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A CLINICAL COMPARISON OF DIRECT
AND INDIRECT BONDING IN ORTHODONTICS

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"The aim and object of all science is to be utilized and to be useful in the interests of mankind, and here is where the scientific theorist and the practical orthodontist must meet on common ground. For all science as it is human in origin is raised above the level of mere theory by the service it renders to humanity; then it must necessarily follow - the greater the service, the greater the science".

- Ralph Waldron - 1924

Presidents' Address Before the
American Society of Orthodontists
P. 600.

TABLE OF CONTENTS

INTRODUCTION	1 - 4
CHAPTER 1 - LITERATURE REVIEW	5 - 74
1.1 The Enamel Surface and the Effect of Enamel Demineralization	5 - 8
1.2 The Effect of Etching Acids on the Tooth Enamel Surface and Resin Penetration	9 - 17
1.3 Adhesion Mechanisms	18 - 24
1.4 The Use of the Acid Etch Technique for Direct Bonding in Orthodontics	25 - 56
1.5 The Indirect Technique	57 - 62
1.6 Types of Bracket Attachments for Direct Bonded Orthodontics	63 - 65
1.7 Advantages and Indications for Orthodontic Banding	66 - 68
1.8 Post Treatment Evaluations in Terms other than Band Failure	69 - 74.

CHAPTER	2	-	MATERIALS AND EQUIPMENT	75 - 80
CHAPTER	3	-	EXPERIMENTAL METHODS	81 - 104
3.1			Indirect Bonding Technique	81 - 97
3.1.1			Laboratory Procedures	81 - 86
3.1.2			Clinical Method of Indirect Bonding	87 - 97
3.2			Direct Bonding	98 - 100
3.3			Scanning Electron Microscopic Examination of the Composite Surface of the Enamel Interface	101 - 104
CHAPTER	4	-	RESULTS AND DISCUSSIONS	105 - 128
4.1			Statistical Analysis of the Failure Rates for the Direct and Indirect Techniques	105 - 110
4.2			Comparison of Direct and Indirect Bonding Techniques	111 - 124
4.2.1			Gingival Condition	115 - 116
4.2.2			Individual Tooth Groups	117 - 124
4.2.2.1			Molars	117 - 118
4.2.2.2			Premolars	118 - 121
4.2.2.3			Anterior Teeth	121 - 124

4.3	Scanning Electron Microscopic Evaluation	124 - 137
4.3.1	Auto-Tach	124 - 127
4.3.2	Concise	127 - 128
CHAPTER 5	- SUMMARY AND CONCLUSION	138 - 142
BIBLIOGRAPHY		143 - 172

LIST OF FIGURES

- Figure 1 - Scanning electron micrograph showing Type 1 etch pattern. Taken from Silverstone L.M. Page 19⁽¹²¹⁾. p. 11.
- Figure 2 - Scanning electron micrograph showing Type 2 etch pattern. Taken from Silverstone L.M. Page 20⁽¹²¹⁾.p. 12.
- Figure 3 - Photograph shows mouthguard adaptor with model and Stay-guard material in position prior to heating. p. 84.
- Figure 4 - Photographs shows model with wax spillways in position Stay-guard material has been heated sufficiently for adaptation to the model. p. 85.
- Figure 5 - Photograph shows model with Stay-guard material adapted. p. 86.
- Figure 6 - Photograph shows adapted positioner or tray. p. 86.
- Figure 7 - Photograph shows patient with Ormco cheek retractor in place. p. 93.
- Figure 8 - Photograph shows teeth isolated with "dry guards" and cotton rolls. Etching process is in progress while saliva ejector is in place. p. 93.
- Figure 9 - Photograph shows hair dryer with flexible tubing and attachable evacuator tip. p. 94.

- Figure 10 - Photograph shows etched and isolated teeth being dried with extension tip on hair dryer. p. 94.
- Figure 11 - Photograph shows isolated teeth with upper tray in position. p. 95.
- Figure 12 - Photograph shows both upper and lower trays in position after setting of the adhesive. p. 95.
- Figure 13 - Photograph shows sectioning of positioner with crown and collar shears. p. 96.
- Figure 14 - Photograph shows removing positioner after sectioning. p. 96.
- Figure 15 - Photograph shows topical fluoride application after isolation withOrmco cheek retractor. p. 97.
- Figure 16 - Photograph shows bonding completed with arch wires in place. p. 97.
- Figure 17 - Photograph shows Synavac E 12/14 coating unit. p. 104.
- Figure 18 - Photograph shows Cambridge Stereoscan S600 scanning electron microscope. p. 104.
- Figure 19 - Scanning electron micrograph showing Auto-Tach Magnification 20X. p. 131.
- Figure 20 - Scanning electron micrograph showing Auto-Tach Magnification 100X. p. 131.

- Figure 21 - Scanning electron micrograph showing
Auto-Tach Magnification 500X. p. 132.
- Figure 22 - Scanning electron micrograph showing
Auto-Tach Magnification 2000X. p. 132.
- Figure 23 - Scanning electron micrograph showing
Auto-Tach Magnification 2000X. p. 133.
- Figure 24 - Scanning electron micrograph showing
Auto-Tach Magnification 5000X. p. 133.
- Figure 25 - Scanning electron micrograph showing
Auto-Tach Magnification 5000X. p. 134.
- Figure 26 - Scanning electron micrograph showing
Concise Magnification 20X. p. 134.
- Figure 27 - Scanning electron micrograph showing
Concise Magnification 100X. p. 135.
- Figure 28 - Scanning electron micrograph showing
Concise Magnification 500X. p. 135.
- Figure 29 - Scanning electron micrograph showing
Concise Magnification 2000X. p. 136.
- Figure 30 - Scanning electron micrograph showing
Concise Magnification 2000X. p. 136.
- Figure 31 - Scanning electron micrograph showing
Concise Magnification 5000X. p. 137.
- Figure 32 - Scanning electron micrograph showing
Concise Magnification 5000X. p. 137.

INTRODUCTION

The first recorded cementation of an orthodontic band was by Magill in 1871⁽¹⁾. This platinum band was to serve as an introduction to fixed appliance therapy and the concomitant necessity of rigidly attached orthodontic attachments. These would facilitate the control of biomechanical forces to effect desired tooth movement. As the state of the art of fixed appliance orthodontics evolved it became apparent that these orthodontic attachments and the adhesive which maintained their position had to be of a robust enough nature to endure a treatment time of several years.

These orthodontic attachments have generally been secured to the teeth by welding or soldering of to metallic bands which encircled the entire tooth. These metallic bands were originally made from precious metal, such as platinum or gold, and later from stainless steel. They relied on being tightly fitted to the coronal section of the tooth and then being cemented into position. Over the years the fitting of such bands has violated a number of biological principles and thereby endangered the integrity of a number of oral structures. This has been accomplished by introducing dangers such as caries due to marginal leakage, periodontal disease

due to food and plaque retention, the possibility of premature contacts, not to mention the discomfort suffered by the patient in the adaptation of such bands.

Positional Retention of Orthodontic Attachments

Since the inception of fixed appliance therapy from the latter part of the 19th century, orthodontists have relied almost entirely on cements or luting agents which were developed for retention or lining of restorations and prostheses, for the retention of their orthodontic bands. It is for this reason that a number of these products are not entirely suitable, as the desirable features of a restorative cement are:⁽⁹⁶⁾

- Retention
- Marginal Seal
- Insulation
- Therapeutic

In orthodontic applications, it is really only retention and to some extent marginal seal, which is of any consequence. The insulative properties are insignificant, as they include protection against thermal changes which are not a factor in orthodontics, while the therapeutic consideration involves only the

maintenance of the enamel surface by protection against attack.

Over the years a number of cements have been used:

- a) Metallic phosphate cements
- b) Zinc Oxide - Eugenol cements
- c) Silicate cements
- d) Modified and reinforced cements

e.g.

- 1) Zinc oxide - Eugenol cements with added resins and synthetic resins

(Phillips et al [1969])⁽⁹⁶⁾

- 11) Silico Phosphate cements

Hybrid Silico Phosphate cements⁽⁹⁶⁾

- e) Acrylic cements
- f) Zinc Polycarboxylate cements
- g) Composite cements

Although many of these materials had little significance in the field of orthodontics, their development has led us to a situation where the bonding of the orthodontic bracket to only one surface of a tooth has become a feasible proposition. Before the development and predictability of this technique may be discussed a number of biological

chemical and physical parameters must be discussed:

- 1) The enamel surface and the effect of enamel demineralization
- 2) The effect of etching acids on the tooth enamel surface and resin penetration
- 3) Adhesion mechanisms

CHAPTER 1LITERATURE REVIEW1.1. The Enamel Surface and the Effect of
Enamel Demineralization

The bonding of orthodontic attachments, composite restorations or preventive fissure sealants to the enamel surface has acquired considerable significance in recent years. These processes are dependent on the selective demineralization of the enamel surface, a process which in turn may be greatly modified by the presence of enamel surface coverings.

It is generally accepted that the developmental structures covering the tooth surfaces are lost soon after eruption. Therefore, the pellicle that is found on the tooth surface under normal conditions is of salivary origin^{(35) (63) (71) (138)}, and various reports indicate that, at least initially, the pellicle is formed by a selective adsorption of salivary proteins⁽⁷⁰⁾. More important perhaps is the finding that there exists essentially the same composition of proteinaceous film, regardless of the proximity of the enamel surface to either parotid or sublingual salivary sources⁽¹³²⁾. This suggests that a selective adsorption takes place in the oral environment, since substantial differences exist in the composition of the two salivary secretions. This adsorption

concept has a precedent in that salivary proteins have been shown to adsorb selectively onto apatite surfaces in vitro⁽⁶⁾ (52).

An overall look at the available literature indicates that, at least in the initial stages, the formation of the tooth pellicle, involves a selective adsorption process of salivary proteins on to the surface of the tooth enamel. As the pellicle ages, it appears that its composition changes in an undetermined manner and probably involves contributions of microbial origin⁽⁵⁾ (6). Thus, the adsorbed salivary proteins act as a sort of template from which the kind of integuments which are found on teeth evolve. These integuments have been described in the literature and it appears that the thickness of the acquired pellicle to which we are referring varies from 1 μm ⁽⁵⁴⁾ (65) to 10 μm ⁽⁷¹⁾.

Therefore the pellicle is a very thin film and yet, on the basis of the experimental work available, it appears to play an important role in the prevention of caries⁽³³⁾. Consequently, it has a marked effect on the action of etching acids on the enamel surface when preparing a tooth for an acid-etch composite restoration, orthodontic attachment of fissure sealant.

The ability of the enamel pellicle to resist acid dissolution seems to stem from the fact that the salivary proteins which constitute it have a high affinity for the apatitic surfaces and display a net electrical charge at physiological pH⁽⁵³⁾. It is through this electrostatic interaction that the pellicle may act as a more effective diffusion carrier for charged particles than was suspected for such a thin structure, i.e. the pellicle may act as an ionic "permselective membrane". Takaesu et al 1973⁽¹³⁶⁾ suggests the possibility that the electrochemical properties of the hydroxyapatite surfaces are vastly altered upon adsorption of the salivary proteins. Even if the pellicle does not behave as a perfect "permselectivity membrane", the magnitude of its permselectivity may be sufficient to act as a retardant of acid dissolution of the mineral fraction of the enamel surface⁽⁸¹⁾.

Alterations to the role of the pellicle have been proposed:⁽⁸³⁾

- a) The role of fluoride and metallic ions which are found in greatest concentration at the outer enamel surface⁽²⁶⁾.
- b) As the solution of calcium phosphate occurs at the deeper layers, it is redeposited in the

surface layers as dissolution progresses.

Whether these alternatives are correct or not it is generally agreed that exposure of etched enamel surfaces to saliva will result in a poor bond or no bond of the resins. On the other hand this also has an important protector effect. Silverstone⁽¹²¹⁾ has shown with his micro-solubility studies that if enamel is etched and then exposed to oral fluid, there is a significant reduction in solubility rate. After periods of 24 hours exposure to oral fluid, the solubility of the previously etched enamel surface approaches that of adjacent sound enamel. This remineralization phenomenon is therefore an important factor in the protection of etched areas not covered by resin, a phenomenon which could to a large extent be attributed to the formation of the enamel pellicle and salivary proteins.

