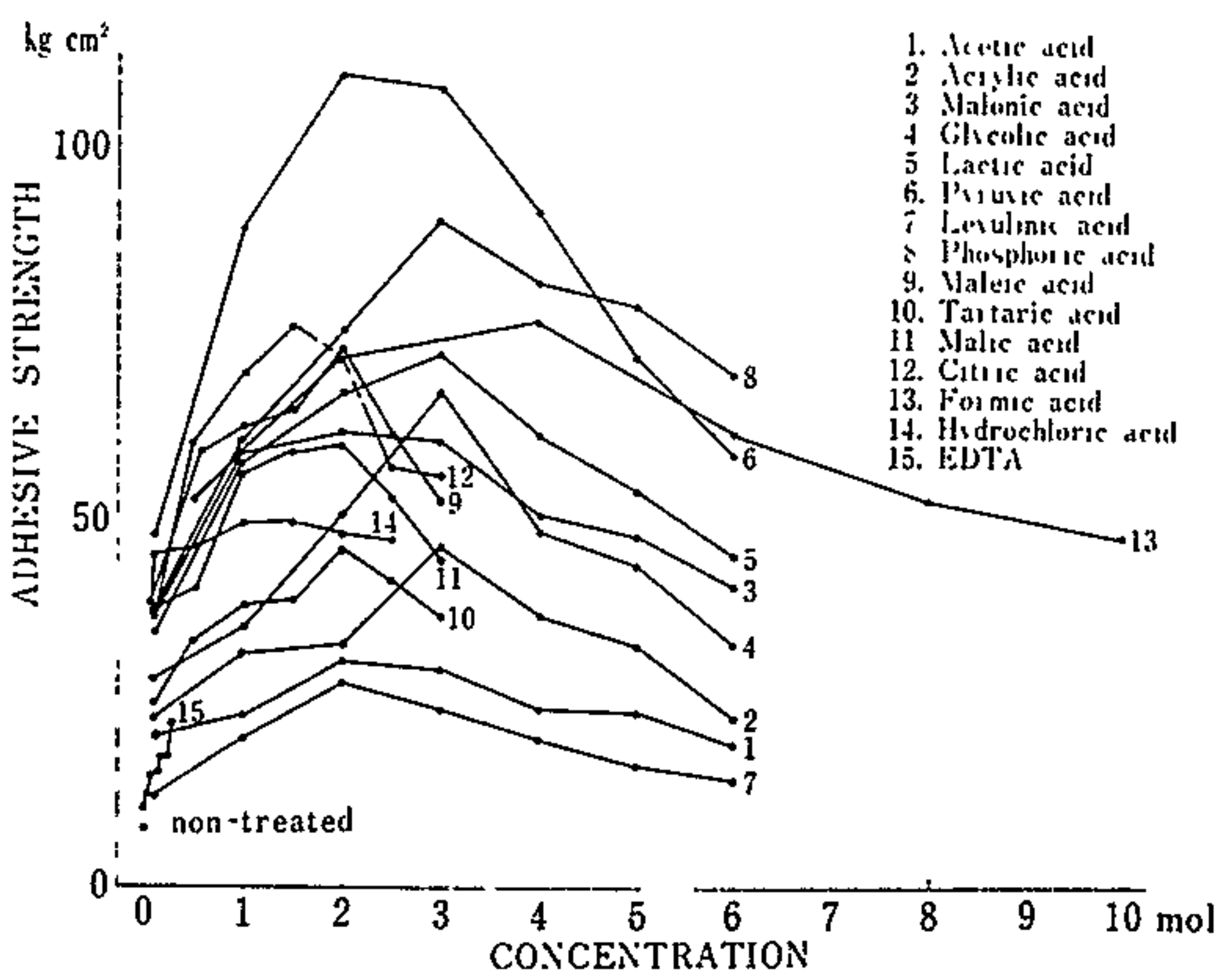
1. All acids except maleic and ethylene diamine

tetra-acetic (EDTA) produced a calcium-solubility curve which rose, peaked, and then fell.

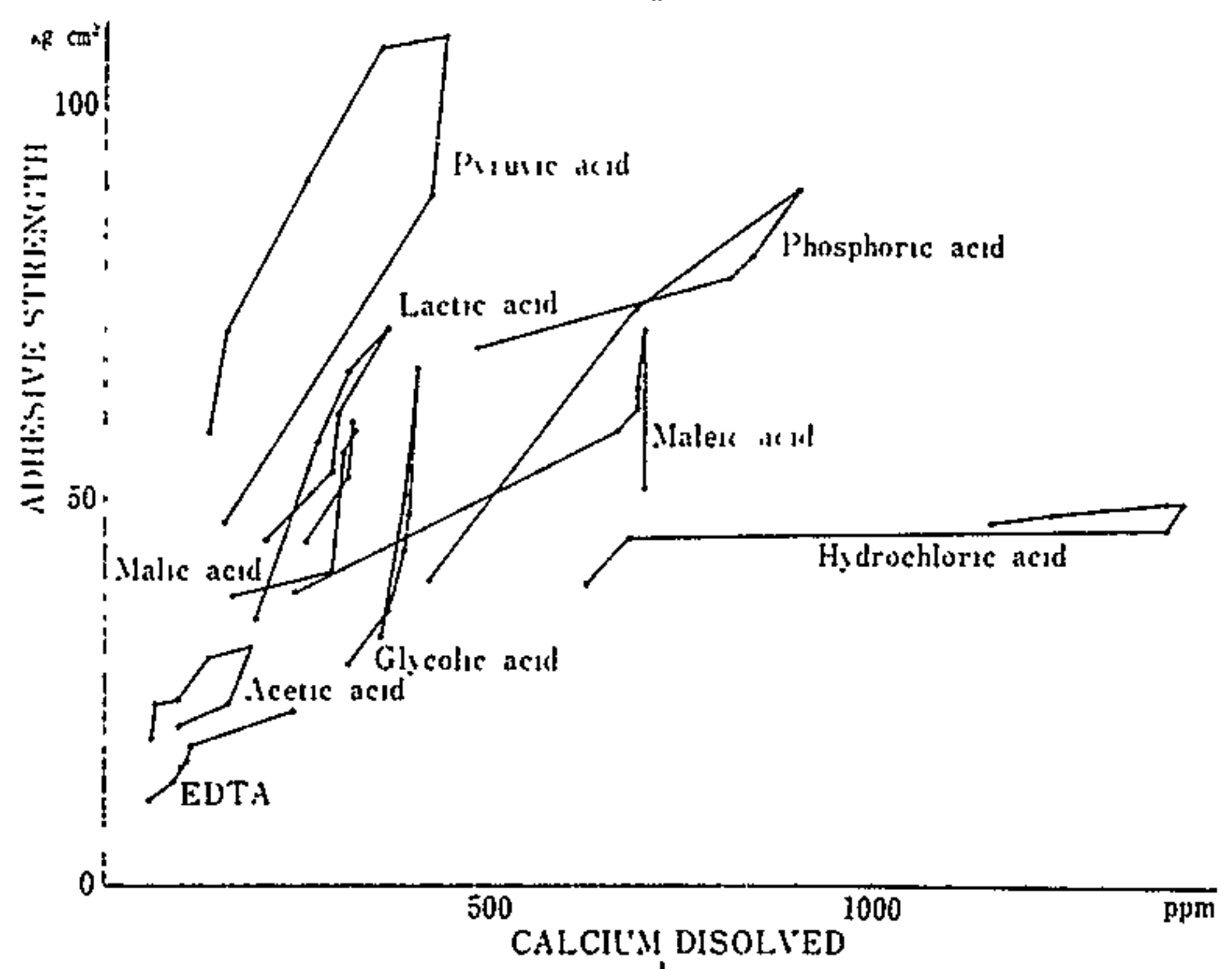
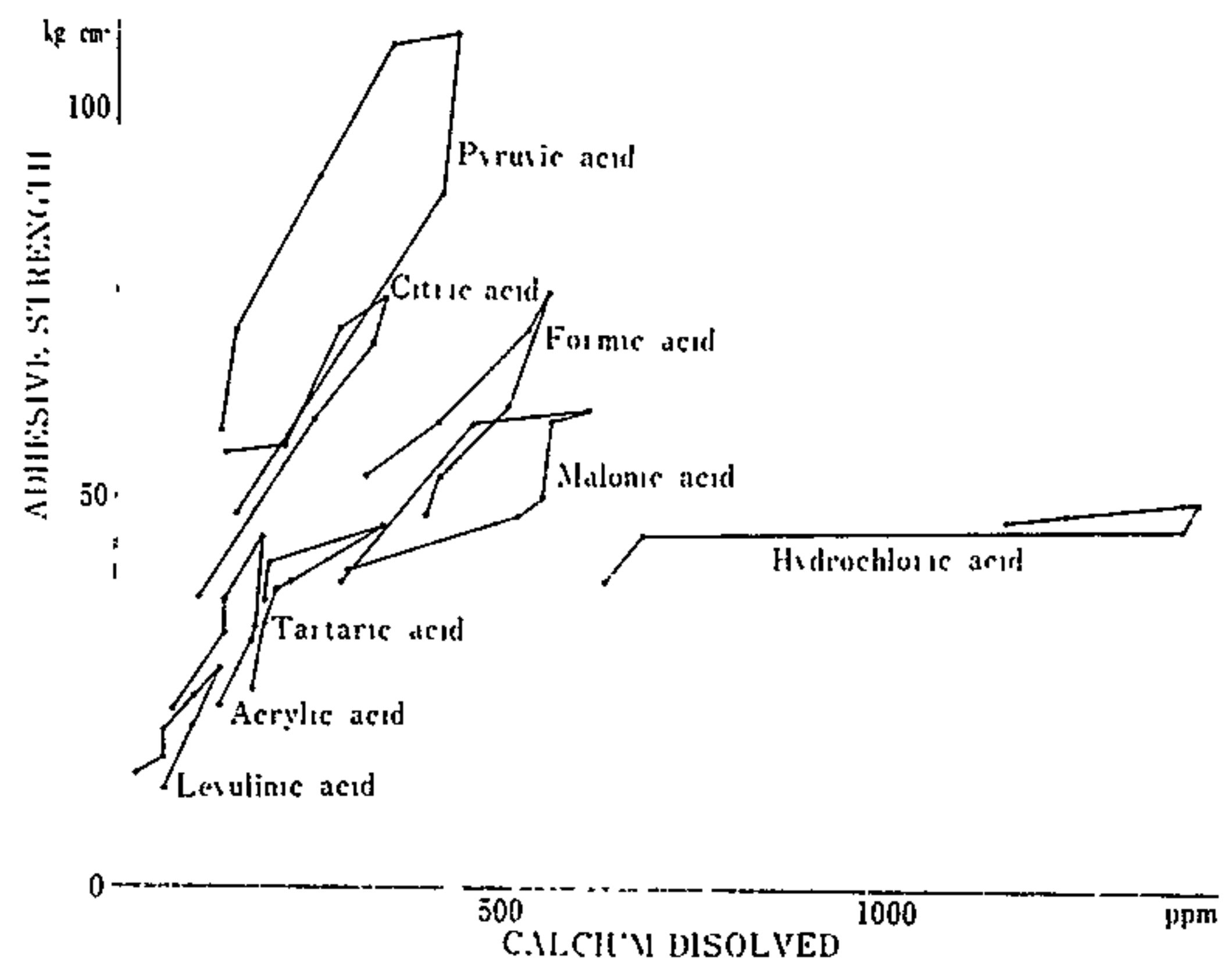
2. Similarly, all acids except EDTA gave a peaked adhesive bond strength against acid-concentration curve.
3. For any individual acid, surface roughness was proportional to calcium dissolution. This, in turn, was proportional to adhesive bond strength.