1.2 The Effect of Etching Acids on the Tooth Enamel Surface and Resin Penetration

The bonding of orthodontic attachments or any restoration to the enamel surface of a tooth requires the use of an acid solution to etch that surface. In his original publication, Buonocore⁽²¹⁾ used 85% phosphoric acid to etch the enamel surface prior to bonding the acrylic restorative materials which he was using. Since this initial breakthrough, a whole science of bonding restorative material has evolved and consequently widespread experimentation into the fields of:

- 1) Acid concentration
- 2) Etching time
- 3) The use of buffers

with many workers using 50% phosphoric acid buffered with 7% zinc oxide by weight as an etching agent.

Silverstone⁽¹²⁰⁾ has shown that the acid solution produces changes on the enamel surface in two ways:

- a) A shallow layer of enamel is removed by etching. Thus, any plaque surface and sub-surface cuticles, are effectively removed from the site to be bonded. In addition, chemically inert

crystallites in surface enamel are also removed, thereby favouring chances of chemical union between hard tissue and resin.

- b) Following the removal of the surface layer by etching, the remaining enamel surface is rendered porous by the acid solution. It should be noted that it is in this region that the resin is able to penetrate and hence bond to the enamel⁽¹²¹⁾.

Recent work⁽¹²³⁾ reported that three basic types of etching patterns were produced by the use of phosphoric acid as an etchant.

- a) Type 1 - where there is a preferential removal of prism cores. see fig. 1.
- b) Type 2 - where there is preferential removal of the prism peripheries. see fig. 2.
- c) Type 3 - this occurs less often but in this type the etched enamel surface bears no resemblance to the enamel morphology seen in fig. 1 or 2.

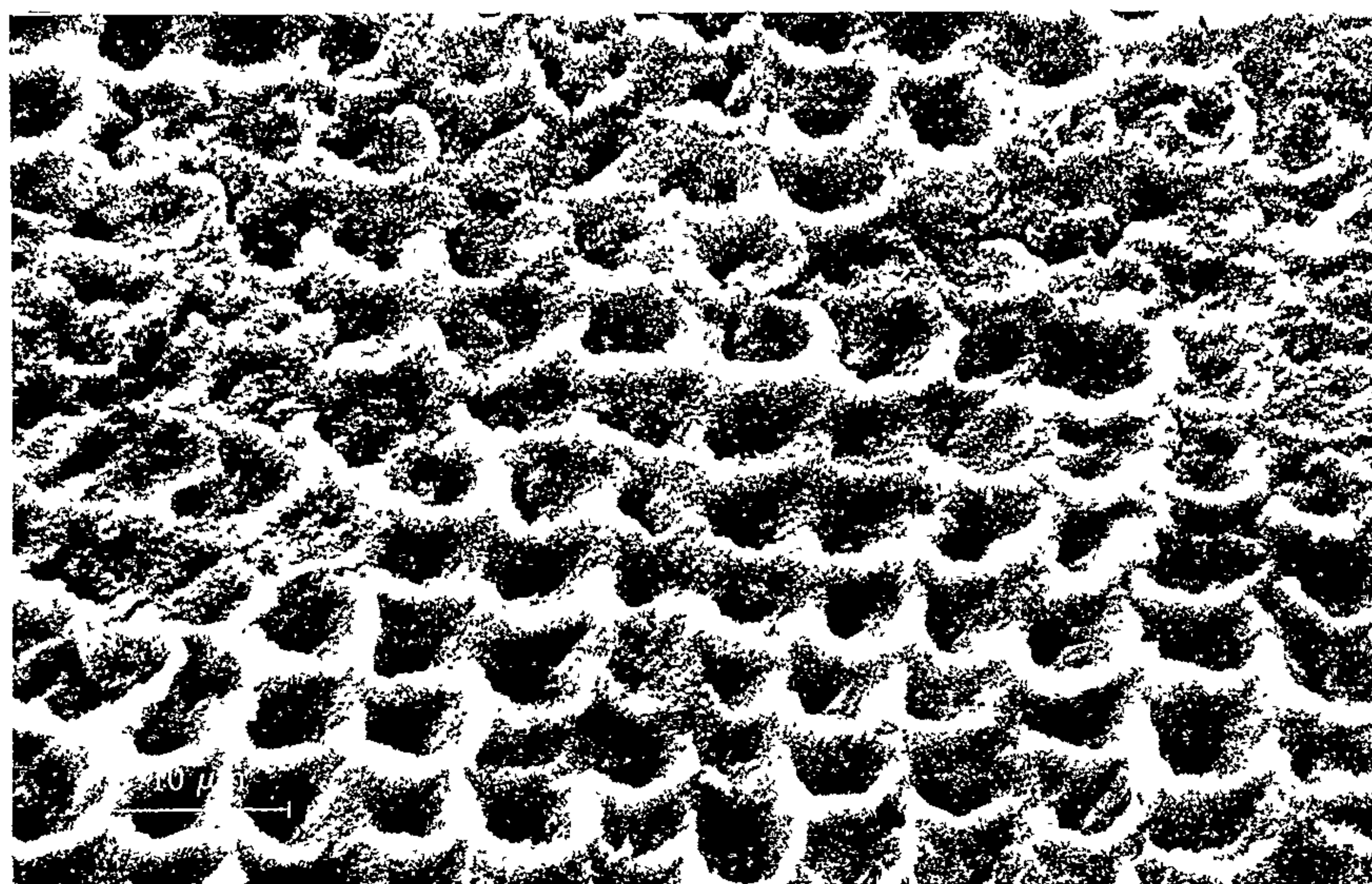


Fig. 5. Scanning electron micrograph of an enamel surface that has been etched for 60 seconds with 30 per cent phosphoric acid. The etch is seen to be evenly distributed over the entire enamel surface. A Type 1 etching pattern is seen in which prism centres have been removed preferentially.

Fig. 1 - Type 1 etch pattern

Taken from Silverstone L.M. Page 19⁽¹²¹⁾

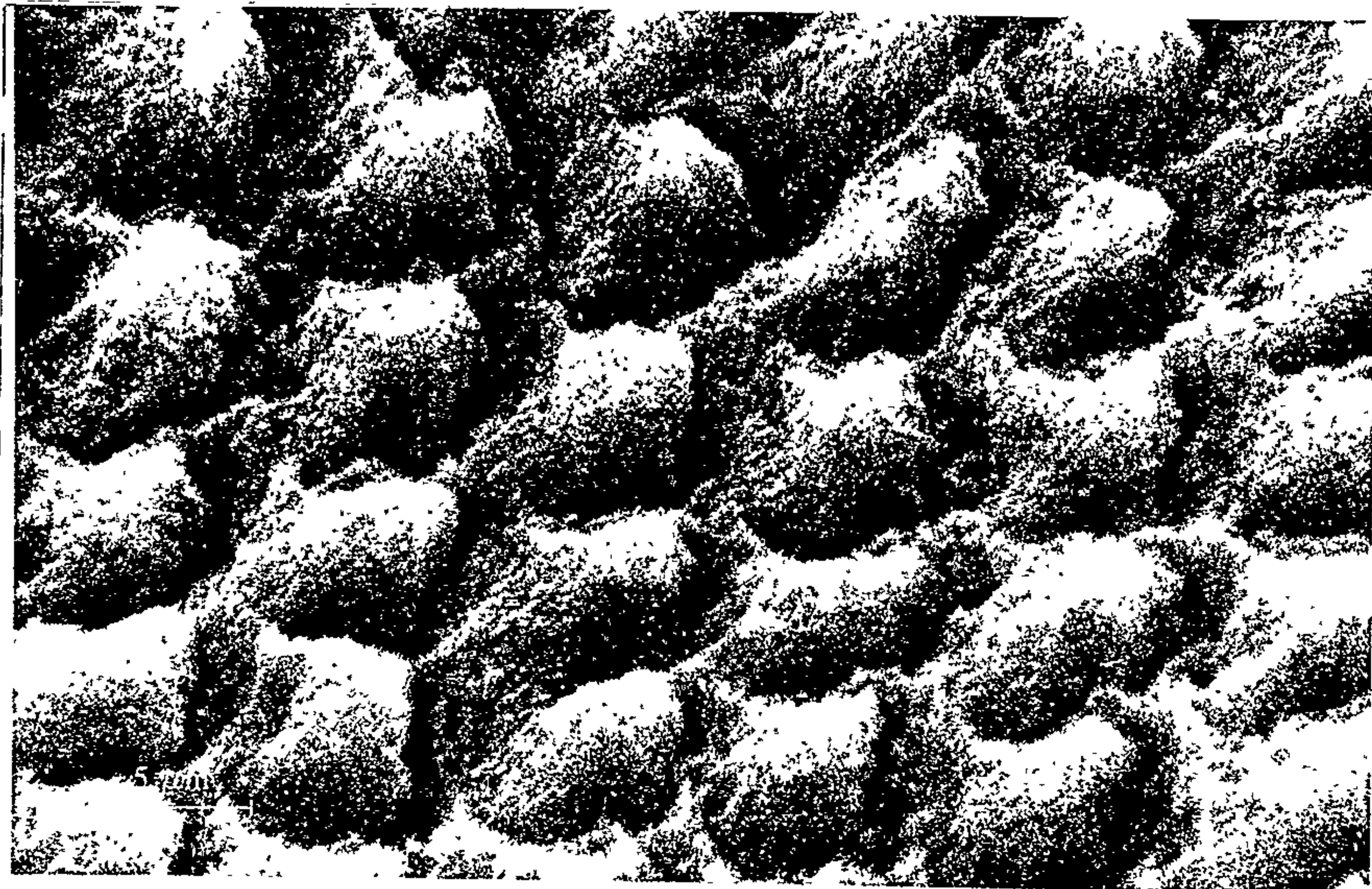


Fig. 7. Scanning electron micrograph of an enamel surface which has been exposed to 40 per cent phosphoric acid for 60 seconds. In this case, the etching pattern is one in which there has been a preferential removal of prism peripheries, termed a Type 2 etching

Fig. 2 - Type 2 etch pattern

Taken from Silverstone L.M. Page 20⁽¹²¹⁾

It should be noted that all three types of etch patterns have been found to occur on a single tooth surface while being produced by the one acid solution. There is generally a gradual transition from a Type 1 to a Type 2 etch pattern.

The most commonly produced etch pattern is the Type 1 showing the removal of prism centres. The second most common pattern is the Type 2 pattern with Type 3 rarely occurring. This highlights the variation in structure which may occur in tooth enamel, not only from one tooth to another, or surface to surface, but from site to site on a single tooth surface.

The concentration of the phosphoric acid used has been shown to be of great significance in the type of etching pattern achieved. Silverstone⁽¹²¹⁾ utilized a one minute etch time and unbuffered phosphoric acid solutions in the concentrate range 5 - 80 per cent. (w/w). He assessed human enamel surfaces with special reference to the variation in degree of etching over a single tooth surface.

He found that concentrations of 5 to 15 per cent and 70 to 80 per cent gave only minimal surface changes. Over the 20 to 60 per cent concentration

range enamel surfaces demonstrated the basic three types of etch patterns but the most evenly distributed and consistent etch surfaces were achieved in the 30 to 40 per cent phosphoric acid concentration range. He claimed that a 37 per cent solution gave the most even and consistent results.

Results concerning the enamel of deciduous teeth have yielded varying reports. Several workers have recorded the presence of areas of prismless enamel⁽¹⁰⁰⁾ ⁽¹⁰¹⁾ and consequently better retention rates of fissure sealants have been reported on permanent teeth when compared to deciduous⁽¹¹⁶⁾.

More recently⁽⁵⁵⁾ a comparison was made of enamel structure and crystallite orientation on the occlusal surfaces of deciduous and permanent teeth. It was concluded that only rarely was a prismless surface in evidence and that the resin crystallite orientation and prism arrangement was identical in deciduous and permanent enamel.

Silverstone⁽¹²¹⁾ concluded that only 17% of deciduous tooth enamel showed areas of prismless enamel and this was found in the cervical and margin area. Mortimer⁽⁸²⁾ had attributed the poor retention of fissure sealants to deciduous enamel and to the presence of areas of prismless enamel.

Silverstone⁽¹²¹⁾ found that by doubling his etching time significant etching patterns were produced on deciduous enamel showing a well defined prism pattern. The prolonged etching time is attributed to the lower mineral content of deciduous teeth. The mineral content of permanent teeth is 92 per cent while that of deciduous teeth is 86 to 88 per cent⁽⁸²⁾.

Therefore, the etching characteristics of deciduous enamel are said to be attributable to the lower mineral content and higher pore volume,⁽¹¹⁹⁾ which may result in the deciduous enamel surface accumulating a larger amount of exogenous organic matter.

Quantitative inhibition studies with polarized light, conducted by Silverstone⁽¹²¹⁾ showed that the effect of phosphoric acid on enamel was in advance of the region being classified as porous by qualitative microscopy. This appears to indicate an effect at three levels which are classified into three specific zones:

- a) A zone of enamel measuring approximately 10 μ m in depth which appears to be lost during etching.
- b) A zone measuring approximately 20 μ m deep which

is rendered porous according to qualitative measures with the polarized microscope.

(Qualitative Porous Zone)

- c) The deepest zone measuring 20 μm in depth. This area appears indistinguishable from sound enamel on qualitative examination but has been rendered slightly porous, as a result of acid solution (Quantitative Porous Zone). The level of porosity of this third zone is stated to be extremely low⁽¹²¹⁾ as it reduces only by a small amount the observed negative birefringence of the enamel. There is still considerable debate as to whether or not resin tags penetrate into this zone.

Human enamel shows variety with respect to size and shape of the pores within it, e.g. they may be spherical or elongated or sometimes in the form of large chambers connected together by smaller channels known as "ink bottle" systems⁽⁹⁷⁾. Just below the surface of human enamel, there occurs a zone showing dark prism markings which are particularly well seen in finely polished sections. This indicates a pore system which must be reasonably extensive, as they are so clearly visible when a section is examined in water. Yet the system must

be almost impenetrable as it is difficult to alter the appearance of the markings. Therefore, such potential space is not available perhaps because the pores are connected together by extremely narrow channels⁽¹²¹⁾. It might be that the impenetrable "ink bottle" pore systems are opened up in the third zone, (Quantitative Porous Zone), such that, although demineralization is negligible, potential space present in sound enamel becomes available for penetration by resin molecules. Silverstone⁽¹²¹⁾ claims this method as being feasible, as he claims to have demonstrated resin tags which penetrate to this depth in enamel. Such a bonding mechanism of resin penetration into etched enamel, would suggest bonding at a molecular level.

1.3 Adhesion Mechanisms

The American Society for Testing Materials has defined an adhesive as "a substance capable of holding materials together by surface attachment" but there is some divergence of views as to the mechanisms of adhesion covered by this definition.

There are basically two schools of thought on the mechanisms of adhesion covered by this definition:

- a) That it includes both mechanical interlocking and interfacial bonding by molecular attraction.
- b) That it includes only interfacial bonding.
(This school appears to predominate).

It is claimed⁽¹²⁸⁾ that in practice both mechanisms contribute to the strength of the bonded joint but one or the other predominates.

Mechanical Interlocking - This involves the penetration of the bonding agent into surface irregularities and it is in this manner that most conventional restorative materials are retained⁽²¹⁾. Buonocore in 1955 pioneered the use of acid etchants to bond resins to teeth. The function of the 50 per cent phosphoric acid was to remove debris from the

tooth surface; increase the wettability and create porosities, into which the monomer composition could flow before hardening, giving rise to resin tags within the enamel which in turn are responsible for interlocking of enamel and adhesive. Buonocore has expounded on his early work by further publication in 1973⁽²⁵⁾.

Adhesion by Intermolecular Attraction - This concerns the intermolecular attraction between adhesive and substrate. This is the most favoured approach to biological bonding^{(7) (94)}.

In order for this type of bonding to occur a very close intermolecular proximity is required. Consequently good wetting and spreading of the adhesive over the enamel surface is required in order for this type of bonding to occur. When this close interfacial relationship is achieved, then a strong bond due to Van der Waals forces, (dispersion, induction and orientation) is achieved. It is not necessary to develop hydrogen bonds, or primary chemical bonds, in order to develop high bond strength, although adhesive bonding may be improved if these are formed⁽⁵⁸⁾.

The adsorption theory of interfacial interaction,

postulates the importance of the role of adhesion and the need to select adhesives whose liquid surface tension (V) is less than the critical surface tension (V_c) of the adherend in order to achieve complete wetting. Zisman⁽¹⁴⁷⁾ (148) introduced the concept of low energy and high energy surfaces. He showed that certain molecules formed "autophobic: adsorption layers which possessed a V_c less than the V of the source liquid. Thus the liquid was unable to spread on its own adsorbed layer and the high energy surface would thereby behave as a low energy surface. The localisation of the attractive forces responsible for adhesion to distances of less than $5A^0$ led Zisman to conclude that spreading would always be associated with cohesive failure of the adherends, rather than the interface.

The diffusion theory of Voyutskii⁽¹³⁹⁾ presents an alternative view of interfacial bonding. This theory emphasizes molecular inter-diffusion and penetration across the boundary. The theory has limitations as it requires the need for mutual solubility and segmental mobility in the adhesive and adherend but, on the other hand, it does account for certain aspects of bonding between polymers.

Bikerman⁽¹¹⁾ expounded another theory of the adhesion mechanism, i.e. the weak boundary layer concept. The basis of this is that joint failure does not occur interfacially but through weak boundary layers, which arise through the presence of stress concentrations from dimensional changes, air porosity, impurities, adsorption layers etc. Therefore, bonding is a function more of the interacting elements of the joint components, rather than the interfacial forces. This conflicts with the adsorption theory, but shows the importance of minimising weak boundaries through the removal of all contaminants from the adherends.

Kaeble⁽⁵⁸⁾ discusses the theories of adhesive action and interprets each as being applicable to only a narrow range of adhesion phenomena. He stresses the need for a generalized adsorption - diffusion theory, and suggests that the adhesion theory has to be fitted to a particular problem. Solomon⁽¹³¹⁾ in his discussion of adhesion phenomena, calls for new approaches which will provide more decisive prognosis for particular adhesion problems.

From the above discussion on adhesive mechanisms it becomes obvious that the nature and state of the adherend surface, combined with the nature and state of the adhesive are important parameters in

establishing a strong joint.

Attempts to assess wetting, spreading and interaction of materials with enamel, have been undertaken by a number of investigators^{(7) (20)}. Despite these investigations it is still not possible to draw any definitive conclusions as to the ultimate desirability of molecular structures for adhesion but two possible solutions have been suggested:

Firstly, that the materials be such, that they will strongly interact with a cleaned enamel surface and thereby displace water.

Secondly, that the tooth surface be conditioned with a primer or coupling agent, thereby providing an adsorbed layer to which the bonding agent could chemically unite⁽²⁰⁾.

It is generally accepted that the cleaning of the enamel surface may be accomplished by the use of a mild abrasive, e.g. pumice and water⁽¹²¹⁾ but additional treatments have been suggested. The use of 0.02M lactic acid⁽⁴⁵⁾ or certain polycarboxylic acids⁽¹⁹⁾ showed improved bonding to enamel with acrylic resins. Comparable improvements in wetting and bonding were achieved by surface treatment with

40 per cent phosphoric acid, which produced extensive etching⁽¹³⁰⁾.

The utilization of coupling agents has been suggested by some authors e.g. glycerophosphoric acid demethacrylate as a cavity primer for acrylic resins⁽⁶²⁾, or N-(2 hydroxy - 3 - methacryloxy - propyl) - N - phenyl glycine (NPG-GMA). These materials are intended to interact with the hydroxy-apatite component of enamel and subsequently copolymerise with the bonding or restorative resin. The above coupling agents have shown only a small improvement in bonding at a clinical level and work done on numerous polymerisable calcium chelating agents by Masuhara et al⁽⁶⁹⁾ has met with little success.

In the light of the preceeding works, it becomes evident that the mechanisms of bonding are difficult to specify clearly. It has been shown that liquids which wet hydroxy-apatite may form hydrogen bonds with the mineral⁽¹¹⁴⁾, whereas Glantz⁽⁴⁵⁾ found that in addition to Van der Waals forces, polar forces, and hydrogen bonding played a part in the adhesion to enamel. Despite these areas of controversy, several general recommendations can be made for

adhesive materials i.e.

- That the material must be of a low viscosity which wets and spreads on clean tooth substance under oral conditions and which solidifies chemically to a material of low setting and thermal contraction.
- The material should be mechanically strong, but have a degree of flexibility to minimize stress concentrations on the bond.
- The bond must be resistant to water displacement.
- The displacement of adsorbed water layers and surface organic films would be desirable.
- The material must be non-toxic.

1.4 The Use of the Acid Etch Technique for Direct Bonding in Orthodontics

The high degree of retention obtainable by the acid etch technique applied to direct bonding has made an impact in the field of orthodontics.

Direct bonding can be defined as that process, whereby an orthodontic attachment is manually fixed directly onto the tooth surface, by a chemical and/or physical means.. 0

The development of this process began after Buonocore (1955)⁽²¹⁾ reported that he had obtained a bond between filling materials (acrylics) and tooth structure by first etching the enamel with 50 per cent phosphoric acid.

In 1958 Sadler⁽¹¹²⁾ surveyed nine commercially available adhesives and reported that none exhibited the stability required for orthodontic needs. It must, however, be stressed that none of these were used with an acid etch technique.

When screening several materials with adhesive potential, Swanson and Beck⁽¹³³⁾ found the best results were obtained from modified cyanoacrylates and epoxy resins. They concentrated their experimental

work on the modified cyanoacrylates, as the setting time of epoxy resins were too prolonged for clinical use.

Their clinical trials were less successful than their in vitro studies which had shown the necessity for acid etching of the enamel. They attributed their poor clinical results to the movement of moisture through the tissues of the tooth, resulting in adhesion breakdown. Their conclusions were that if this type of moisture movement was responsible for adhesion failure, then no material available at that time would give an adequate bond.

The authors did however stress that if bonding was to be successful, the enamel surface must be clean, etched, dry and that moisture was the greatest deterrent to adhesion.

The use of coupling agents, adhesion promoters, vinyl or acrylic monomers, surface active agents (such as water resistant copolymers), cyanoacrylates with fillers and rapid curing flexible epoxy resin formulations were suggested by Newman⁽⁸⁶⁾ as adhesive materials with potential for the attachment of plastic orthodontic brackets.

The development of a technique for testing bond strengths between adhesive materials and tooth tissues⁽¹³⁾ led Bowen to the conclusion that strong and stable adhesion between resin and tooth required a waterproof bonding mechanism. Bowen⁽¹⁴⁾ later found that surface active agents, with hydrocarbon portions of sufficient polarity to compete successfully with water for the surface of powdered tooth tissue particles, were theoretically capable of forming a chelating ring with surface ions. This led to a theory that a coupling agent containing such groups, as well as groups capable of copolymerizing with the dental material should improve bonding. He described these agents as "surface-active comonomers". V-phenyl glycine and glycidyl methacrylate (NPG-GMA) were synthesised in an addition reaction, for use as such an agent. This was subsequently shown to promote a significant increase in water resistant bonding between the resin tested and tooth surfaces. The pretreatment of the dentine surface with dilute acid further increased adhesion⁽¹⁵⁾. NPG-GMA also increased adhesion to enamel and fluoroapatite. As there is no organic matter in fluoroapatite, the presumption was made that organic constituents of enamel and dentine were not essential to the mechanism of bonding⁽¹⁶⁾. Bowen then proceeded to confirm that the mechanism may be primarily due to interaction of the mineral phase of tooth structure, after NPG-GMA

failed to improve bonding with collagen⁽¹⁷⁾. It was concluded from this work by Bowen, that the action of acid pretreatment of enamel would most likely be acting by modifying the mineral surface, rather than by increasing the exposure of organic content.