Amount of calcium dissolved from enamel tablet



Adhesion of the enamel pre-treated by varying solutions.  
 Note: Adhesion of non-treated enamel: 8.0 kg/cm<sup>2</sup>.



Relation between the amount of calcium dissolved from the enamel tablet and adhesion to the treated enamel surface in the treatments with varying acid solutions.  
 Note: The curves of pyruvic acid and hydrochloric acid are included in both figures.

Fig.3: Relationships between acid type, concentration, calcium dissolution and adhesive bond strength.  
 (From: Ohsawa, 1972.)

PHOSPHORIC ACID AS AN ETCHANT

The most widely tested and clinically accepted etchant is phosphoric acid. Retief (1975b) believed that this is based, arbitrarily, on its ready availability as the liquid component of zinc phosphate cements. Grenadier, Philips and Stein (1969) reported on 10 years of direct-bonding orthodontic appliances using "regular cement liquid" as an etchant.

Silverstone (1975) examined the action of 5-80% phosphoric acid on human enamel. He found that 5-15% and 70-80% produced minimal effects and that acid concentration was inversely proportional to etching and porosity in the range of 20-80%. Experiments by Gwinnett and Buonocore (1965), Retief (1975b) and Soetopo, Beech and Hardwick (1978) produced comparable results, while Williams, von Fraunhofer and Winter (1976) found no variation in bond strengths with 30-70% phosphoric acid etchants.

The apparent paradox of stronger acids producing less etching was explained by Chow and Brown (1973). They showed that over approximately 30%, phosphoric acid etchant produces monocalcium acid phosphate hemihydrate,  $\text{Ca}(\text{H}_2\text{PO}_4)_2 \cdot \text{H}_2\text{O}$ . This precipitates onto the surface and inhibits further demineralisation.

The effect of acid preparation type on etching has also been studied. Maijer and Smith (1978) found that 44% gel dissolved more calcium and produced less desirable etching surfaces than either 36% or 40% solutions of phosphoric acid. Brannstrom, Nordenvall and Malmgren (1978) disagreed and demonstrated similar etched surfaces and resin replicas with a 50% or a 37% liquid etchant.

That alteration of etching time or rinsing time can also affect the resultant bond strengths was also shown by Williams and von Fraunhofer (1977) and Soetopo et al. (1978).

AUTHOR(S)	DATE	ETCHANT (ACID)	TIME (SEC)
Newman	1965	40% phosphoric	60
Gwinnett & Buonocore	1965	50% phosphoric + 7% zinc oxide	60
Mulholland & de Shazer	1968	pH2 hydrochloric	60
Miura et al	1971	65% phosphoric	30
Ohsawa	1972	2M pyruvic	30
Brauer & Termini	1972	20% lactic	20
Wickwire & Rentz	1973	50% phosphoric	240
Silverstone	1974	30% phosphoric	60
Retief	1975	50% phosphoric	60
Retief et al	1976	10% pyruvic	90
Keizer et al	1976	50% phosphoric + 8% zinc oxide	30
Hocevar	1977	37% phosphoric	60

Table 1: Showing variations in etchants used or recommended.

#### 4. ADHESIVES FOR THE ACID-ETCH TECHNIQUE

Lee (1966) surveyed the available commercial resins for possible use as adhesive restorative materials. Only seven had the desired properties of a liquid monomer and reasonable reactivity at 37<sup>0</sup>C. When applied to etched enamel, formation of resin tags would create an adhesive bond. The effect on bond strength of monomer viscosity and setting rate has been the subject of much controversy.

Dogon (1975) and Buonocore (1975) stated that lower viscosity leads to better penetration of the etched surface. Ten Cate, Keizer and Arends (1977) agreed and also concluded that a prolonged penetration time, at least 50 seconds, was essential for thorough surface wetting.

Asmussen (1977), however, showed theoretically that penetration of the micropores of etched enamel should only take 1.7 seconds for the most viscous monomer mixture used in the composite resins he tested. Jorgensen and Shimokobe (1975) and Pahlavan, Dennison and Charbeneau (1976) found similar tag production for different viscosity resins.

The use of an unfilled intermediary resin phase of low viscosity did not increase bond strengths according to Reynolds and von Fraunhofer (1976b), Rider, Kenny and Tanner (1977) and Soetopo et al. (1978). Faust, Grego, Fan and Powers (1978) and Raadal (1978) found an inverse correlation between bond strengths and viscosity of resins.

Fillers which are added to resin monomers to improve physical properties do not affect the underlying monomer viscosity (Asmussen, 1977). The major purposes or advantages of fillers are reduction of setting shrinkage and increased strength and

hardness (Bowen,1977).

#### EPOXY RESINS

Newman (1965) described an epoxy resin preparation for orthodontic bonding. The material was cumbersome, taking 15-30 minutes to gel, and four days for complete cure.

Retief et al. (1970) reported clinical trials with a commercial epoxy. The procedures and success rates were recorded by Dijkmann and Retief (1972) but subsequently these materials have only been found useful for laboratory tests (Retief, 1974,1975b 1975c.)

#### ACRYLIC AND DIACRYLATE RESINS

Acrylics are thermoplastic linear polymers whose long chains have been likened to the strands in a bowl of spaghetti (Phillips,1973). Modification by crosslinking can improve strengths and reduce solubility and water sorption.

Although reinforcing fillers have been tried with poly-methyl methacrylate (PMMA) they were not successful (Paffenbarger and Rupp, 1973).

Diacrylates are mainly based on Bowen's resin (Bowen, 1963) which is the addition reaction product of a bisphenol with glycidyl methacrylate. This adduct is known as Bis-GMA, and is the major constituent of most modern composite resins (Braden, 1978). Pure Bis-GMA is too viscous for clinical use so it is diluted with similar comonomers (Paffenbarger and Rupp, 1973).

Diacrylates have proved successful matrices for inorganic fillers, provided that these have been treated with a coupling agent, such as a vinylsilane (Bowen,1973). The resultant thermosetting, crosslinked,

filled system is termed a composite. The composition of such a material for use as an orthodontic adhesive (Concise) was quoted by Gorelick (1977) as 23% resin and 76% filler. The resin was mainly Bis-GMA, with a diluent dimethacrylate monomer. The filler was quartz, having an average particle diameter of 15 microns and had been treated with a vinylsilane.

#### ORTHODONTIC BONDING WITH ACRYLICS AND DIACRYLATES

Newman, Snyder and Wilson (1968) first reported on the use of acrylic for orthodontic bonding. They experimented with various copolymers, and also tried quartz fillers, which improved bond strengths. Water immersion for 30 days reduced the bond, but extrapolation of results led to the conclusion that reliable, fast setting acrylic adhesives were attainable.

Grenadier et al. (1969) described the technique they had developed and used over 10 years with a cold-cure restorative acrylic resin. This provided an adjunct to normal banding in certain problem cases, such as partially erupted teeth.

Newman (1969a) discussed the use of plastic brackets and other attachments with acrylic adhesives. He referred to them as part, only, of his orthodontic armamentarium, not a replacement, in toto, for metal bands. The plastic attachments had inherent weaknesses and problems, and the conclusion that "light orthodontic forces foster permanency of adhesive bonds" should be emphasised.

Newman (1969b) then presented the first commercial acrylic bonding agent ("O.I.S."). He recommended that brackets be contoured to approximate the tooth surface and minimise the adhesive thickness. Archwires could be placed after only five minutes.

Miura, Nakagawa and Masuhara (1971) introduced

"Direct Bonding System" adhesive for use with plastic brackets and also presented case reports. Thirty-two patients, with a total of 278 edgewise plastic brackets on upper or lower incisors, canines or premolars, lost only a total of 17 attachments during treatment. The acrylic was simple PMMA, but the catalyst was a tri-n-butyl borane derivative (TBB). This novel catalyst is activated on contact with water, which is always present on the tooth surface, and therefore polymerisation should begin at the enamel-resin interface. Theoretically, this should improve bond strengths by reducing stresses of setting shrinkage. A silane coupling agent completed the materials and was stated to further improve the bond strength, both initially, and after 30 days water immersion. Immersion for six months gave a 20% decrease in bonds, but this still left an average strength of around  $40 \text{ kg/cm}^2$  ( $3.92 \text{ N/mm}^2$ ), which was well in excess of the clinical maximum shear stress of about  $14 \text{ kg/cm}^2$  ( $1.37 \text{ N/mm}^2$ ) suggested by Newman (1965).

Silverman, Cohen, Gianelly and Dietz (1972) reported the first use of diacrylate-based adhesives. They polymerised a fissure sealant (initiated by ultraviolet light) on to the treated enamel and then used an acrylic to bond either plastic or metal brackets. These brackets were located by the "indirect" technique, which they described, and any tooth, including molars, could be bonded.

Newman (1973) surveyed five commercial bonding systems, four of which were simple acrylics and the fifth was the sealant/acrylic combination mentioned above. He described clinical procedures and explained reasons for bond failures. He also presented his own routine, which had a chemically cured diacrylate resin sealant, then a PMMA bracket adhesive. This could be used for either direct or indirect techniques.

Cohen and Silverman (1974) used an ultraviolet-light-initiated system with an unfilled resin phase and a filled adhesive. Using the indirect technique they bonded all their cases.

Feeling that current systems were either inadequate or clumsy, Lee et al. (1974) introduced a single step system (Genie), which consisted of mono- and di-methacrylate monomers, and polymethacrylate filler. This material bonded to metal and plastic attachments but long term results were not quoted.

In a comparison of five orthodontic adhesives in-vitro, Nagel (1975) found no significant differences in bond strengths. Four of the materials were acrylics and the fifth was the combination sealant/acrylic method (Nuva-Seal with GAC Bracket Bond).

Clinically, however, Zachrisson (1975) showed the trend towards composites and away from acrylics. While still using an acrylic (Orthomite IIS) for plastic brackets, he reported an overall 5% failure rate over nine months for his selected composite (Concise). With this he bonded metal brackets and molar tubes and contrasted these results with the 26% failures over 10 months from his previously preferred "Orbond".

Reynolds and von Fraunhofer (1976a) tested bonding systems in-vitro. Initially bond strengths were comparable. However, the unfilled acrylic showed significant weakening after six months in water, while diacrylate-based resins did not.

Similar laboratory trials by Moser et al. (1976) and Johnson, Hembree and Weber (1976) reached comparable conclusions. Filled diacrylates gave stronger bonds than acrylics for periods of one day

to three months water immersion.

The importance of attachment base material was emphasised by Reynolds and von Fraunhofer (1976b). They found that coarser mesh gauges gave better mechanical retention thus reducing failures at the bracket-adhesive interface.

In an attempt to speed up their technique still further Silverman and Cohen (1976) began using a single step, chemically-cured composite with the indirect technique. Brackets were fixed to the models with a similar, but ultraviolet-light-initiated, composite.

Using a simple acrylic adhesive with a primer, Barnard (1976) claimed a 5.1% failure rate over 24 months, bonding all teeth except molars. Despite the variability of bond strengths in-vitro, as shown by Keizer et al. (1976), this demonstrated the clinical success of such systems.

Composites, however, continued to increase in acceptance because of their higher in-vitro strengths, their clinically greater success rates and, probably, their simplified handling properties.

Hocevar (1977), Gorelick (1977) and Zachrisson (1977), all similarly described their clinical techniques with the Concise system. This included etching the whole facial surface of the tooth and applying unfilled resin over this area, followed by composite paste to the brackets. Zachrisson and Gorelick used perforated bracket bases, while Hocevar preferred mesh, welded directly to the attachment. Zachrisson recorded an overall 13% failure rate throughout treatment of 46 children, with bonds on any tooth, and Gorelick claimed 5.8% over 12 months,

not bonding to molars. Both these authors were gratified to note that teeth could be rebonded, provided that surfaces were re-prepared.

In-vitro tests on 13 commercial orthodontic adhesives bonded to extracted human central incisors were conducted by Faust et al. (1978). Approximately half were acrylic-based, one was a polycarboxylate and the remainder were composites. Bond and re-bond strength tests to metal and plastic brackets gave some interesting results and permit valuable comparisons between available materials. Re-bond strengths to re-prepared teeth were very close to the original bond values. Some materials, based on Bis-GMA, would not adhere to plastic brackets and some of those materials which could be used with either bases gave stronger bonds to plastic. Those materials having an unfilled intermediary resin phase or primer had lower strengths than most others using a one step procedure, which indicated the superfluity of sealants.

This later conclusion has been supported by the in-vitro studies of Reynolds and von Fraunhofer (1976), Rider, Kenny and Tanner (1977), Raadal (1978), and Soetopo et al. (1978).

Gorelick (1977) and Zachrisson (1977) subjectively believed that total facial coverage with sealant would improve adhesion and decrease decalcification, which is a problem in their unfluoridated regions.

It is interesting that Zachrisson later (Zachrisson, 1978) said that thin films of sealant would not polymerise in the presence of air, but he still felt they could give advantages in caries protection, bond strength, moisture control, and

debonding. He reported failure rates of 2-4% with two different two-phase composites (Concise and Endur), and contrasted this with a study by Mizrahi (1977) which showed that 21% of bands needed recementing during treatment of 102 children.

Zachrisson and Brobakken (1978) investigated variations of bracket base, adhesive, and methods of bonding on 42 children. They used covered mesh or perforated base brackets, with three composites, and direct or indirect bonding. They found that direct bonding led to fewer failures and that mesh brackets used with Endur adhesive were the most hygienic.

Schimann (1978), however, found no significant difference in bond failures between the direct and indirect techniques with a one-step composite adhesive (Auto Tach).

Thanos, Munholland and Caputo (1979) experimentally compared the strengths of exposed mesh-backed and perforated brackets, although neither of these represents the optimum bonding base. Clinically, covered mesh-backed brackets seem preferable. The foil layer between mesh and attachment controls the spread of adhesive, thus improving hygiene and reducing the risk of bracket blockage (Zachrisson and Brobakken, 1978; "Round Table", 1978).

In a recent survey of American orthodontists (Gorelick, 1979) the advance of bonding and the dominance of composite adhesives were underlined. Of about 2000 respondents, 93% used bonding, 57% had three or more years experience with the techniques, and 56% felt that their bonds held as well as bands. Composite adhesives were preferred to acrylics in a

ratio of almost 4:1. Gorelick concluded that "bonding is widely used, and seems to be here to stay."

## 5. DEBONDING

As orthodontic bonding has progressed improvements in techniques, attachments and adhesives have resulted in more durable and stronger bonds. This in turn has led to the need for research on satisfactory methods of "debonding"; that is, removing attachments and residual adhesive and restoring, as far as possible, the integrity of the tooth surface.

Possible iatrogenic harmful effects of debonding are:

1. Pain: removal of attachments and adhesives involves stresses on teeth and supporting tissues, which may already have had their threshold lowered by orthodontic forces.
2. Enamel damage: this includes gross and microscopic fractures, gouging and faceting and unnecessary wear from abrasive instrumentation.
3. Residue: possible complications are colour instability or staining, gingival irritation and focus formation for plaque, calculus or caries.

Gorelick (1979) found in his survey that over 40% of respondents' patients disliked debonding procedures and approximately 70% of operators took longer for this than for debanding. He concluded that there was a great deal of room for technique improvement.

When adhesives were simple acrylics, removal of attachments and residue were uncomplicated procedures, which were only referred to in passing in the literature. Newman (1969b) used band removers

and scalers, followed by a prophylaxis with a fluoride paste. Miura et al. (1971) preferred pin cutters, scalers and a final clean with chloroform which dissolved acrylic remnants.

With the advent of Bis-GMA based adhesives the increased bond strengths, tensile strengths and abrasion resistances meant that rotary cutting and grinding instruments became necessary.

Silverman et al. (1972) advocated a Rotopro bur for bracket removal, followed by "a stone, and fluoride treatment."

Retief (1974) took a more serious look at the enamel-adhesive interface, testing to destruction bonds between an epoxy resin and extracted human maxillary incisors. He found that when the bond strength exceeded approximately  $1400 \text{ lb/in}^2$  ( $9.7 \text{ N/mm}^2$ ) fractures could occur within the enamel. He compared this figure to the mean tensile strength of enamel given by Bowen and Rodriguez (1962) as  $1500 \text{ lb/in}^2$  ( $10.3 \text{ N/mm}^2$ ). Tags of resin up to 50 microns long were demonstrated, and an apparently clean interfacial break actually involved spicules of enamel being retained within the bulk adhesive, and tags of resin left in the enamel (Fig.4).

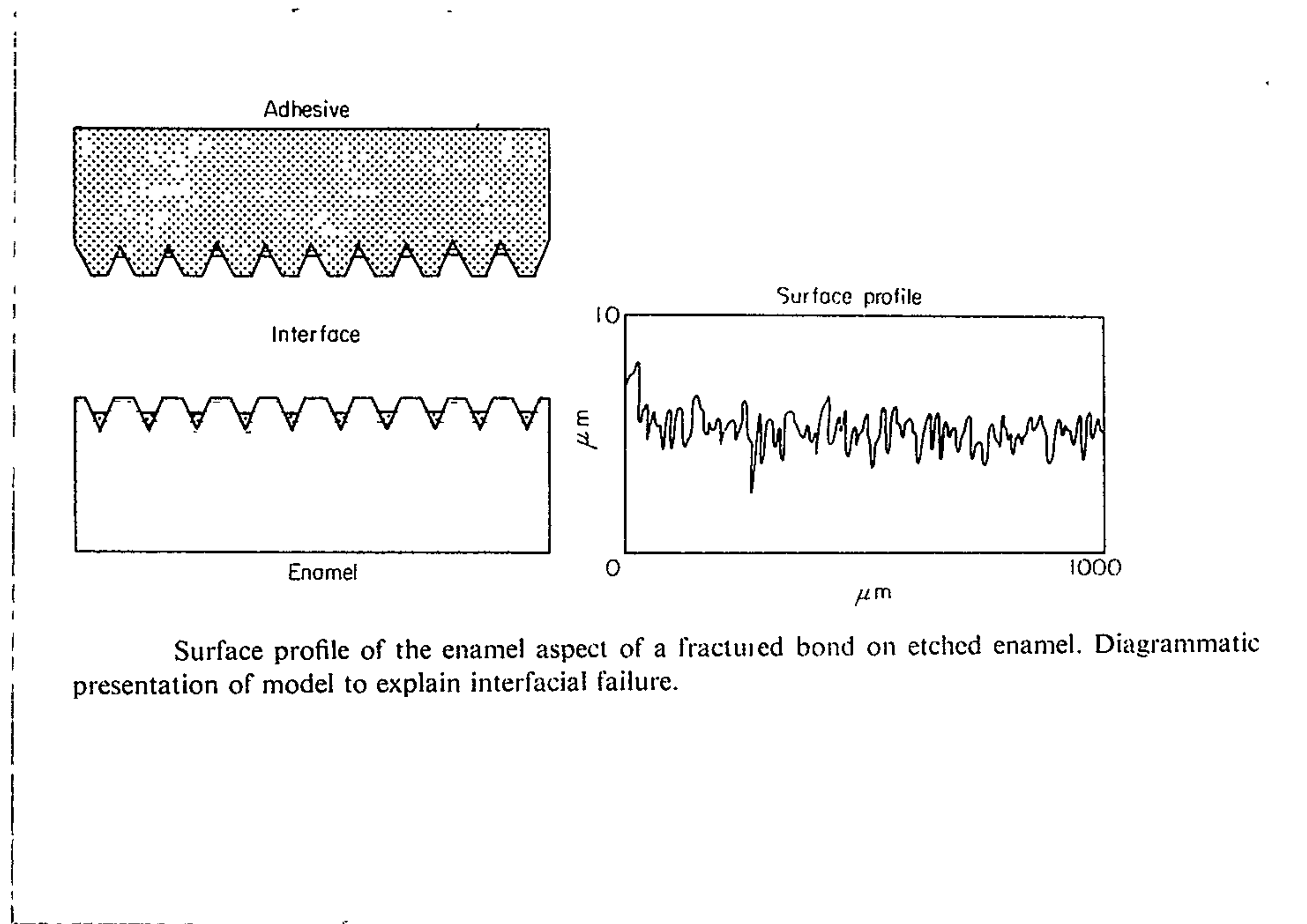


Fig.4: (From: Retief, 1974.)

Mitchem and Turner (1974) tested seven diacrylate and one acrylic restorative resin systems and found that all the former gave bonds to human enamel in excess of the previously quoted enamel tensile strength. The highest average was  $4530 \text{ lb/in}^2$  ( $31.3 \text{ N/mm}^2$ ) after 24 hours, which decreased only to  $4050 \text{ lb/in}^2$  ( $27.9 \text{ N/mm}^2$ ) after 60 days in water. For this composite, seven of the eight specimens tested showed enamel failure as the site of fracture. Other authors, including Moser et al. (1976) and Keizer et al. (1976), have demonstrated bonds with orthodontic adhesives in excess of the critical enamel-failure value, although these may decay during the treatment period in-vivo.

Newman (1965) stated that "Physiologically, the forces employed in orthodontic treatment should not be over 1/2 pound when exerted upon a tooth. A vertical loop (0.021 by 0.025 inch) when opened 1 mm exerts a force of approximately 1 pound, depending on the length of the loop and its activation. If the metal bracket is 1/8 inch square, the shear force on the attachment is 64 psi, which, when distributed over the band, is much less. A load of 10 pounds or 200 psi (including extraneous forces) is the maximum which probably occurs under clinical conditions."

This last figure appears to have been arrived at empirically, and is often quoted or misquoted. Miura et al. (1971) repeated the "200 psi" from Newman's article, but converted this to "about  $29 \text{ kg/cm}^2$ ," where in fact it should be about  $14 \text{ kg/cm}^2$  ( $1.38 \text{ N/mm}^2$ ).

This error was perpetuated by Keizer et al. (1976), who quoted from Miura et al. (1971) and concluded that, for a reliable adhesive " the

average bond strength, minus three standard deviations, should equal the maximum force exerted on a bracket." Using this criterion, a reliable adhesive's bonds should be clinically sound at values considerably below the tensile strength of enamel, thus avoiding or minimising the risks of enamel fracture.

Brandt et al. (1975) discussing a composite adhesive, noted that brackets could be sheared off with pliers and "although in most instances there will be edges of enamel attached, this is not a significant loss." Adhesive residue was considered the major problem and was removed with sharp scalers or sandpaper discs.