Epoxy resins were regarded as more promising by Newman⁽⁸⁷⁾ for use in direct orthodontic bonding as:

- 1) They are solvent free solids thus eliminating the problem of solvent evaporation on setting.
- 2) They have high shear strength and rigidity.
- 3) They show excellent wetting properties.
- 4) They appear resistant to acids and alkalis of the oral fluid.

The above properties may not be pertinent to all epoxies, and amine curing agents may be toxic. It was for this reason that Bowen⁽¹⁷⁾ chose "relatively innocuous flexibilizing polyamide - polyamines" as curing agents. Cold cure acrylic, plexiglass and polycarbonate orthodontic attachments,

shaped to the tooth were used. In shear and tensile testing, the plexiglass gave the best results per unit bond area but the cold cure acrylic gave the highest breaking strengths. Then comparing etched and non-etched tooth surfaces, he found that etched surfaces gave higher bond strengths. The favouring of these epoxy formulations was based on increased flexibility of the joint, reduction of irritation potential, low toxicity and reduced sensitivity to damage from moisture in the oral cavity. However, the slow setting time of 15 to 30 minutes of these non-toxic epoxies was found to be their greatest disadvantage, especially as it took 4 days to achieve complete setting. The disadvantage was severe enough to class these materials as "clinically inconvenient".

Examination of the interface between etched enamel and cyanoacrylate⁽⁴⁹⁾ showed "tag-like" projections of approximately 10 μ m, which were attributed to the penetration of superficial enamel by adhesive. The origin of these extensions into the enamel were attributed to liquid monomer penetrating and polymerizing within the cores of the enamel prisms⁽⁵⁰⁾. The postulation that such penetration could encapsulate the crystallite components of enamel and provide an effective mechanical bond, while at the same time protecting

the outermost enamel was consequently given. Gwinnett and Matsui⁽⁵⁰⁾ tested eight materials comprising cyanoacrylates, methacrylates and commercial dental restorative resins. They observed tag lengths from 1 to 25 μm depending on the material and also on the individual tooth structure as well as the area bonded. When enamel was not acid etched, poor bonding resulted. Polarised light studies showed deeper resin penetration in inter-prismatic areas and that the tags consisted of a combination of, resin and entrapped organic material of the enamel. The conclusion was that at that time there was no material capable of forming a permanent bond with untreated enamel under normal oral conditions⁽²²⁾.

Using a cyanoacrylate adhesive as a pit and fissure sealant, Cueto and Buonocore⁽³²⁾ reported satisfactory bonding for periods up to one year under oral conditions. Takeuchi and Kizu⁽¹³⁴⁾ and Takeuchi et al⁽¹³⁵⁾ also demonstrated the potential of a cyanoacrylate - methyl methacrylate mixture to seal pits and fissures of untreated human enamel - but they did not discuss the means by which the material was retained.

In a review of the problems of polymer chemistry and the adhesion of polymers to tooth structure

in the oral environment⁽⁹⁵⁾ it is stated that a material of highly specialised composition and an exacting technique, are required so that the advantageous physical and chemical properties of the adhesive are retained.

It further stresses the problem of:

1. The attainment of a meticulously clean enamel surface to promote maximum wetting.
2. Stress concentrations building up in areas of decreased adhesion. These stresses are activated by thermal changes and force applications are greatly magnified by enamel surface irregularities.
3. The non-homogeneous nature of tooth structure i.e. a polymer system adhering to an organic phase and vice versa.
4. The ability of the adhesive to displace water on the tooth surface or make use of it by reaction and maintenance of adhesion in a continuous aqueous environment. It was suggested that the eventual solution may require the use of a rubbery "inter-liner" which would adhere to the tooth and serve as a thermal and mechanical

stress absorber.

The elimination of orthodontic bands was the motivating idea when Mitchell⁽⁷²⁾ designed and constructed a 24 carat gold bracket base to which the bracket was soldered. The 24 carat base was soft enough to allow it to be burnished to the tooth, so that the margins would give greater protection to the adhesive joint. Epoxy and black copper cements were then tested clinically using this bracket base, but the epoxy was unsuccessful as the brackets dislodged during arch wire placement, due to the slow rate of curing of the resin. The black copper cement was found to be reasonably successful over several months but on removal of the brackets all the bonds fractured at the bracket cement interface and it was considered that better mechanical locking would be an improvement. The bracket design was considered a partial success in protecting the adhesive from moisture but overall the strength of the copper cement was not sufficient to be regarded as a complete success under oral conditions.

The advantages of direct bonding of orthodontic attachments encouraged Retief and Dreyer⁽¹⁰³⁾ to develop an epoxy adhesive suitable for this purpose. They excluded the high temperature curing epoxies

and recognised the advantage of enamel pretreatment. They also found 50 per cent phosphoric acid as had previously been recommended⁽³²⁾ the most suitable. Only stainless steel attachments were used as their epoxy formulation would not adhere to polycarbonate. Their brackets were welded to a piece of orthodontic band material and an underlying base of stainless steel mesh. This ensured adequate union and easier placement.

Curing time was controlled by preheating of the mixed resin and also by the use of phenol as a catalyst. The initial curing time was 5 minutes during which a dry field was maintained. Clinical trials were initiated after initial tests showed tensile strengths of up to 100 p.s.i.

A thixotropic agent had been added to the resin in order to decrease the flow without affecting the adhesive qualities thereby making bracket placement easier. In addition a new metal bracket which was less bulky and had metal slots for retention was utilized. The results of the 3 year clinical trial where one hundred and two brackets were bonded to teeth of seventeen patients, including two cases where extra oral appliances were attached to bonded molar tubes, showed that twenty two brackets became detached; the

majority within 24 hours of placement. The results showed that:

- a) No detrimental effects on the enamel by the acid pretreatment.
- b) Catalyst action was the only practical method by which the rate of cure could be further increased after bracket placement.
- c) A dry field must be maintained although no action could be taken to control the flow of fluid from the pulp as had previously been demonstrated⁽¹²⁾ (66).
- d) No toxic or irritant reactions in any patients.

Reassessment of the technique showed that reduced adhesion was due to low activity of free phosphoric acid on the tooth surface and limited reagent shelf life.

In further clinical trials⁽³⁶⁾ teeth were isolated with rubber dam prior to etching and bracket placement. Brackets used this time were welded directly to stainless steel mesh which offered greater mechanical interlocking than those

tested in 1967. The resulting failure rates compared favourably with those of Miura et al⁽⁷³⁾ and Mizrahi and Smith⁽⁷⁷⁾. The results indicated a higher failure rate in the younger patients. This was attributed to either:

a) Lower clinical crown heights and therefore increased bite interference.

or

b) Increased flow of fluid at the cervical margins of young permanent teeth.

They concluded that older patients were more desirable and although they were satisfied with their results they could not see direct bonding replacing bands.

The use of adhesive systems containing homo- and copolymers of methyl methacrylate became items of greater interest⁽⁸⁸⁾. They gave minimal mucosal irritation, showed ease of application and polymerization in situ, gave rapid setting times which could be varied, and could readily have their properties varied with the incorporation of suitable comonomers.

Newman et al⁽⁸⁸⁾ used polycarbonate attachments and treated the enamel with 85 per cent phosphoric acid. They realised the importance of keeping setting shrinkage to a minimum without adversely affecting the mechanical properties. This was accomplished by the addition of polymer additives (molecular weight 20,000). A further increase in joint strength was obtained by addition of a fused glass filler.

Therefore, a reliable fast setting acrylic adhesive system was attainable but further investigation was necessary if such a system with clinical practicality was to be developed.

Newman⁽⁸⁹⁾ felt that bonded attachments were not the panacea for orthodontic treatment and at best, would only be an adjunct to banding. He concluded that modification of philosophies and techniques which used heavy forces was necessary, an opinion which was reiterated by Schwartz⁽¹¹⁵⁾. Newman became resigned to the fact that only an integrated adhesive system would be practicable i.e. where the adhesive was congruent with the plastic attachment, the oral environment, the forces of mastication and the stresses exerted by the arch wires.

Grenadier et al⁽⁴⁸⁾ used acrylic adhesive with both metal and plastic attachments and recommended direct bonding procedures in adults, especially in areas where it was not possible to place a band.

A material which today appears to have little clinical application in the field of direct bonding are the polycarboxylate cements. Designed by Smith⁽¹²⁶⁾ especially for the oral environment these cements were formerly heralded as materials of great promise. Under oral conditions they created a hydrophillic chelating agent forming stable chelates with calcium. He showed the polyacrylic acid of the cement has a chelating reaction with the calcium of tooth structure and the zinc of the zinc oxide. He also claimed it formed complexes with proteins to further promote adhesion. Direct spectroscopic evidence of the reaction of the polyacrylic acid and enamel to produce ionised groups, became available in 1972 and provided further evidence for the formation of ionic bonds.

The claim that polycarboxylate cements, which use sulphate containing polyacrylic acid, may give rise to crystal growth at the enamel interface has been made⁽¹²⁶⁾. Therefore, the adhesion may involve intercrystalline bonding in addition to the previously claimed calcium complexation.

Laboratory tests have shown zinc polycarboxylate cement to be of low irritancy and to show superior adhesion compared with conventional zinc phosphate cements (78 kg/cm^2 as compared with 29 kg/cm^2)⁽⁷⁶⁾. Whereas zinc phosphate cements failed mainly at the adherend cement interface, the polycarboxylates failed cohesively, thereby indicating that the bond between the cement and adherend was stronger than the cement itself. However, it was later shown⁽³⁹⁾ by scanning electron microscope studies of fracture bonds of a polycarboxylate cement and enamel, that the topography of the enamel was an important factor in the fracture pattern even if the fracture was cohesive.

Further testing by Mizrahi and Smith⁽⁷⁷⁾ led to the conclusion that satisfactory results could be obtained in light wire techniques and considered further clinical trials were justified. It was claimed that bracket bases would require modification by extension to more closely approximate the tooth surface and also, that they should be a certain minimum size⁽³⁸⁾. A stainless steel patch was developed⁽⁶⁸⁾ which was accurately contoured to the tooth surface in order to obtain a uniform film thickness of the adhesive while at the same time covering as large an area as possible.

It was observed that polycarboxylate cement showed a higher strength under wet conditions, than three cyanoacrylate adhesives⁽³¹⁾ as the setting reaction had gone further towards completion.

Clinical trials by Mizrahi and Smith⁽⁷⁷⁾ had shown that some attachments remained in place for fourteen months. They felt that improved surface preparation methods were necessary. In further clinical trials by Mizrahi⁽⁷⁸⁾ a change to a mesh backed type of attachment was made and the enamel pretreated with 50 per cent sulphuric acid. These trials showed reasonable clinical success but, only involved the use of upper anterior teeth with limited tooth movement and restricted patient selection.

In 1973 it was found that the polycarboxylate cement, Durelon, had only 72 per cent of the tensile strength of the acrylic resin Sevitron. This caused serious apprehensions about the suitability of polycarboxylates as direct bonding materials, specially when this strength disparity was even greater with in vivo results⁽⁹⁹⁾.

The greatest advantage of polycarboxylates over most other adhesives for direct bonding in orthodontics, is that the enamel does not require etching, rather a

clean surface is indicated. It is suggested that there is some "ideal roughness"⁽³⁹⁾ which produces optimum wetting due to capillary pressure and yet not so rough that air will be entrapped at the interface. A great disadvantage with polycarboxylates, is that they will not bond with polycarbonate and hence mechanical retention was found to be necessary⁽⁹⁰⁾. In reviewing dental cements, Smith⁽¹²⁷⁾ still considered the polycarboxylates to be in their early stages of development and did not recommend their indiscriminate use.

A unique direct bonding system based on cold curing methyl methacrylate resin accelerated by tributyle borane has been described by Miura⁽⁷³⁾. The polymerization reaction is initiated by contact with water and therefore is first seen at the interface. A more stable bond is claimed, because of lack of resin shrinkage on the side of the enamel surface. Conventional acrylic resins polymerise from the inside first and consequently contraction tends to peel the adhesive material away from the tooth surface.