Discussing iatrogenic damage during orthodontic treatment Zachrisson (1976) rejected the possibility of discolouration of adhesive residues based on his clinical observations, one year after debonding. This was upheld by in-vitro studies on 14 composite and acrylic restorative materials by Jones, McCabe and Spence (1977), who found only slight colour changes after exposure to ultraviolet light. Zachrisson (1976) suggested a plain-cut tungsten carbide fissure bur, at low speed, for bulk adhesive removal and criticised the use of diamond instruments which would leave extremely rough, scratched enamel surfaces.

Gorelick (1977), Hocevar (1977) and Zachrisson (1977), all proposed techniques for debonding a two-phase composite system (Concise) which they had used clinically. Gorelick noted the difficulty involved, and the frequency of bulk adhesive remnants following bracket removal. He also noted the increased plaque accumulation on composite surfaces. Tests by Weitman and Eames (1975) using four methods of "finishing" composite restorations,

found that these were covered with plaque within 24 hours, compared with three days for sound enamel as a control.

Zachrisson (1977) repeated his earlier debonding advice of pliers, scalers, and plain-cut tungsten carbide fissure burs and added a final polish with rubber polishing discs. Hocevar (1977) dissented, saying that "should (sic) any composite remain, it can be removed by sandpaper discs, fine stones or plain fissure burs." These suggestions were in discord with in-vitro studies by Gwinnett and Gorelick (1977). Their microscopic examinations showed that discs, stones, diamonds, burs, and hand instruments all produced varying degrees of enamel scratches, gouges, and faceting. By trial and error they ascertained that a "green rubber wheel" removed heavily filled composites best, while unfilled or lightly filled resins were usually removable with scalers. Pumicing subsequently eliminated fine, residual scratches following such methods.

Zachrisson and Arthun (1979) while agreeing that diamonds and discs were inadvisable, preferred the finish after a slow-run, tungsten carbide fissure bur to that of a green rubber wheel. They pointed out, however, that Gwinnett and Gorelick (1977) had used burs run at high speeds only, which could explain conflicting opinions.

For an acrylic adhesive, Casparsen (1977) demonstrated microscopically that clinically-clean debonded surfaces always retained some residue, in the form of thin films or islands, and proposed chemical cleaning, as used by Miura et al. (1971).

Fitzpatrick and Way (1977) measured the thickness

of enamel loss from bonding and debonding procedures and stated an average total of 55.6 microns. They concluded that, on a normal enamel thickness of 1500-2000 microns, this was not a critical loss, and would ensure removal of originally etched surface plus resin tags, leaving a surface similar to untouched enamel. As their method involved sinking pins below the tooth surface, thus breaking the enamel integrity, their resultant losses from abrasion may be exaggerated and their conclusions could then be spurious. In a follow-up article Brown and Way (1978) stated that the original debonding routine of Fitzpatrick and Way (1977) had used a tungsten carbide bur at "high speed." Gwinnett and Gorelick (1977) rejected this technique as removing too much enamel, advising that any rotary instrument used to remove bulk adhesive "must be discontinued before the enamel is reached."

Tag remnants in etched enamel were considered by Silverstone (1977) as beneficial, since they increased the resistance to simulated caries attack by acid-etching.

Concern over adhesive residue led Burapavong, Marshall, Apfel and Perry (1978) to quantitatively examine remnants and enamel damage, for one acrylic and one two-phase composite bonding system. Considerable resin was left by green stones, hand scalers or ultrasonic scalers, but this was reduced by subsequent pumicing. Their conclusion that all detectable adhesive was removed must be tempered by the understanding that their methods would not disclose very thin films or tags of resin, and that their sample size was only three specimens for each experiment.

Using a sealant-composite system, Gwinnett and

Ceen (1978) demonstrated resin remnants in-vivo (following a green rubber wheel and pumicing debonding procedure), by ultraviolet light photography. These remnants did not form foci for plaque growth in the 10 dental student subjects over a six month period and "began to wear away with time."

Retief and Denys (1979) tested seven methods of debonding and examined the resultant tooth surfaces under a scanning electron microscope. They concluded that the use of pliers or scalers for bulk residue removal could not be recommended as they produced serious enamel damage. Gross resin remnants should be removed with a 12-bladed tungsten carbide fissure bur at high speed, without attempting complete removal and stopping short of the enamel. Finishing with Sof-lex discs or Ceramiste wheels, followed by pumicing, produced the optimum surface, but procedures were tedious. They supported the view of Gwinnett and Gorelick (1977) that lightly filled resins, having less abrasion resistance, were preferable for bonding.

Two less conventional methods were reported by Weisser (1977), who used a "Stripppo" knife, and Dragiff (1979), who advocated a pneumatic chisel in combination with a compound splint.

A different approach was suggested by Hocevar (1979), who proposed that the strength of the adhesive-enamel bond should be reduced below that at the composite-bracket interface. This would effectively reduce adhesive residue and so minimise the risk of iatrogenic insult to the enamel.

ORIGINAL WORKAIMS

Removal of appliances and adhesives carries that risk of iatrogenic damage attendant on all current procedures. It would therefore be prudent to include debonding requirements when evaluating a material for bonding.

Studies by Casparsen (1977) and Gwinnett and Ceen (1979) of teeth debonded in-vivo observed the posttreatment existence of resin remnants. Burapavong et al. (1978) and Fitzpatrick and Way (1977) suggested that such residue should be removed by the prophylaxis. This difference of opinion could be due to three possible variables:

1. Debonding techniques.
2. Adhesive resins used.
3. Residue identification and estimation procedures.

All the debonding routines in those studies involved the use of rotary instruments including stones, wheels or burs. Prolonged use of these abrasives will ensure total resin removal, but concomitantly must result in unnecessary enamel damage. Recent research proposes only bulk removal with such implements. This is then followed by a finishing prophylaxis with pastes on rotating brush or rubber cup (Gwinnett and Gorelick, 1977; Zachrisson and Arthun, 1979), or fine polishers, such as Sof-Lex discs (Retief and Denys, 1979).

The aim of this study was to investigate, in-vitro, the differences in residue of dissimilar adhesive resins, following a standardised debonding procedure.

To facilitate comparisons it was first necessary to develop a routine for demonstrating and quantifying these residues. This was then applied to teeth which underwent simulated bonding and debonding techniques with three orthodontic adhesives.

PREAMBLEMICROSCOPY

The small areas covered by bonded orthodontic bases require magnification for accurate evaluation. The two systems available for this are light or electron microscopy.

The latter has been popular for similar studies (Casparsen, 1977; Gwinnett and Gorelick, 1977; Burapavong et al., 1978; Retief and Denys, 1979; Zachrisson and Arthun, 1979) because of its excellent resolution and large depth of field. These properties, however, make quantification less accurate since they permit two-dimensional photographic reproduction of non-planar surfaces. Distortions will then occur on any surface not perpendicular to the line of observation.

Light microscopes on the other hand have much smaller depths of field and so demand flatter experimental surfaces. At 50X magnification a simple light optical microscope with an objective NA = 0.12 would have a field depth of less than 150 microns (Birchon, 1961). For a scanning electron microscope (SEM) at 50X magnification the depth of focus can be over 1cm (Wells, 1974).

Burapavong et al. (1978) also noted the difficulty of discriminating between tooth surface and thin films of resin when using the SEM.

For these reasons it was decided to use a light-optical photomicrography system to record surfaces for quantification.

### TEST SURFACES

Obtaining teeth with sufficiently flat areas for experimentation proved problematic. The possibility of discing the enamel was considered but rejected, since it was felt that removal of surface layers and normal topography would create an abnormal substrate. Although testing was to be in-vitro, it was desired to simulate oral conditions wherever possible to validate comparisons of results with clinical situations. For similar reasons bovine teeth were also eliminated, and the shortage of incisors extracted from patients of orthodontic age precluded their use. Premolars, which were available in copious quantities, have some small area on their buccal surfaces which is reasonably flat. Trial and error experiments, to develop the protocol for the second part of this study, were carried out on these teeth. They were furnished with T.P. 256-351 brackets (T.P. Laboratories), bonded with various materials and debonded by various techniques. Debonded surfaces were examined under a light microscope with incident light. The close colour match of adhesives to tooth substance indicated the necessity of contrasting these two phases in some way.

### STAINING

Tests suggested that polymerised adhesives were inert, while clean tooth enamel would readily take up a specific stain for calcium. This stain, Alizarin Red S (B.D.H. Chemicals), was prepared by making a 2% solution of sodium alizarinosulphonate in distilled water (Smith and Bruton, 1977). The pH of the solution was corrected to 4.2 with ammonium hydroxide and tested by glass-electrode pH meter. Ratification of the differential nature of the staining reaction was carried out as follows. The three adhesive resins under trial were placed in cavities cut into the enamel of experimental teeth. After 15 minutes setting time these

specimens were then ground flat with a diamond disc, stained and examined under the microscope. No stain was observed in the resin and there was clear demarcation between polymer and enamel. Resins were unaffected while calcium in the enamel showed an orange-red colour.

## MAIN STUDY

### MATERIALS AND METHODS

#### TEETH

One hundred and fifty premolar teeth extracted for orthodontic reasons at the Exodontia Department of the United Dental Hospital, Sydney were used in the main study. Following extraction, these were washed and stored at room temperature in normal saline solution, to which a thymol crystal had been added.

These teeth were selected from several hundred on the basis of having a sufficiently flat area of approximately 2mm square on an undamaged buccal surface. This property was checked in two ways. Firstly, by naked eye observation of the fit of a flattened 2mm square bonding base and secondly, by microscopic evaluation.

Using incident light, a nominal magnification of 40X and an objective of NA = 0.10, teeth were observed with proposed test area perpendicular to the microscope tube. The criterion of selection was that the 2mm square zone delineated by the eyepiece graticule should be all in focus to the observer. According to Birchon (1961), the depth of field for such a system, including that due to accommodation of the human eye, would be less than 0.3mm.

The 150 selected teeth were randomly divided into three equal groups, each of which was assigned to a particular adhesive.

## BONDING ADHESIVES

A large number of commercial bonding systems are available for orthodontic purposes. Three of these were selected for testing on the basis that they represent different physical and clinical characteristics.

### a. DYNA-BOND (Unitek Corp.)

This is a two-phase composite resin "based on Bis GMA and having a mixture of hard and soft fillers with a low hard filler content to allow easy adhesive removal" (Unitek Corp., 1979).

The kit contains "Catalyst Adhesive" and "Universal Adhesive" pastes in jars, and "Catalyst Sealant" and "Universal Sealant" in plastic dropper bottles. The etchant is 37% phosphoric acid solution and plastic spatulas, paper mixing pads and brushes for sealant application are provided.

Relevant points of manufacturer's bonding instructions are:

1. "Follow standard etching procedure".
2. Apply mixed sealant to etched tooth enamel.
3. Apply mixed adhesive to bracket base and place on sealed tooth. It is not necessary to wait for sealant to polymerise.

### b. ORTHOMITE IIS (Rocky Mountain Orthodontics)

This is an unfilled acrylic resin whose catalyst is activated by contact with water. It was developed by Masuhara and has been reviewed by Miura and his co-workers (Miura et al., 1972; Miura, Nakagawa and Ishizaki, 1973).

The kit contains adhesive in powder and liquid

forms plus a syringe of catalyst. The etchant is 65% phosphoric acid as an orange-coloured thixotropic preparation. A glass mixing dish and brushes for adhesive application complete the presentation.

Relevant points of manufacturer's bonding instructions are:

1. Dip brush tip into activated liquid, then into powder and apply the blend to etched enamel and bracket base.
2. Place bracket on tooth.

C. SOLO-TACH (L.D. Caulk Co.)

This is a composite, based on Bis-GMA resin, containing only vitreous fillers and designed for direct bonding techniques (Silverman and Cohen, 1976).

The kit contains adhesive catalyst and base pastes, activator powder and colourless 50% phosphoric acid solution. Paper pads and plastic spatulas are provided for mixing. The activator powder must be stirred into the catalyst paste at least 24 hours before the initial use of the material.

Relevant points of manufacturer's bonding instructions are:

1. Apply mixed adhesive to bracket base.
2. Place bracket on tooth.

### BONDING BASES

Mesh-backed bonding bases of a nominal 2mm square were obtained by halving Lok-Mesh D2240 bases (Rocky Mountain Corp.). Although this is smaller than normal brackets it permitted coverage of only the selected flat test surface and facilitated evaluation of residue for the entire bonded area.

Following the previously stated manufacturers' instructions one base was bonded to each of the test teeth. Pumicing prior to bonding was with a slurry of laboratory pumice and water for 10 seconds. If any tooth did not show the desirable matt, frosted appearance subsequent to etching, it was re-etched for a further 30 seconds.

Fifteen minutes were allowed to ensure hardening, then the teeth were returned to water storage at room temperature for a further 14 days to permit total polymerisation.

Delineation of the bonded area was then achieved by cutting shallow grooves, with a diamond disc, along each edge of the base.

### DEBONDING ROUTINE

Fourteen days after bonding the test teeth were debonded following a routine based on that suggested by Gwinnett and Gorelick (1977).

- Stage 1: attachments removed with Dentronix 230 debonding pliers (Dentaurum).
- Stage 2: bulk adhesive removal, if possible, with hand scalers until surface was apparently clean to the naked eye.
- Stage 3: abrasion of remaining bulk resin with green rubber wheel (Dedeco Medium) without reaching the enamel surface.
- Stage 4: prophylaxis with Zircate polishing paste on a bristle brush for 10 seconds.

For each material, 25 teeth were subject to Stages 1 and 2 only, and the remaining 25 specimens received the full four stages of debonding.

All teeth were then returned to water storage, at room temperature, until required for quantification.

#### STAINING PROCEDURE

The standardised routine used was:

1. Wash tooth thoroughly under running water.
2. Clean with 50% phosphoric acid for one minute. This was found necessary to remove incidental surface contaminants and was not considered to affect adhesive residue.
3. Rinse well and dry.
4. Stain with Alizarin Red S solution for five minutes.
5. Differentiate under running water for five minutes.
6. Dry.

#### PHOTOMICROGRAPHY

A Leitz Ortholux binocular light microscope with Orthomat camera attachment was used at a nominal 25X magnification. A photomicrograph of the entire test area of each specimen, under incident light, was taken on Kodak Ektachrome colour transparency film (ASA 160). This avoided colour variations found in printed films.

The camera has an automatic control which pre-determines the exposure time and opens and closes the electromagnetic shutter without vibration.

#### QUANTIFICATION

To estimate the areal coverage of resin residue, a point counting method was used. This is a system taken from metallography (Hilliard, 1968) which has been applied to adhesive residue by Burapavong et al.

(1978).

The colour slides of the test areas were projected onto the flat screen of a Cabin 900A viewer. A grid of 300 points was placed over the entire debonded field on this projection and the number of points falling on each phase (tooth or resin) was counted. Any point falling on the boundary between the two phases was scored as a half. From these scores the areal fraction can be calculated as:

$$A_x = \frac{P_x}{P}$$

where  $A_x$  = areal fraction of phase  $x$  (resin).

$P_x$  = number of points falling on phase  $x$ .

$P$  = total number of points on a test area.

This is then converted to a percentage to show adhesive residue coverage of the debonded base area.

#### RELIABILITY OF POINT COUNTING

Hilliard (1968) said that the statistical accuracy of a point count is related to the number of observations (i.e. total number of points counted). The variance (S.D.<sup>2</sup>) of an areal analysis is quoted as:

$$S.D.^2(P_x) = P A_x(1-A_x)$$

where abbreviations are as above.

Although errors in the nature of the observations made were considered of minor importance by Hilliard (1968) they were relevant to this study.

Therefore, to test the experimental error 50 slides at random were counted twice at one week's interval. A "t" test on the differences showed that these were not statistically significant ( $P > 0.05$ ).

RESULTS AND DISCUSSION

Quantitative results are summarised in tables 2-5 and Figure 5.

MATERIAL	NUMBER OF SPECIMENS	MEAN % RESIDUE	STANDARD DEVIATION	STANDARD ERROR	RANGE (%)
DYNA-BOND	25	74.72	14.83	2.97	46.7-97.5
ORTHOMITE IIS	25	8.48	8.94	1.79	0.0-29.5
SOLO-TACH	25	73.88	21.18	4.24	11.2-96.8

Table 2: Showing adhesive residue at debonding Stage 2 as percentage coverage of base area.

MATERIAL	NUMBER OF SPECIMENS	MEAN % RESIDUE	STANDARD DEVIATION	STANDARD ERROR	RANGE (%)
DYNA-BOND	25	24.23	21.47	4.29	0.0-67.0
ORTHOMITE IIS	25	3.76	5.14	1.03	0.0-17.5
SOLO-TACH	25	18.82	17.07	3.41	2.1-63.5

Table 3: Showing adhesive residue at debonding Stage 4 as percentage coverage of base area.

MATERIALS COMPARED	't' VALUE	P	SIGNIFICANCE
ORTHOMITE IIS with DYNA-BOND	19.10	< 0.001	H.S.
ORTHOMITE IIS with SOLO-TACH	14.21	< 0.001	H.S.
SOLO-TACH with DYNA-BOND	0.16	> 0.5	N.S.

Table 4: Showing statistical comparisons of mean percentage residues, at debonding Stage 2, by Student 't' test.

MATERIALS COMPARED	't' VALUE	P	SIGNIFICANCE
ORTHOMITE IIS with DYNA-BOND	4.64	< 0.001	H.S.
ORTHOMITE IIS with SOLO-TACH	4.23	< 0.001	H.S.
SOLO-TACH with DYNA-BOND	0.99	> 0.2	N.S.

Table 5: Showing statistical comparisons of mean percentage residues, at debonding Stage 4, by Student 't' test.

H.S. = highly significant.

N.S. = not significant.

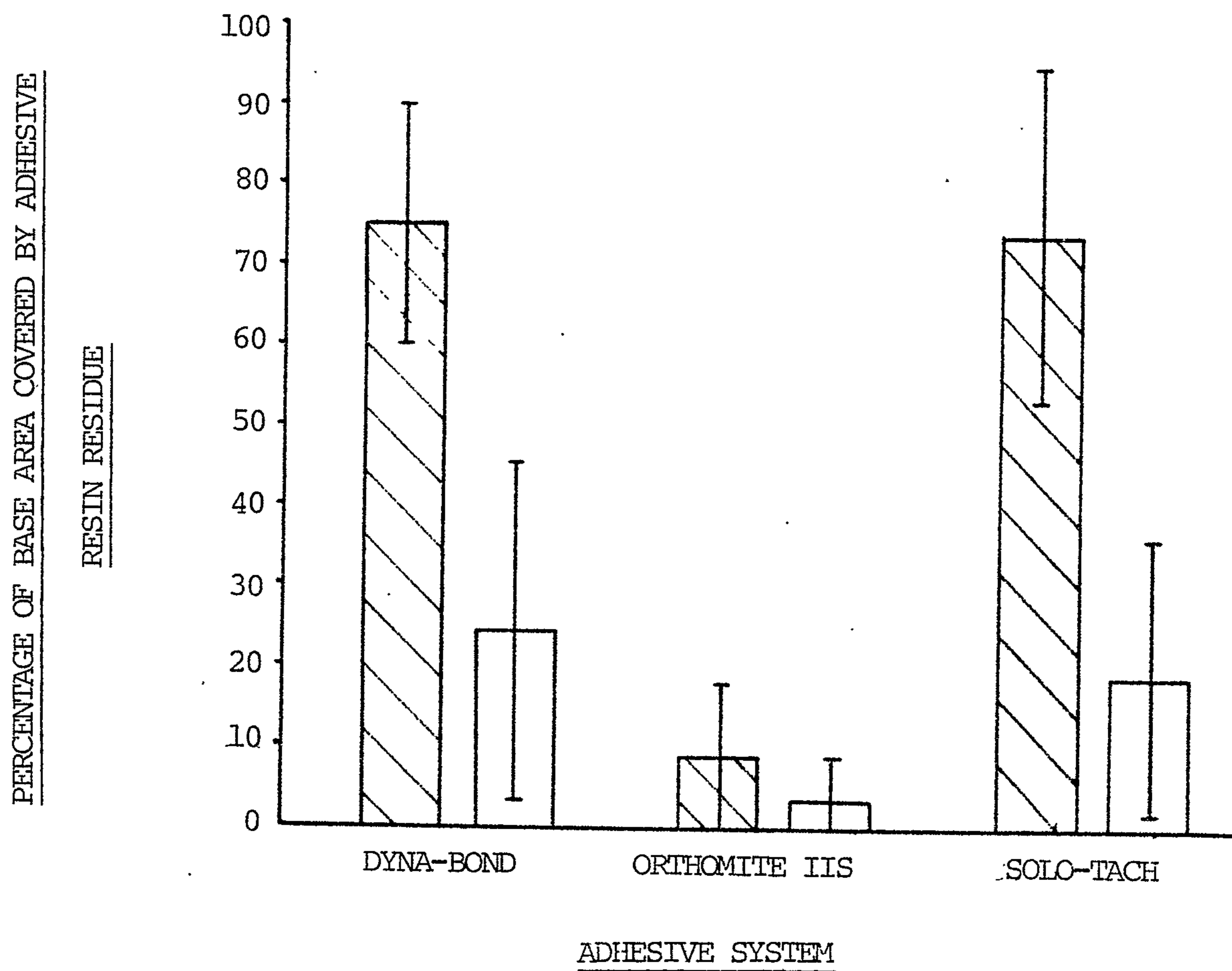


Fig.5: Histogram showing mean areal percentages of resin residue.

 -- debonded to Stage 2.

 -- debonded to Stage 4.

1 bar equals  $\pm$  1 standard deviation.

EXAMINATION AT DEBONDING STAGE 2

The residue of Orthomite IIS was significantly less than that of the two composite materials. There was no difference between values for Dyna-Bond or Solo-Tach.

Qualitatively, residue at this stage could be seen as either thin films or discrete islands. Cohesive resin failure near the enamel surface will leave films, while grosser remnants result from difficulties in detection or removal of residue.

Subjectively, Orthomite IIS was the easiest material to debond in Stages 1 and 2, while Solo-Tach was markedly the hardest. This latter was evidenced by the breakage of three hand-scaler points during attempted debonding of the specimens of Solo-Tach.

All visible fragments of Orthomite IIS and Dyna-Bond could be removed with scalers. The high residue reading for Dyna-Bond represented mostly resin films. This resulted from the two-phase bonding routine which, theoretically, encourages cohesive failure in the unfilled sealant, close to the enamel-resin interface.

Orthomite IIS showed mainly interfacial failure on base removal, which, as discussed by Retief (1974), should leave tags of acrylic in the enamel. The remnants of this material appeared as small islands only.

Solo-Tach, with its extremely high tensile bond strength (Faust et al., 1978) and vitreous fillers, was the only adhesive which could not reasonably be removed with hand instruments. The residue shown at Stage 2 for Solo-Tach was predominantly bulk composite.