In the above technique the enamel is etched with 65 per cent phosphoric acid and subsequently treated with silane (methacryloxypropyltri - methoxy silane). The silane is used to react with the

calcium ions of the enamel surface while simultaneously affecting the wettability to increase the flow of resin into the etched enamel. Silane coupling agents have been described as bifunctional monomeric silicone chemicals which will form covalent chemical bonds with both organic polymer and inorganic substrate⁽⁴⁰⁾.

A later scanning electron microscope study by Miura⁽⁷⁵⁾ found that the silane created a thin film across the exposed enamel rods of the etched enamel, thereby confirming his earlier claims.

The technique described used polycarbonate brackets and reported only a minute decrease in bonding strength after long term immersion in water. Clinical reports of the system were found to give "encouraging" results with anterior teeth whereas those of posterior teeth seemed less so. Miura⁽⁷⁵⁾ considered the system to be a valuable clinical aid to daily practice. A commercially available derivative of this material is D.B.S. Orthomite (Rocky Mountain Products, Denver, Colorado).

Buonocore's early work⁽²²⁾ had shown that although sealing of pits and fissures was a good preventive measure against caries, an improved adhesive was required with a greatly simplified

technique for its application.

In 1970 Buonocore⁽²³⁾ described such an improved adhesive which is composed of the reaction product of bisphenol-A and glycidyl methacrylate and methyl methacrylate monomer. Synthetic calcium hydroxyapatite and calcium fluoride were also added. Two per cent of benzoin methyl ether is added just prior to use of the adhesive so that an ultra violet sensitive mixture was obtained. Therefore, greater penetration of the etched enamel surface was possible as the adhesive would not polymerise until application of the ultra violet light. The polymerisation was rapid once the ultra violet light was applied. This adhesive is marketed as Nuva Seal (L.D. Caulk Co., Milford, Delaware).

When this material was used as a pit and fissure sealant the clinical trials were considered excellent. Eighteen months of clinical trials showed the material to be simple to use, rapid, painless and possess a wide range of applications⁽²⁴⁾.

Initially the manufacturers claimed the long wave of ultra violet light to be safe but since then the United States Food and Drug Administration has warned practising dentists that unnecessary ultra violet emissions may present risk of injury to the

eye or skin⁽⁸⁾.

To assess the clinical viability of such a system, polycarbonate brackets were used on acid preconditioned enamel⁽²⁹⁾. The objectives of this investigation were:

1. Determine the usefulness of the system under active orthodontic conditions.
2. Determine shear and tensile strength.
3. Investigate the fracture patterns and locations of various interfaces by use of scanning electron microscope techniques.

The results which were evaluated with a ten month clinical retention period showed a failure rate considerably lower than that obtained from epoxy resins of Retief et al⁽¹⁰³⁾ but higher than the methacrylate system of Miura et al⁽⁷³⁾.

Laboratory tests showed an average shear strength of 821 p.s.i. (57.7 kg/cm^2) and a mean tensile strength of 508 p.s.i. (35.8 kg/cm^2) after 30 days storage in water. This compared very favourably with the systems of Retief et al⁽¹⁰³⁾ and Miura et al⁽⁷³⁾. These strength values are

quite adequate for clinical orthodontics, as it has been claimed that the maximum force under such conditions is 10 pounds or 200 p.s.i. However, this does not take into account the effect of sudden impact and it should be noted that impact strength was not measured in any of the above studies.

The bracket-adhesive interface and the bracket itself were found to be the weakest links in this system⁽²⁹⁾. The conclusions of the study were that the system had clinical orthodontic potential as:

- 1) there was no time delay before application of force was made to the brackets.
- 2) there was no necessity for finishing procedures.
- 3) there was adequate time for bracket placement but only required 20 seconds for polymerization.
- 4) the aesthetic qualities were improved.

When evaluating several direct bonding systems including two acrylic resins, Hunter et al⁽⁵⁶⁾ found that precoating the etched enamel with Nuva-Seal enhanced the bonding strengths of both adhesives. This has been attributed to the superior wetting of

the etched enamel by the Nuva-Seal⁽²³⁾ (100).

The actual tag lengths of the resin within the enamel have aroused a degree of controversy. Scanning electron microscope studies by Yankelson et al⁽¹⁴⁰⁾ found tag lengths in excess of 50 μm , a claim which has also been made by Silverstone⁽¹²¹⁾ (who previously worked with Yankelson). This degree of tag length is well in excess of that reported by Gwinnett and Matsui⁽⁵⁰⁾ Myers et al⁽⁸⁴⁾ reported tag lengths of only 25 microns when examining the interface of Nuva-Seal and enamel etched with 50 per cent orthophosphoric acid and 7 per cent zinc oxide attenuating agent.

Tag lengths of up to 50 μm have been reported with the use of epoxy resin adhesives on enamel preconditioned with 50 per cent phosphoric acid (without a zinc oxide attenuating agent) for 60 seconds⁽¹⁰⁴⁾. This greater penetration was attributed to:

- a) More severe etching without any attenuating agent.
- b) Slower setting of the epoxy adhesive. A condition which could explain the tag lengths claimed by some investigators using Nuva-Seal.

Retief⁽¹⁰⁴⁾ also confirmed the major role played by mechanical retention although he did suggest that additional chemical bonding may occur.

Other uses of Nuva-Seal in orthodontic treatment have included retention of rotations, closure of diastemas, gaining attachment to partially erupted teeth, lower cuspid to cuspid retainers⁽³⁰⁾, rapid maxillary expansion⁽¹¹⁷⁾ and uprighting impacted lower second and third molars with attachments bonded to the buccal or occlusal surfaces⁽¹¹³⁾.

In reviewing direct bonding systems up to 1973 Newman⁽⁹⁰⁾ found that although polycarbonate was the best plastic tested due to its high impact strength and its ease of bonding with acrylic adhesives it had the disadvantage of readily absorbing water. This led to softening over a period of time, a fault which is common to all plastic brackets. Most of the failures with plastic brackets were recorded at the adhesive-bracket interface or in the bracket itself. Newman⁽⁹⁰⁾ also made the suggestion that plastic brackets should be limited to the upper six anterior teeth. In this evaluation, twelve adhesive systems were given an in vitro evaluation. This showed systems employing primers, such as Nuva-Seal, and his epoxy acrylate primer gave higher bond strengths. These

two primers when used with any other acrylic adhesive gave higher breaking strengths, a finding which concurs with that of Hunter et al⁽¹⁹⁾. Clinically acceptable performance using acid etching, rubber dam, plastic and metal brackets has also been achieved by using Nuva-Seal as a primer for other adhesives. It was found that the enamel adhesive interface was the most common site of failure, a point which conflicts with the findings of Newman⁽⁹⁰⁾.

Raft and Lugassy⁽⁹⁸⁾ observed that forces applied directly to bonded plastic brackets should be modified to reduce the incidence of bracket failure. They suggested that either a stronger plastic material be used or that the polycarbonates be reinforced.

Another direct bonding system was introduced by Lee et al⁽⁶⁴⁾. This was "based on a unique thermosetting combination of mono- and diacrylates and a high molecular weight polymeric filler" and claimed a superior bond strength to both etched enamel and polycarbonate brackets. When compared to two other commercially available direct bonding systems (unnamed) the new adhesive (Genie - Lee Pharmaceuticals South El Monte, California) was found superior in all respects, except adhesion to stainless steel. They claimed that polycarbonate brackets were the weak link, their threshold distortion

limits being exceeded in tensile testing. Clinical evaluation showed only a 2 per cent failure rate with plastic brackets and 5 per cent for metal brackets over a six month period. These figures are extremely low when compared to other reports^{(73) (77) (89) (103)}.

Another laboratory study⁽⁶¹⁾ researched two commercially available direct bonding system products (Orthomite D.B.S. and edgewise polycarbonate brackets.) The adhesive bond was found to be much stronger than the polycarbonate bracket when bonding to etched human enamel. It must be noted that the brackets failed at forces well above those generally required to move teeth⁽¹³⁷⁾. The findings did show that there was no significant weakening of the bond strength with increasing exposure to moisture which is consistent with the findings of other investigators^{(29) (74) (99)}.

When testing two commercially available direct bonding systems, Felsen⁽⁴²⁾ found that both fulfilled the stress requirements needed to deliver orthodontic forces to the teeth effectively, via polycarbonate auxiliary brackets. He maintained that torquing auxiliaries could be used provided consideration was given to the flexibility of the bracket. He concluded that further work was required to improve both the strength of the material used for bracket fabrication and the

design of the bracket.

Evaluations, to determine the tendency of two edgewise polycarbonate brackets to deform and creep while a torque force was applied by a rectangular arch wire, concluded that the brackets used would be limited for this purpose, since much of the applied force would be dissipated in the distortion of the brackets. Dobrins et al⁽³⁷⁾ therefore recommended use of torquing auxiliaries only. This finding had been previously advocated by other authors^{(73) (89) (98) (115)}.

In 1975 Retief and Sadowsky⁽¹⁰⁷⁾ published the results of clinical findings based on seven years practical experience with a direct bonding system. The system involved an epoxy resin formulation, which required preheating to 50⁰C for six minutes and therefore had a reduced flow rate. The etching solution was 50 per cent phosphoric acid, a choice based on a previous study⁽¹⁰⁶⁾. Stainless steel attachments were used with sixty-mesh stainless steel gauze welded to contoured stainless steel band material, to which an edgewise orthodontic bracket was welded. This bracket attachment system overcame the problem of epoxy not adhering to stainless steel⁽¹⁰²⁾.

The clinical study involved a variety of malocclusions and a total of 123 attachments over a treatment time of 5 to 35 months. Results showed a failure rate of 18.8 per cent. Despite this apparent high failure rate the study represents the adaption of a physically acceptable bracket and the authors conclude: " The acid etch technique and the development of improved composite resin systems have made the direct bonding of orthodontic attachments an accepted clinical procedure. This technique can be used with confidence as an adjunct in the armamentarium of the orthodontist".

Johnson et al⁽⁵⁷⁾ examined seven direct bonding adhesives for shear strength using bovine enamel in vitro and found a marked decrease over three months in all but one adhesive. Unfortunately, the adhesives were not named but these findings foreshadow serious implications. During the latter part of fixed appliance therapy, i.e. where torquing forces are applied, there is a decrease in shear strength. It is at this stage that the greatest shear strength is required.

When examining the tensile bond strength of nine adhesive systems with mesh-backed orthodontic buttons (50 mesh with a contact area of 10.4 mm^2)

no statistically significant differences were apparent. Except for "poly F" which was unsatisfactory⁽¹¹⁰⁾, a finding which is in agreement with other workers⁽⁸⁵⁾ (107).

Prolonged water immersion i.e. for six months, resulted in a significant decrease in tensile bond strength of the acrylic material but had no significant effect on the diacrylates and the filled polyacrylic materials.

The use of Nuva-Seal as an interfacial agent or adhesion promoter for acrylic had no significant effect on bond strength. Therefore, this procedure would appear to have no clinical advantage.

Cavina⁽²⁸⁾ reported on a two to three year study of direct bonding using metal mesh-backed brackets of the Begg and Edgewise type with Protecto adhesive (a filled diacrylate resin).

Of the total number of 1150 attachments bonded, 176 failed, a failure rate of 15.3 per cent. A failure rate of 10.4 per cent was reported for upper anterior teeth while a percentage of 17.4 per cent was recorded for lower anterior teeth, a disparity attributed both to occlusion and the inability to maintain a dry field.

Interesting comparative figures were derived between Begg and Edgewise brackets. Begg brackets showed a failure rate of 18.5 per cent while the Edgewise brackets failure rate was only 11 per cent. The higher failure rates for Begg brackets was suggested to be due to the shearing forces used in bite opening and those exerted by the auxiliaries.

Figures indicated that during the first year of treatment a failure rate of 15.9 per cent occurred while during the second year it was only 9.5 per cent. This would tend to indicate that the longer bonds are in place the less likelihood there is of their failing. This reinforces the notions that diacrylates are not weakened by oral fluids during ongoing clinical treatment. The overall failure rate of 11 per cent for edgewise brackets has also been reported by Zachrisson⁽¹⁴³⁾.

Gorelick⁽⁴⁶⁾ studied 1349 brackets; 549 for 12 months and 800 for 6 months on children aged between 8 and 16. Using Concise (3M St. Paul Minn.) and perforated metal bases under recommended conditions, as well as varying the paste catalyst to alter setting time, the following results were obtained.

Of the 549 bonded brackets observed for a 12 month period 5.8 per cent failed. Breakdown of

failure rates was as follows:

1. 4.0 per cent for upper anterior teeth
2. 2.6 per cent for lower anterior teeth
3. 6.5 per cent for upper premolars and
4. 7.0 per cent for lower premolars.

Of the additional 800 bonded brackets observed for a 6 month period 5.8 per cent failed.

Breakdown of failure rates was as follows:

1. 5.7 per cent for upper anterior teeth
2. 5.8 per cent for lower anterior teeth
3. 5.2 per cent for upper premolars
4. 8.1 per cent for lower premolars

Most failures occurred at the bracket - adhesive interface with the entire composite still remaining on the tooth. This was probably due to the choice of an unsuitable type of base design⁽¹⁰⁹⁾ (111).

Zachrisson conducted a detailed and well designed post-treatment evaluation of direct bonding⁽¹⁴³⁾ (144). The latter report was based on some 705 attachments, which were directly bonded to the different teeth and involved a good cross section of malocclusions. For his evaluation, he utilized Concise Enamel Bond-Composite system, (3M Company, St. Paul. Minn.) and mesh backed metal edgewise attachments, (G.A.C. International Inc, Farmingdale N.Y.).

The results of his investigation in terms of failure is summarised in the following table.

	No.	No.	%
	Bonded	Failures	Failures
Maxilla			
First Molars	32	6	18.8%
Second Premolars	70	15	21.4%
First Premolars	30	3	10.0%
Canines	76	6	7.9%
Lateral Incisors	73	3	4.1%
Central Incisors	76	4	5.2%
Mandible			
Second Molars	36	8	22.2%
First Molars	44	13	29.5%
Second Premolars	66	3	4.6%
First Premolars	37	3	8.1%
Canines	55	4	7.3%
Incisors	110	11	10.0%

It should be noted that all patients were treated with light wire Edgewise and no comparable data, has been published to date with respect to the Begg light wire technique.

In the early stages, in the development of direct bonding systems, lack of bond strength was a source of worry. A recent evaluation⁽⁴¹⁾ of the penetration coefficients, tensile strength and bond strength of thirteen direct bonding orthodontic cements has given clinicians a good guide, in the selection of adhesive materials in everyday practice. The results show Auto-Tach and Solo-Tach (L.D. Caulk Co. Milford Delaware) to have the highest bond strength, and rebond strength, of all materials tested. The results of penetration coefficient tests showed these materials to have one of the lowest coefficients of penetration while, at the same time having the highest bond strengths. This implies that the risk of post debonding discolouration is greatly reduced, as penetration of resin into the enamel is not as great as with some of the materials which use an initial sealant layer of low viscosity e.g. Endur (Ormco Corp., Glendora California); "The cements that use a sealant, (or primer) and bracket adhesive had lower values of bond strength than the cements that involved a one step procedure, regardless of the bracket used"⁽⁴¹⁾.

It should be remembered that when we speak of success and failure rates of bonded brackets, there are the before-mentioned quantitative results to talk about. On the other hand, very little has been written about the failure rate of bands. It is difficult to arrive at such a result, as there are a number of factors which influence the retention of an orthodontic band e.g. tooth morphology, sex, malocclusion, salivary conditions, quality of banding etc. Mizrahi⁽⁷⁹⁾ showed that 21 per cent of bands were recemented during the period of treatment in 102 consecutively completed cases. This figure included bands recemented if they became loose or if they peeled away from the tooth surface. The breakdown of failure rates ranged from 77 per cent for maxillary centrals to 3 per cent for maxillary cuspids.

There is no doubt that the failure rates with the best orthodontic bonding adhesives, are considerably lower than the recementation figures reported by Mizrahi⁽⁷⁹⁾, particularly in the maxillary anterior region.

1.5 The Indirect Technique

Fixed appliance orthodontics is very reliant on the exact placement of the orthodontic bracket, in order to obtain optimal results. With the correct placement of the bracket, corrections of rotations are simplified, correct vertical positioning of the teeth in the arch is accomplished without compensating bends in the arch wires, and finishing stages of treatment are not complicated by the necessity for compensatory archwire adjustments.

In direct bonding the brackets are placed on the tooth with the aid of a pair of tweezers or pliers. This technique is quite adequate if only one or two brackets are to be placed at a time, but becomes more difficult as the number of brackets placed increases and as one proceeds more distally in the mouth.

Because of the setting characteristics of certain adhesives, it is extremely difficult to hand hold the bracket steady, in its exact position, while the material sets sufficiently to maintain the bracket in its desired location. "If one is placing direct-bonded brackets on a full arch, hand placement of each bracket, especially in the premolar area, lacks the finesse achievable with a banded technique" (125).

It was this problem, which prompted a number of investigators, to develop ways of positioning all the brackets in a matrix and accomplishing, the bonding of an entire arch in one step.

The technique was pioneered by Silverman and Cohen⁽¹¹⁷⁾ in 1972. Their report was based on a six months trial and encompassed 100 patients. The technique employed the construction of working models at the time of study model production. All brackets and tubes are placed exactly in the desired position on the working models, thus eliminating the situation where prewelded bands dictate the position of brackets and attachments. The brackets were secured and positioned on the working model with the adhesive (in the early cases "G.A.C. experimental adhesive"). Once the brackets were secured in position by the polymerised adhesive, they were placed in a "Vanguard unit", and plastic mouthguard type of material adapted over the positioned attachments. When the plastic positioner had cooled, it was removed from the working model with the brackets embedded in exactly the correct position. The positioner was then cleaned, trimmed and stored ready for bonding. Bonding was achieved by etching with 50 per cent phosphoric acid, then polymerising a layer of Nuva-Seal over the etched areas for 30 seconds on each tooth. The G.A.C. adhesive was then

applied in small proportions to the brackets positioned in the mouthguard which was then placed in the mouth and held in position, for 5 minutes. The plastic was then removed leaving the brackets secured to exactly the correct position on the teeth.

Results of the six month trial, showed "a high percentage of success" and the authors hoped to increase their success rate to 90 or 100 per cent margin by refinement of their technique.

A follow-up to this early work was published in 1974⁽⁴⁷⁾ and described refinements to the technique. The major change was the use of Nuva-Tach, (L.D. Caulk), as the adhesive (Nuva-Seal still being used as the sealant). The report gave a success rate of 99 per cent, with most failures occurring on lower second premolars; a figure which would tend to indicate great refinement in the technique. The authors claimed that they were having a good success with second molars and preferred a U.V. light-activated adhesive to a chemical catalyst as this gave them exactly the working time they desired.

In 1976 Silverman and Cohen⁽¹¹⁸⁾ reported that they had "achieved perfection" in their technique, by discarding Nuva-Tach and Nuva-Seal in the clinical

stages of their technique. They replaced the Nuva-Seal Nuva-Tach combination by Auto-Tach (L.D. Caulk Co., Milford Delaware). This is a thermosetting self-polymerising, low viscosity adhesive, developed specifically for the indirect technique.

Although in 1974, both authors treated almost all of their fixed appliance cases using the new adhesive⁽⁴⁷⁾, there is no available data on the number of patients treated or the success/failure rate of this later technique.

A number of alternative methods have been proposed for positioning brackets on the working models. There is also great variety in materials used as positioners.

- Smaha⁽¹²⁵⁾ positioned his brackets with wire over the occlusal edge and manufactured his positioners out of cold cure acrylic.
- Newman⁽⁹¹⁾ positioned brackets on the working models with "Duco" Cement and hand formed a Vanguard positioner.

- Brandt et al⁽¹⁸⁾ positioned brackets with double-sided adhesive tape (Carpetak Tape") and formed the positioner with Optosil Regular, Unitek. Monrovia California.
- Moin and Dogon⁽⁸⁰⁾ secured the brackets to the working model with sticky wax and formed the positioner with Optosil or Bondosil (Orthobond Co., Midland Park N.J.)
- Simmons⁽¹²⁴⁾ positioned brackets with caramel sugar and formed the positioner with Optosil, Bandosil or Citricon (Kerr Mtg. Co., Romulus Michigan).
- McLaughlin⁽⁶⁷⁾ positioned brackets with Nuva-Tach and formed his positioner from Sta-Guard (Buffalo Dental).

The available literature to date, claims that indirect bonding carries with it all the advantages of direct bonding, as well as having the added advantages of:

- 1) Saving more chairside time.
- 2) Delegating more time-consuming work to auxiliaries.

- 3) Allowing more accurate bracket placement.
- 4) Allowing better and more accurate bonding to posterior teeth, e.g. second molars⁽⁴⁷⁾.
- 5) Being more comfortable for the patient.

However, no articles to date describe a well conducted clinical research programme, which compares direct and indirect bonding, under controlled conditions. Thus, there is no data available to compare clinical performance, in terms of bond failure, aesthetics, bracket position and chairside time between the two techniques.

1.6 Types of Bracket Attachments for Direct Bonded Orthodontics

At present there are basically only two types of orthodontic attachments available for direct bonding:

- a) Plastic or polycarbonate brackets
- b) Metallic brackets on bases where retention is provided by undercuts in the form of metal lips, perforations or mesh backings.

The polycarbonate brackets have the limitations that they can only be used with acrylic-type resin adhesives whereas metal can be used with both acrylic and diacrylic-type resin adhesives⁽¹⁰⁸⁾. In vitro studies have shown little difference between the two types of adhesive although acrylic resin exhibits a decrease in bond strength with prolonged water immersion^{(73) (109) (110)}. Reynolds and Von Fraunhofer⁽¹⁰⁹⁾ found that coarse mesh gauze (British Standard number 50 to 70) as used by Dijkman and Retief⁽³⁶⁾ provided better retention than fine meshed gauze (British Standard number 100 and higher) as used by Mizrahi⁽⁷⁸⁾.

The greatest bond strengths between bracket and

adhesive as expressed by tensile load to failure were found with the polycarbonate-acrylic resin adhesive system. The lowest bond strength was found for the metallic attachment with perforated boxes. The Orobond polymer coated attachment showed slightly greater bond strengths than the perforated base system but the mean strength was 40 per cent less than that obtained by mesh backed brackets. The greatest bond strengths were obtained with polycarbonate brackets and acrylic resin⁽¹¹¹⁾.

It should, however, be noted that bond strength itself is not the only criterion of success in the direct bonding technique. Special techniques had to be devised to test these brackets since the bond strength exceeded the strength of the bracket itself. It is for this reason that bond strength studies with polycarbonate brackets have usually involved shear tests rather than the more rigorous tensile tests.

Therefore gauze metallic brackets with coarse gauze backings appear to be the most favourable bracket system for direct bonding⁽¹¹¹⁾ available at the moment. These metallic brackets could certainly be improved aesthetically and in fact attempts have been made to do this by manufacturing tooth coloured metal brackets (Dentaurum, Phorzheim, W. Germany) but the colour appears to wear off in a few months⁽¹⁴³⁾.

More recently Lancer Pacific have announced the development of an enamel coated mesh backed metal bracket which could possibly eliminate or reduce the aesthetic problem of metal brackets.

1.7 Advantages and Indications for Orthodontic Bonding

The development of techniques and materials over the past twenty years has now placed us in a situation where the bonding of orthodontic attachments directly to enamel is not only physically possible, but also practically advantageous for a number of reasons. Some of the stated advantages are as follows:

- 1) The conventional bonding of partially erupted teeth is often difficult and traumatic for the patient. Direct bonding of attachments to the exposed surfaces of these teeth presents no problems.
- 2) The elimination of the need for separation of crowded teeth.
- 3) The impingement on arch length by interproximal band material is eliminated. In total this may amount to 4 mm⁽⁹⁸⁾, and there are times when this may be enough to decide on a non-extraction procedure.
- 4) No space closure is required after removal of bonded brackets as it is with conventional bands.