EXAMINATION AT DEBONDING STAGE 4

Again, the only significant difference lay between Orthomite IIS and the composites. This, however, must be qualified. Since Solo-Tach was the only material to defy removal with hand scalers, it was, therefore, the only one to require Stage 3 of the debonding routine, the green rubber wheel.

Gwinnett and Gorelick (1977), who propounded the use of such instruments, recommended that abrasion be discontinued just before the enamel surface. This requirement did not prove easy to implement and the resultant enamel faceting would probably be unacceptable in clinical conditions. A plain-cut tungsten carbide fissure bur, at low speed, as suggested by Zachrisson and Arthun (1978) and Retief and Denys (1979) creates less heat and vibration. This would be better tolerated in-vivo but may still produce scratches and gouges. Obviously, therefore, materials such as Solo-Tach, which can only be removed with rotary grinding or cutting instruments are not as desirable as materials which can be removed less traumatically.

The reduction of residue for Dyna-Bond from 75% mean at Stage 2, to 24% mean at Stage 4 was accomplished merely by prophylaxis. Similar values for Solo-Tach, indicated the relatively lower abrasion resistance of Dyna-Bond. This supports the manufacturer's claim of soft fillers facilitating debonding.

Three zones of staining reaction were observed following complete debonding procedures. "Pink" areas merged into the red-stained enamel and these contrasted with the unstained resins. Observation at high magnification (320X) indicated that these "pink" zones represented areas of diffuse resin residue whose

fragments were too small to register at the test power (25X). Interspersed with the fragments could be seen normal enamel topography.

Although such intermediate staining demonstrated the presence of residue, this was not quantified because:

- a. "Pink" and "red" stained zones had no definite interfaces and so could not be delimited.
- b. Resin fragments were so small (estimated diameter 20 microns) that they were considered negligible.

Dyna-Bond and Solo-Tach showed considerable areas of "pink" stain. Orthomite IIS mostly showed apparently clean enamel surfaces.

#### DEBONDING IN PERSPECTIVE

The existence of some residue on 84% of fully debonded specimen teeth indicates the problems of identifying such remnants with the naked eye. With low viscosity resins this may be worsened since the adhesive may flow onto undesired surfaces such as interproximal and gingival areas. Staining the enamel proved a simple, reliable method of delineating residue in-vitro. For clinical situations routines having less permanent effects would be necessary. The use of loupes or fluorescent dyes and ultraviolet light might greatly enhance the prospects of total adhesive residue removal.

But the question then arises "is it necessary to remove all resin remnants?"

Several studies on debonding have concerned themselves with the return of the enamel surface to "normal". This has been assessed by SEM examination

at 50X (Zachrisson and Arthun, 1979), 500X (Gwinnett and Gorelick, 1977), 700X (Retief and Denys, 1979) and even up to 1000X (Burapavong et al., 1978). These studies have shown that a range of rotary abrasive instruments, followed by pumicing, are capable of producing a microscopically acceptable enamel surface.

To bring such experiments into clinical perspective it is essential to remember that all instruments which can remove resins will also abrade enamel. The macroscopic faceting and gouging produced by overuse of stones, wheels, burs, diamonds or discs are considerably more undesirable than minute scratches because they are obvious and unaesthetic. Orthodontic adhesives, on the other hand, are virtually unnoticeable as is shown by the difficulties involved in residue detection.

Zachrisson (1976) stated that he had not observed resin discolouration in patients up to one year after debonding. Jones et al. (1977) found no significant colour changes in 14 tested resins exposed to ultraviolet light.

Although Weitman and Eames (1975) found increased plaque accumulation on surfaces of composite restorations, it must be noted that these were class V cavities which extended into the gingival crevice, a plaque-prone area. Gwinnett and Ceen (1978) observed 10 debonded patients over six months and reported no tendency to plaque formation on adhesive resin fragments. If the residue is limited to "self-cleaning" areas, such as the occlusal or incisal two-thirds of buccal surfaces, there should be no hygiene or gingival problems.

The low abrasion resistance of resins compared to tooth enamel (Paffenbarger and Rupp, 1973) ensures that residual fragments will wear away relatively rapidly.

It is possible that the comparatively rough surfaces of vitreous-filled composites might attract stains from foods, drinks or smoking. These are, however, only surface anomalies which can be readily removed by prophylaxis and should not even occur in patients with good oral hygiene.

#### EVALUATION OF ADHESIVES

Difficulties in debonding will increase in proportion to the tensile bond strength, cohesive strength, and abrasion resistance of the adhesive used, and the area over which it is applied.

The use of "softer" adhesives will minimise such difficulties. Limiting the etched area and spread of resin will further reduce the residue. No advantage in bond strength has been shown by extending the etch or adhesive beyond the bracket-base area (Reynolds and von Fraunhofer, 1976b).

Excluding technique, the major factors in control of superfluous resins are the handling characteristics of each adhesive. It is relevant, therefore, to look at these properties for the three tested materials.

##### a. ORTHOMITE IIS

The ability to vary the viscosity of this material facilitates exact bracket location, although this is perhaps offset by the complicated mixing routine. However, if too thin a slurry of adhesive is applied to the tooth the resin can flow into undesired areas such as gingival crevices or interproximal regions. If these zones are unetched then surplus removal is simple. The orange, thixotropic etchant is simple to control so etching can easily be limited to only the bracket base area.

### b. DYNA-BOND

The unfilled intermediary sealant phase of this and other similar adhesives is claimed to improve caries protection, bond strengths, moisture control and debonding (Zachrisson, 1978). These are contentious claims and there are two major failings of such systems: sealant "drift" and non-polymerisation ("Round Table", 1979). The first occurs because of the low viscosity of the resin and can increase adhesive spread. The second results from oxygen-inhibition of the chemical reaction of current polymers, and complicates bracket positioning by increasing the tendency to "slide".

The colourless liquid etchant provided is difficult to control. The resultant extensive etching, plus the low viscosity sealant, can result in bonding to undesired areas in-vivo, such as "bridging" between adjacent teeth. The overlong setting time for both sealant and adhesive magnifies the difficulties of bracket placement and spread of resin.

### c. SOLO-TACH

This is the simplest of the three adhesives to use. The relatively high viscosity facilitates exact bracket placement, as does the rapid set. The liquid etchant again poses problems in control, but the higher resin viscosity permits limitation of undesirable excess.

### SIMPLIFYING DEBONDING

Minimising the difficulties of debonding can be approached in two ways, preventive or curative.

The adhesive used should give adequate but not excessive tensile bond strengths. This can be determined

either by personal trials or from the literature (i.e. Faust et al., 1978). "Softer" adhesives such as acrylics or modified composites (i.e. Dyna-Bond) make residue removal simpler, because of their lower abrasion resistance. Only the area destined for bracket placement should be etched. Adhesive flow, viscosity and required technique should obviate superfluous resin.

When debonding there is no evidence, to date, that non-irritant, aesthetically acceptable adhesive residue must be removed. It would be preferable to smooth over the remnants with mild abrasives, such as prophylaxis paste, rather than risk iatrogenic enamel damage with rotary grinding or cutting instruments.

SUMMARY

An in-vitro method was derived to demonstrate and quantify adhesive residue following debonding. The techniques involved staining the enamel, photomicrography and a random point count areal estimation.

Three types of orthodontic adhesives were compared by these techniques: an acrylic, a one-step composite and a two-phase sealant-composite with "soft" fillers. Twenty five specimen teeth were quantified for each adhesive at two stages of a debonding routine.

Residue removal with hand instruments alone was easiest for Orthomite IIS, possible for Dyna-Bond, and most difficult for Solo-Tach. Some remnants of Solo-Tach completely defied such techniques. Orthomite IIS left considerably less residue than either of the composites.

Evaluation at completion of debonding again showed the lowest residue for Orthomite IIS. Solo-Tach was the only material to require abrasion with the green rubber wheel, which was considered an undesirable factor. Considerable areas of specimens of Dyna-Bond and Solo-Tach showed a "pink" staining which was investigated at high magnification and represented diffuse resin residue. This could not be quantified.

The handling properties of the bonding adhesives were discussed and related to the control of spread of the resins and thence to debonding problems.

A logical approach to debonding was suggested involving limitation of the original bonding area, the use of "softer" adhesives, and the preferability of

harmless residue over iatrogenic enamel damage.

This study is in accordance with the findings of Casparsen (1977) and Gwinnett and Ceen (1978) that resin residue is present on most debonded teeth. In this case 84% of 75 fully debonded test specimens showed adhesive residue ranging from 1.1% up to 67% of the bonded area. The removal of all remnants would only be achievable at the expense of the integrity of the enamel surface, as in the techniques propounded by Fitzpatrick and Way (1977) whose findings cannot therefore be supported.

CONCLUSIONS

1. Staining enamel with Alizarin Red S is a simple, reliable method of disclosing resin residue, in-vitro.

2. Three zones of such staining reaction occur in debonded specimens: white, pink and red, representing bulk resin, diffuse resin and enamel, respectively.

3. Detection of adhesive residue with the naked eye is not reliable. Residue occurs on the majority of debonded teeth and the use of loupes or temporary stains would be useful in-vivo.

4. Limitation of etching and adhesive to the desired bracket area will reduce problems of excess resin.

5. Low viscosity resins are difficult to control in terms of undesired spread or precise bracket placement.

6. Orthomite IIS is the easiest material to debond and leaves the cleanest enamel surfaces.

7. Dyna-Bond, as a result of its sealant and "soft" fillers, is easier to debond with hand instruments than the other composite, Solo-Tach. Pumicing with a bristle brush considerably reduces the thin films of residue left by Dyna-Bond.

8. Solo-Tach, the hardest to debond, is the only material to need abrasion with the green rubber wheel.

9. The frequently published advice of cessation of resin abrasion just before the adhesive-enamel interface is impossible to implement because of delineation

problems. The use of "softer" adhesives, not requiring rotary grinding or cutting instruments, is advisable since all such implements can scar the enamel surface.

10. There is no evidence, to date, that it is essential to remove remnants of adhesive resins which are non-irritant and aesthetically and hygienically acceptable.