- 5) Gingival irritation is decreased as bonded attachments do not impinge on gingival tissues.
- 6) Oral hygiene of patients with bonded brackets is improved. (This is a subjective conclusion) (107)
- 7) Orthodontic bands may become loose and may remain undetected during treatment. This may lead to decalcification under these bands. This does not occur with bonded brackets, as any failure is total and easily detected.
- 8) The fitting of bonded brackets is far less painful than that of fitting conventional bands.
- 9) The fitting of bonded brackets is far less time-consuming than banding.
- 10) Improved aesthetics.
- 11) The ability to floss interproximally during treatment.
- 12) The ability to apply fluoride effectively during treatment.
- 13) The ability to progressively strip interproximally

during treatment.

As well as these obvious advantages, bonding has found other applications in orthodontic treatment. Of particular note is the use of lingually bonded canine-to-canine retainer^{(67) (80)}. This particular type of retainer has many applications⁽¹⁴⁴⁾ which may be further extended in the field of periodontics. The extension of direct bonding into the realm of surgery has been documented⁽⁹²⁾ and claims considerable success with impacted teeth.

1.8 Post Treatment Evaluations in Terms
Other than Bond Failure

Important aspects of bonding relative to iatrogenic damage are:

- A. The appearance of the tooth following the removal of attachments.
- B. Gingival irritation and plaque retention.
- C. The risk of caries.

A. Appearance of the Tooth Following
Removal of Attachment

It has been demonstrated⁽¹⁰⁵⁾ that the fracture between an adhesive system and etched enamel, occurs within both the material and the enamel. It is conceivable that the thin filamentous tags which have penetrated the etched enamel surfaces, will fracture during debonding and remain embedded in the enamel. Similarly, spicules of enamel are retained on the adhesive side⁽¹⁰⁵⁾. The presence of organic material would result in a smoother surface profile and seal the surface against caries, but a possible late effect might be discolouration⁽¹⁴²⁾. However, clinical experience to date indicates that no such

discolouration occurs within the first year after bracket removal⁽¹⁴²⁾ ⁽¹⁴⁴⁾. More clinically important for the surface appearance after debonding is the influence of different removal and polishing techniques.

Removal of adhesive after the orthodontic treatment was initially a problem. Therefore, a technique based on scanning electron microscope studies was developed⁽¹⁴⁴⁾. The technique recommended E.T.M. pliers (E.T.M. Monrovia Calif. Plier Nos. 1026 and 349) and a plain-cut tungsten carbide fissure bur, rotated at low speed. The brackets were removed with pliers, or a ligature cutter. Remaining adhesive was scraped off with a cement scaler or the pliers. Bonding material that cannot easily be scraped off should be removed with the tungsten carbide bur. To increase visual contrast against enamel, water cooling is not recommended while the last remnants of adhesive are being removed. The final polish of the enamel is attained with a rubber polishing disc (A.A.B.A. - Dental, Indentoflex A.G. Buchs/S.G., Switzerland).

Some recommended methods of debonding are harmful to enamel and other dental tissues, as was pointed out recently by Gwinnett and Gorelick⁽⁵¹⁾. Among such damage are scratches and grooves, which

may contribute to plaque accumulation, discolouration, odour and demineralization through bacterial activity, as well as damage including fracture of incisal edges and vertical cracks in the enamel. Considerable damage can be done by careless use of scalers and band removers, the most marked damage being obtained with diamond instruments. Also the removal of excess adhesive by instruments, rotated at high speed is not desirable and can only constitute a hazard to the tooth surface.

Fitzpatrick and Way⁽⁴³⁾ attempted to ascertain if there was any difference in wear between etched and unetched enamel in vivo over a 12 week period. At the same time, they attempted to determine the approximate amount of enamel loss in the process of bonding, debonding and clean-up. They also attempted to establish if there were any microscopic differences between the appearance of the enamel surface immediately following bracket removal, as compared with the surface 2 months following bracket removal. Their findings showed:

- 1) The return of a previously etched surface to an apparently normal surface, is primarily a function of reconstitution rather than abrasive wear.

- 11) Etching caused an additional 3.0 μm loss of enamel over and above the normal wear of 1.6 μm , in an 85-day period. Most of the additional wear occurs in the first 28 days and then levels off during the remainder of the test period.
- 111) Approximately 55.6 μm of enamel was lost as a result of etching, bracket placement, bracket removal and "clean-up".
- 1V) Etching, bracket placement, bracket removal and "clean-up" resulted in a smooth surface which was clinically and microscopically comparable to an untouched surface.
- V) No significant change occurred in the appearance of the enamel surface over a 2-month period following bracket removal.

It must be remembered that these results pertain to only a narrow range of variables, i.e. 30 per cent phosphoric acid for 90 seconds, on premolars, using the Nuva-Tach, Nuva-Seal bonding system and a particular clean-up regime. The results do however give an indication of what happens if the instructions to most bonding systems are followed.

B. Gingival Condition

Improved gingival health is generally mentioned as one of the many advantages of direct bonding⁽¹⁸⁾ (108). Other findings⁽¹⁴⁴⁾ (145) emphasise that whenever bracket bases are overextended in size, or excess sealant or adhesive is used, the gingiva could be worse than when bands are used, irrespective of the oral hygiene situation. This appears to be most evident in the lower anterior region. On the other hand, if bases are small, little adhesive is used, uncomplicated arch wires are designed, and oral hygiene co-operation is good, the gingiva can be maintained in a normal healthy condition throughout treatment⁽¹⁴⁶⁾. This response is never registered in full-banded patients⁽¹⁴¹⁾.

C. Caries Risk

Zachrisson⁽¹⁴⁶⁾ claims the caries rate to be much lower in bonded patients provided that a sealant is used, good oral hygiene is evident and fluoride supplementation (.05 neutral sodium fluoride) is maintained.

In a recent study⁽¹⁴⁴⁾ 39 out of 46 patients did not get any white spot lesions. This is an

excellent result in a country (Norway) with a high caries rate and no water fluoridation.

It should however be pointed out that when the above procedures are neglected and a "rough surface" adhesive with excess amounts of "flash" is used, the caries rate may be very high.

Zachrisson⁽¹⁴⁵⁾ does point out that interproximal caries protection is lacking in bonded appliances and this is the reason he prefers to band all first molars.

It should further be pointed out that with bonded brackets, flossing, topical fluoride and regular bite wing X-rays may be an advantage in caries protection. This early detection is not available with banded patients.

CHAPTER 2MATERIALS AND EQUIPMENT USED

The materials used in the various aspects of this research topic are contained in the following list. The manufacturers batch numbers or date of manufacturer are listed wherever possible.

1. Bonding Adhesives

a) Auto-Tach

L.D. Caulk Company

Division of Dentsply International Inc.

Milford Delaware 19963

- Catalyst - 120976

- Base - 121376

b) Concise Orthodontic Bonding System

No. 1960 Batch No. 72131

- 3M Company

St. Paul Minnesota U.S.A.

2. Cheek Retractor

Ormco Cheek Retractor

- Large. No. 720 - 1010

- Small. No. 720 - 1010 (s)

Manuf. Ormco Corporation

1332 South Lone Hill Avenue

Glendora California 91740

3. Double Sided Adhesive

Scotch Brand Double Coated

Tape No. 410

- 3M Company

St. Paul Minnesota U.S.A.

4. Fluoride Solution

Alpha Gel

1.23 per cent ($\pm$ 10%) fluoride ion

derived from sodium fluoride and

hydrofluoric acid in 0.1 M

orthophosphoric acid

Manuf. De Trey GmbH.

Wiesbaden

5. Hair Dryer

Universal 1200 watts

Model UPR4

- Australian General Electric
(appliances) Pty. Ltd.

6. Impression Material

Unijel II

Type I - Fast Setting

Manuf. - Unitek

2724 South Peck Rd.

Monrovia California 91016

Cat. No. 710-007

Lot. 1102

7. Metal Backed High-Speed Abrasive Strips

Horico - safe sided

- steelcarbo - strips

Size - 6 mm width

Supplied by - Martin Halas

209 Bourke Street,

Sydney. 2010 N.S.W.

8. Model Stone

Investo Greenstone

- Extra Hard

Manuf. Investo Manufacturing Co.

134 Military Road,

Neutral Bay. 2089 N.S.W.

9. Mouthguard Material

Stay-Guard

Manuf. - Unknown

- Made in U.S.A. expressly for

Rudolf Gunz & Co.

Australia Pty. Ltd.

10. Mouthguard Vacuum Adaptor

Manuf. - Omnident Corp.,

Harrisburg P.A. U.S.A.

Model 4-5X5

Serial No. B 738.

11. Orthodontic Attachments

Ormco Oromesh Pads.

with the T.P. 256-500 light wire bracket

Catalogue No. 121-/500

Manuf. - Ormco Corporation

1332 South Lone Hill Avenue

Glendora California 91740

Batch No. 7F 004.

12. Pumice

Type: Coarse

Manuf. - Investo Manufacturing Company

134 Military Road,

Neutral Bay. 2089 N.S.W.

13. Rubber Cups

Mandrel Mounted Rubber Polishing Cups

- Products Dentaires

S.A. Vevey (Suisse)

14. Virilium Dry Guard

Sizes - Medium and Small

Manuf. - Virilium Company Ltd.

Virilium House

Holywell Industrial Estate

Watford, Merts England

15. Wax

Investo Dental Modeling Wax

Investo Manufacturing Co.

134 Military Road,

Neutral Bay. 2089 N.S.W.

Although Auto-Tach was designed to be used for the indirect technique it was decided to use this material for both the direct and indirect techniques. This was done for purposes of standardization and to derive more meaningful results with respect to comparative failure rates for the respective techniques. The three minute setting time of Auto-Tach created no problems as 3 to 4 brackets were usually placed with one mix. This meant that by the time the last bracket was placed the material had almost set. The manufacturers market an almost identical product (Solo-Tach) designed for the direct technique. The basic difference between the two materials being a faster setting time which is an advantage when only placing one or two brackets.

CHAPTER 3EXPERIMENTAL METHODS3.1 Indirect Bonding Technique

3.1.1 Laboratory Procedures

Within one week prior to bonding, an impression of the upper and lower arches was taken in alginate. The model was then poured up in dental stone, (Greenstone) and removed from the impression after one hour. A hole was placed in the centre of the base of each model.

The models were then transferred to a laboratory oven maintained at $40 \pm 1^{\circ}\text{C}$; at this temperature there is no transformation from calcium sulphate hemihydrate⁽²⁾. The specimens remained in the oven in the presence of silica gel (A period of at least 48 hours.) until a constant weight was reached. At this stage all free water in the models had evaporated to facilitate bracket placement with the double-sided adhesive.

The mesh-backedOrmco bracket attachments were prepared by placing the double-sided adhesive on the mesh so that the adhesive left no peripheral flash or excess.

The desired level and mesio-distal orientation of the brackets and molar tubes, was determined by marking these positions with a lead pencil prior to placement. The attachments which were contoured to the desired shape for the particular tooth, prior to having the double sided adhesive placed, were then placed in the predetermined position by pressing the attachments against the model tooth with tweezers. This method allowed easy removal and replacement of brackets to obtain ideal positioning.

The attachment was ideally placed at this time, with a minimum of space between it and the stone model.

In the event, of too much adhesive being placed on the bracket at the time of in vivo bracket fixation, a spillway was incorporated into the tray of positioner. This was formed by placing a narrow bead of wax, running from the middle of occlusal margin of the bracket, to the occlusal or incisal edge of the tooth. (see fig. 4)

The model with brackets in position, was then coated with a very thin smear of vaseline to act as a separating medium. This stopped the Stay-Guard material adhering to the plaster. (Water had proved to be an unsatisfactory separating medium, as it

acted as a solvent for the glue on the double sided adhesive. This allowed displacement of the brackets during positioner manufacture).