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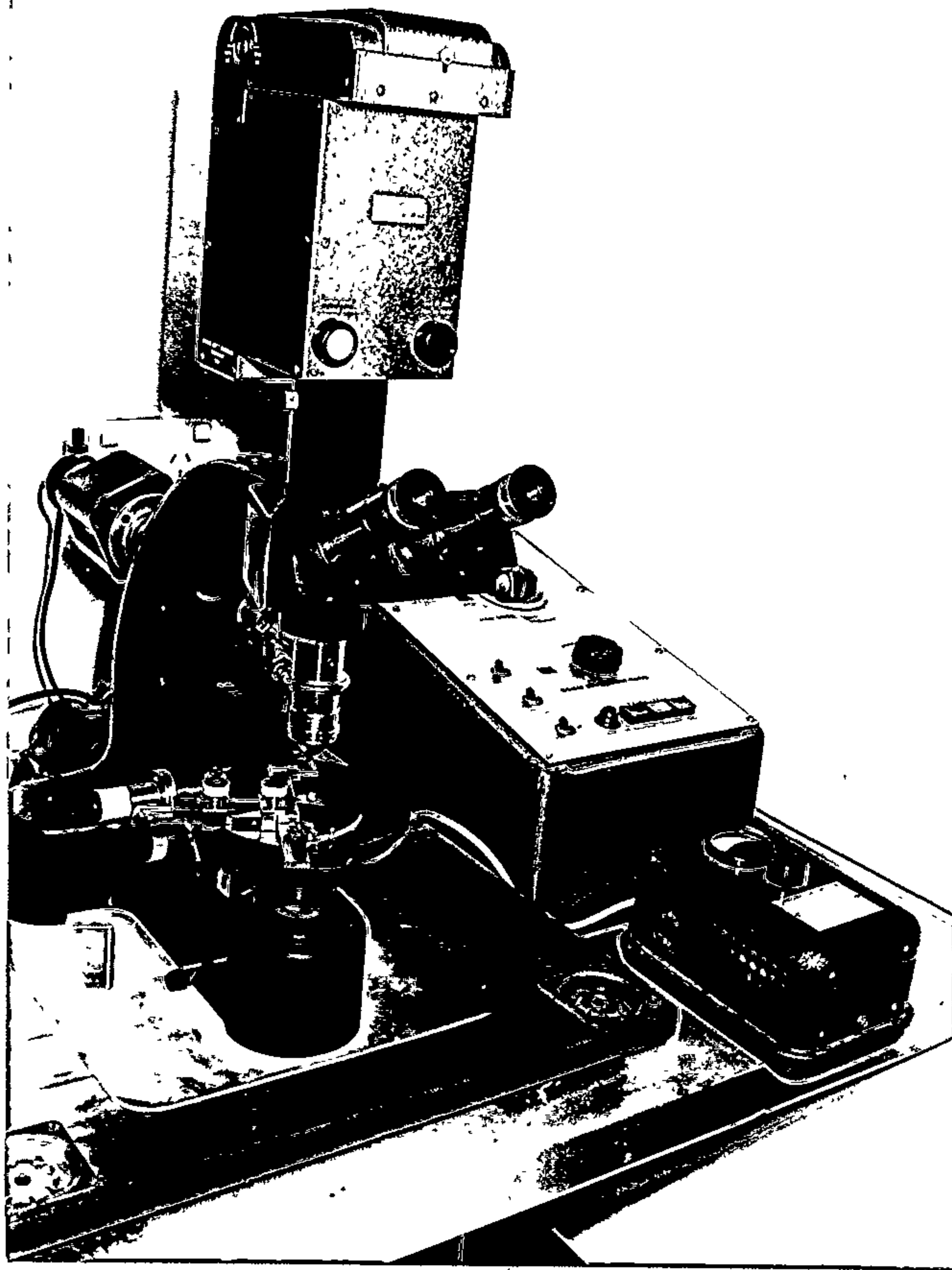
APPENDIX

Fig.6: The Leitz Ortholux microscope.

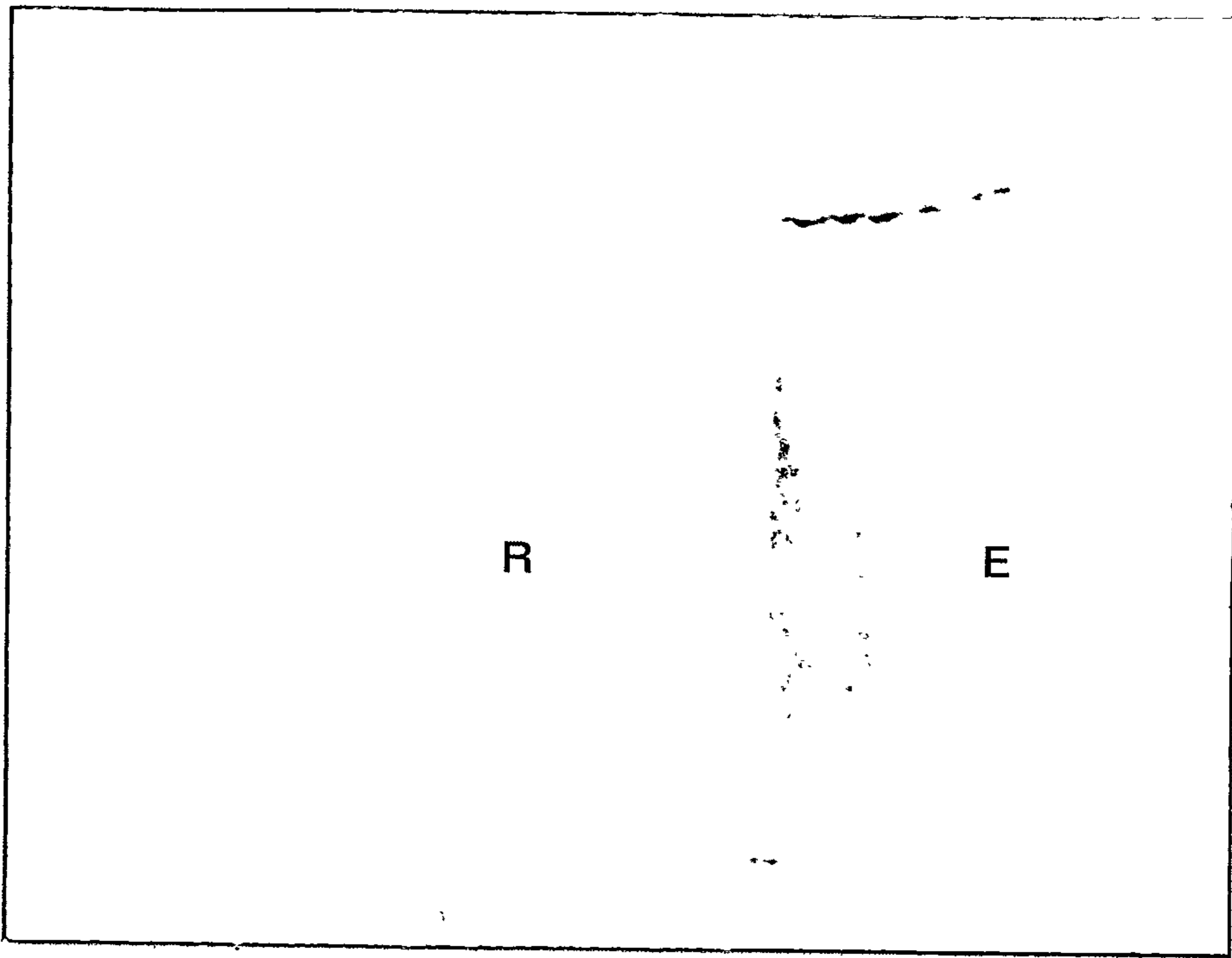


Fig.7: Showing testing for differentiation with Alizarin Red S. Stain is taken up by enamel (E), and not by resin (R). (Original magnification 110X).

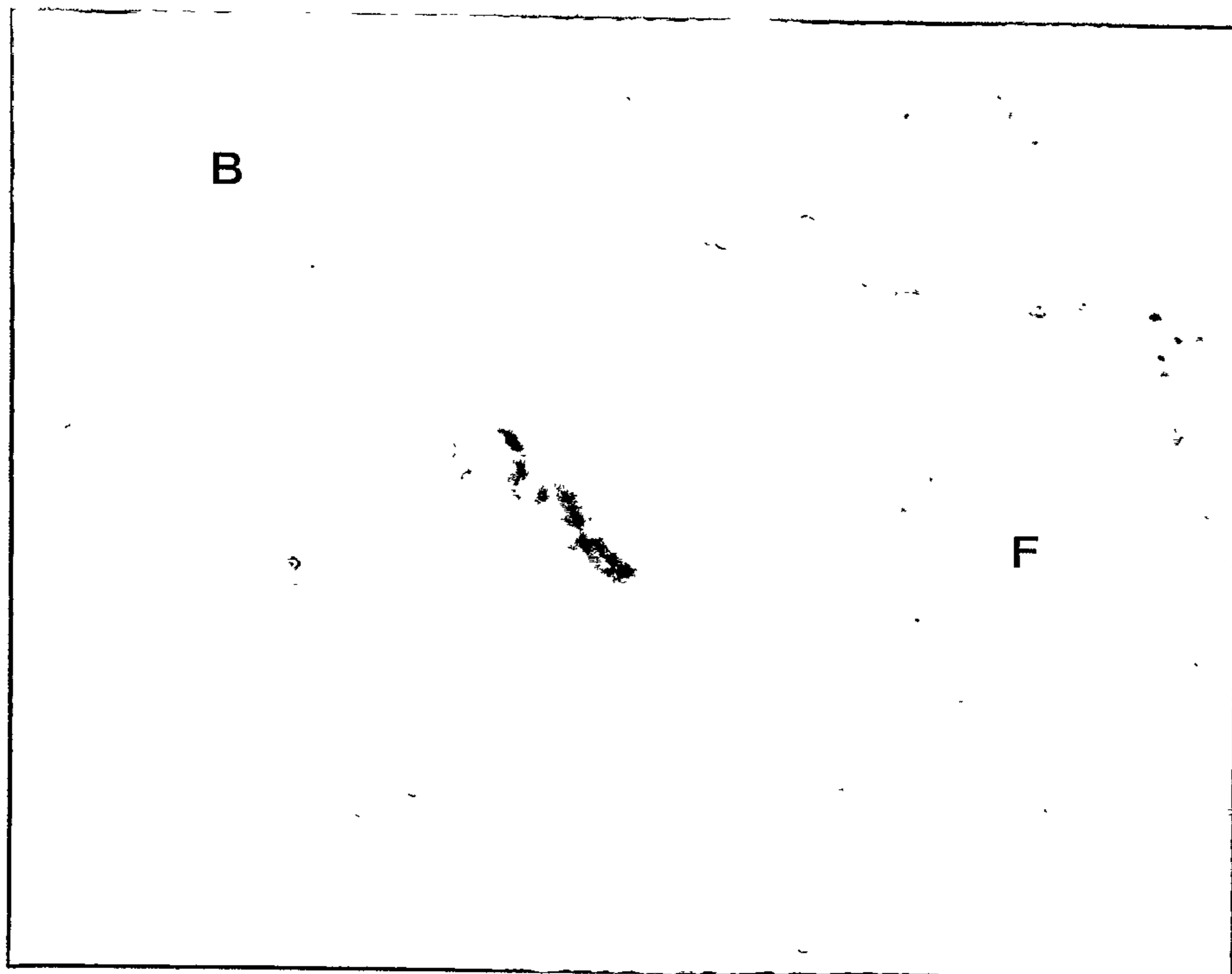


Fig.8: Showing bulk (B) and film (F) resin residue, at debonding Stage 2. (Original magnification 40X).

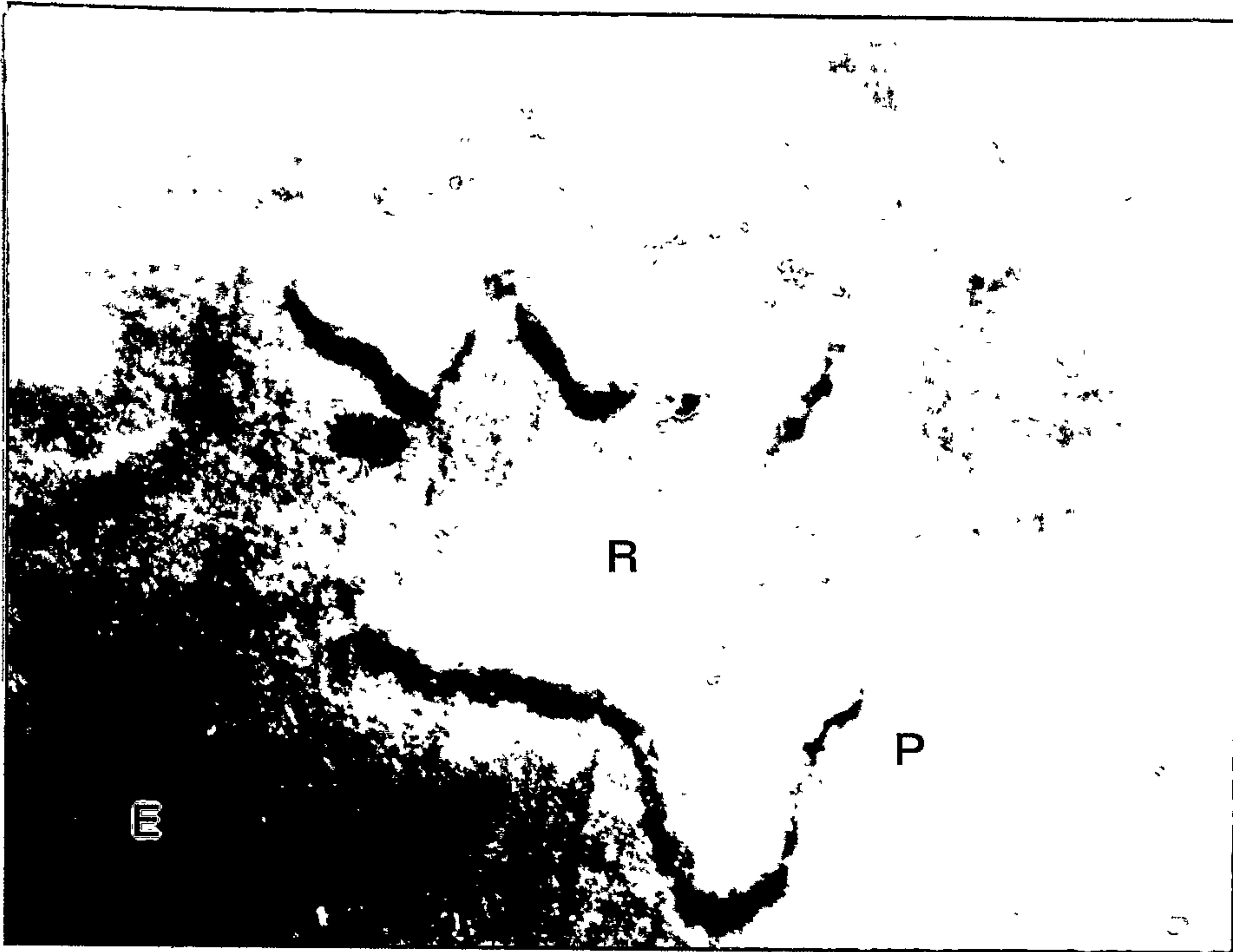


Fig.9: Showing resin residue (R), "pink" stained (P) and normal enamel (E) zones, at debonding Stage 4. (Original magnification 40X).

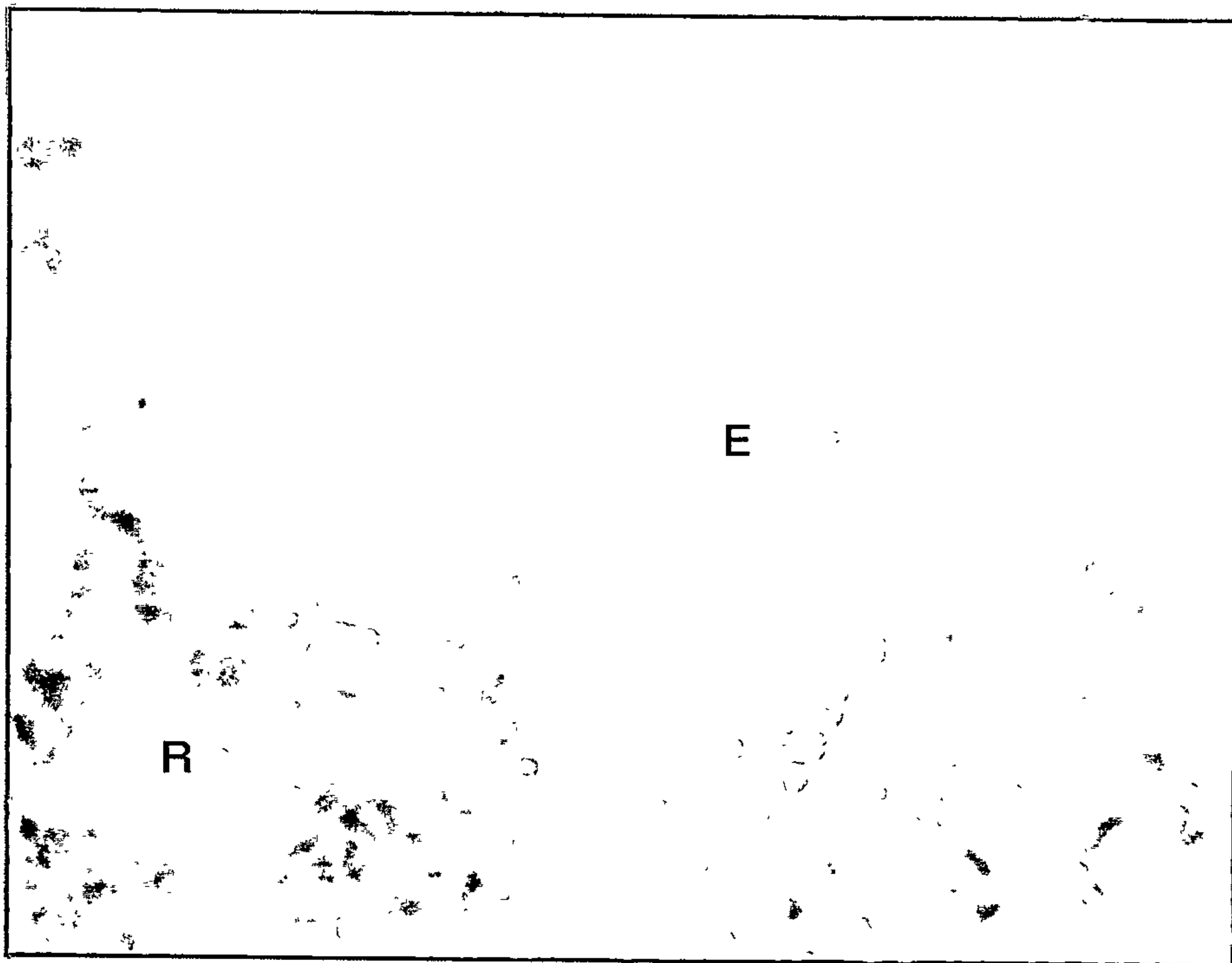


Fig.10: Showing higher magnification view of "pink" zone. Resin fragments (R) and enamel prisms (E) are visible. (Original magnification 320X).

DYNA-BOND				ORTHOMITE IIS				SOLO-TACH			
Stage 2		Stage 4		Stage 2		Stage 4		Stage 2		Stage 4	
#	%	#	%	#	%	#	%	#	%	#	%
1	93.3	1	23.2	1	0.0	1	0.0	1	69.8	1	19.3
2	93.3	2	0.0	2	6.0	2	0.0	2	84.2	2	30.3
3	89.2	3	1.1	3	2.1	3	2.5	3	60.0	3	4.6
4	76.2	4	0.4	4	29.5	4	1.4	4	80.0	4	3.9
5	86.3	5	54.7	5	14.7	5	17.5	5	73.0	5	3.2
6	75.8	6	17.2	6	1.4	6	13.0	6	87.4	6	44.6
7	64.6	7	28.4	7	0.0	7	1.8	7	11.2	7	9.5
8	59.6	8	41.1	8	1.4	8	6.0	8	79.7	8	18.6
9	60.3	9	67.0	9	2.5	9	0.0	9	17.8	9	4.2
10	85.1	10	19.3	10	2.8	10	0.0	10	67.7	10	4.9
11	78.6	11	7.4	11	11.2	11	13.3	11	69.2	11	18.9
12	83.1	12	39.3	12	0.4	12	8.8	12	92.3	12	2.5
13	67.4	13	56.1	13	20.7	13	0.0	13	74.1	13	11.6
14	82.5	14	62.5	14	28.1	14	1.1	14	95.9	14	20.0
15	46.7	15	28.1	15	1.8	15	4.9	15	81.1	15	63.5
16	63.4	16	23.5	16	11.9	16	0.0	16	76.8	16	3.9
17	65.6	17	51.2	17	12.3	17	0.0	17	94.4	17	2.1
18	81.1	18	21.4	18	7.7	18	0.0	18	75.4	18	19.6
19	56.8	19	1.4	19	2.5	19	1.1	19	82.8	19	30.5
20	97.5	20	1.8	20	3.1	20	1.8	20	76.1	20	2.1
21	77.2	21	1.8	21	5.7	21	4.2	21	55.9	21	9.1
22	92.3	22	15.4	22	24.2	22	0.0	22	61.9	22	31.2
23	49.6	23	0.0	23	2.5	23	11.9	23	96.8	23	53.7
24	87.7	24	33.7	24	14.2	24	0.0	24	87.4	24	36.8
25	54.7	25	9.8	25	5.3	25	4.6	25	96.1	25	21.8

Table 6: Showing adhesive residue as percentage coverage of base area for each test tooth.

# = specimen tooth number.

% = percentage residue.

#	%A	%B	DIFF.	#	%A	%B	DIFF.
1	93.3	90.9	-2.4	26	2.5	2.1	-0.4
2	6.0	5.6	-0.4	27	51.2	54.4	+3.2
3	23.2	24.9	+1.7	28	46.7	47.1	+0.4
4	93.3	90.9	-2.4	29	2.8	3.2	+0.4
5	0.0	0.0	0.0	30	1.4	0.0	-1.4
6	1.1	1.1	0.0	31	65.6	67.4	+1.8
7	89.2	89.6	+0.4	32	11.2	15.8	+4.6
8	2.1	5.6	+3.5	33	1.8	1.8	0.0
9	54.7	53.0	-1.7	34	81.1	77.3	-3.8
10	76.2	76.2	0.0	35	0.4	1.1	+0.7
11	29.5	33.7	+4.2	36	33.7	35.8	+2.1
12	28.4	31.6	+3.2	37	77.2	79.3	+2.1
13	86.3	89.8	+3.5	38	20.7	17.2	-3.5
14	14.7	17.2	+2.5	39	0.0	0.0	0.0
15	67.0	67.7	+0.7	40	92.3	87.5	-4.8
16	78.6	87.0	+8.4	41	49.6	45.9	-3.7
17	1.4	1.4	0.0	42	7.7	7.0	-0.7
18	7.4	8.4	+1.0	43	12.3	12.6	+0.3
19	83.1	90.4	+7.3	44	87.7	84.2	-3.5
20	0.0	0.0	0.0	45	2.5	1.8	-0.7
21	56.1	59.8	+3.7	46	11.9	12.3	+0.4
22	67.4	65.4	-2.0	47	9.8	11.6	+1.8
23	1.4	1.1	-0.3	48	54.7	57.5	+2.8
24	28.1	30.2	+2.1	49	60.3	64.9	+4.6
25	82.5	86.0	+3.5	50	63.4	59.8	-3.6

Table 7: Showing repeated measurements, at one week's interval, of fifty randomly selected specimens to test the significance of the error of the method, by Student 't' test.

# = specimen number.

%A = percentage residue at first reading.

%B = percentage residue at second reading.

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