The Stay-Guard material was placed in the mouthguard vacuum adaptor (fig. 3) and heated until the sheet of material sagged half an inch below the lower border of the frame securing the sheet of material (fig. 4). At this time the vacuum apparatus of the mouthguard adaptor was switched on for 60 seconds and the frame securing the softened Stay-Guard material was lowered thus allowing the mouthguard material to adapt very closely to the model and brackets. (fig. 5)

The Stay-Guard material was then allowed to cool, and subsequently trimmed to the correct peripheral extensions. The brackets remained in their correctly positioned state, while the double-sided adhesive was peeled from the mesh with tweezers. The wax was removed with a le Cron carver, giving the final product seen in fig. 6.

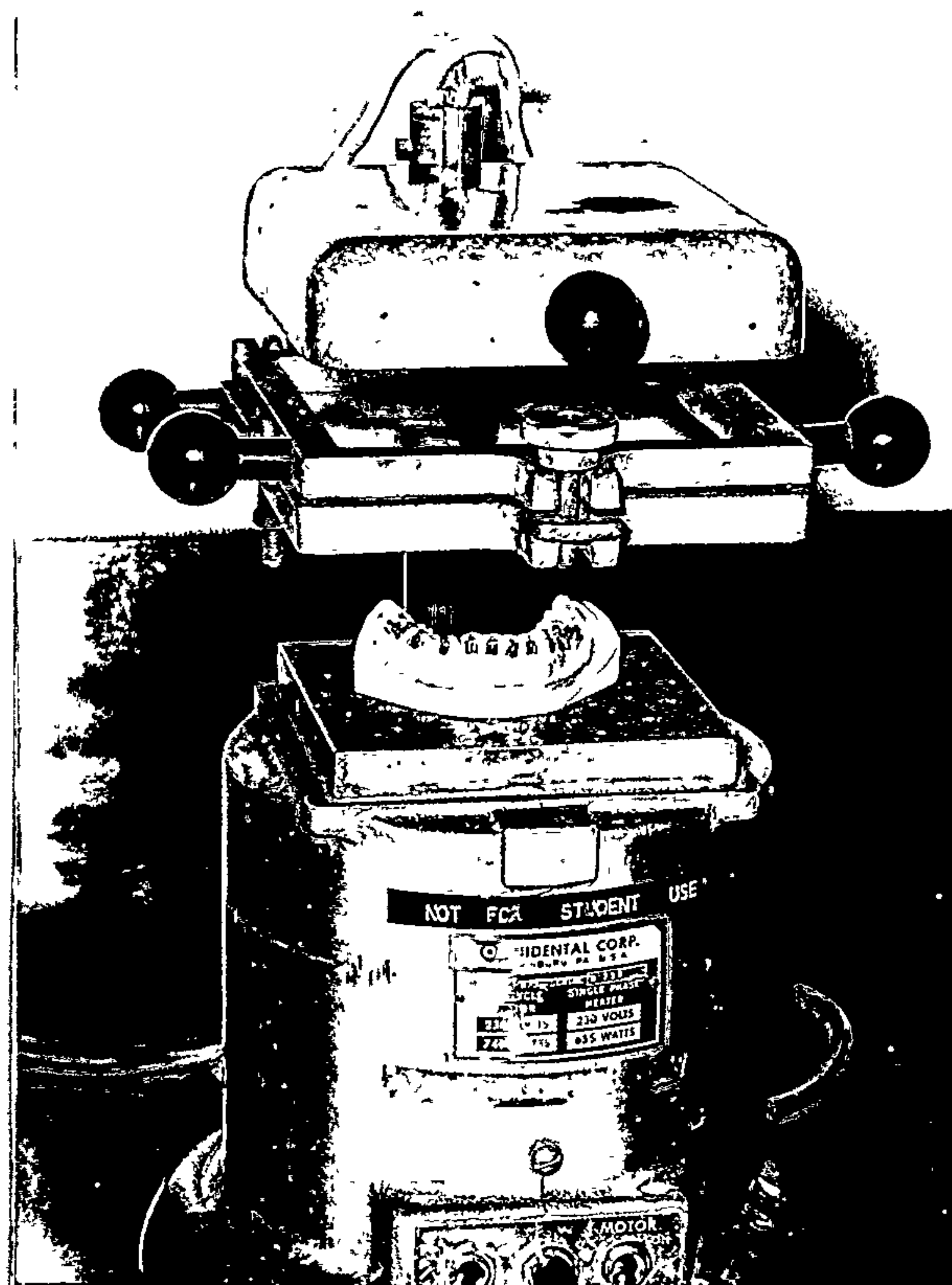


Fig. 3 - Mouthguard adaptor with model and Stay-guard material in position prior to heating.

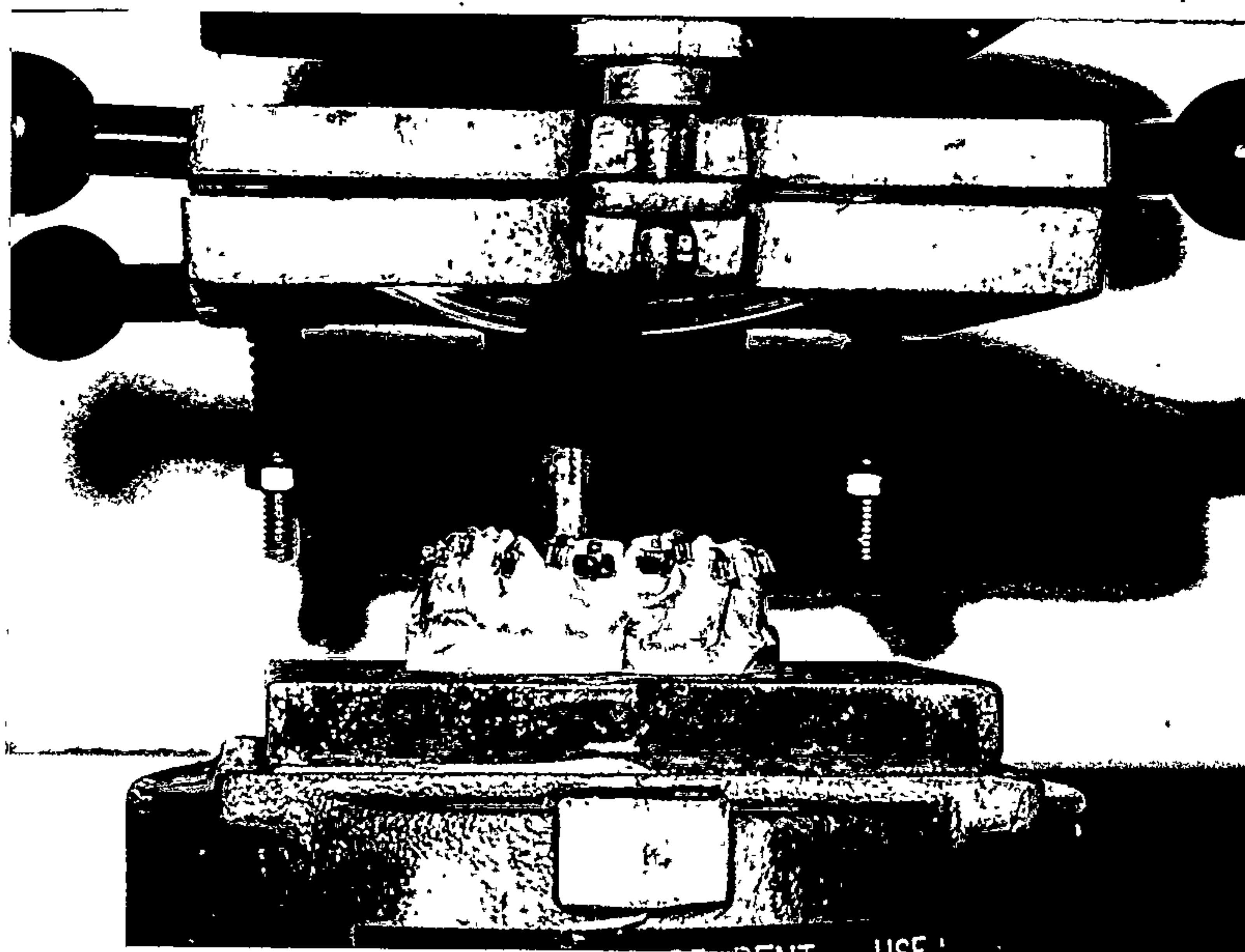


Fig. 4 - Model with wax spillways in position
Stay-Guard material has been heated
sufficiently for adaptation to the
model.

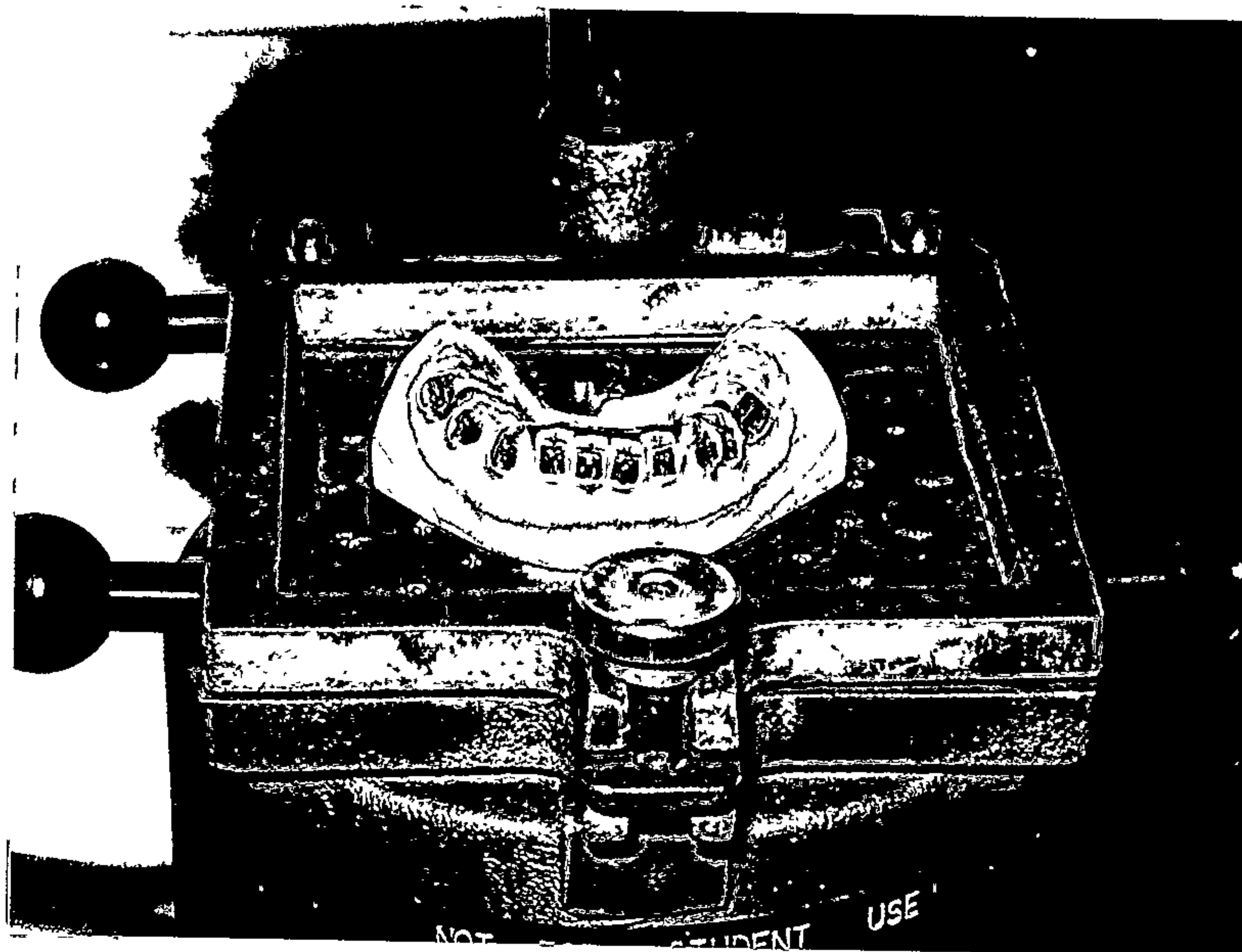


Fig. 5 - Model with Stay-guard material adapted.

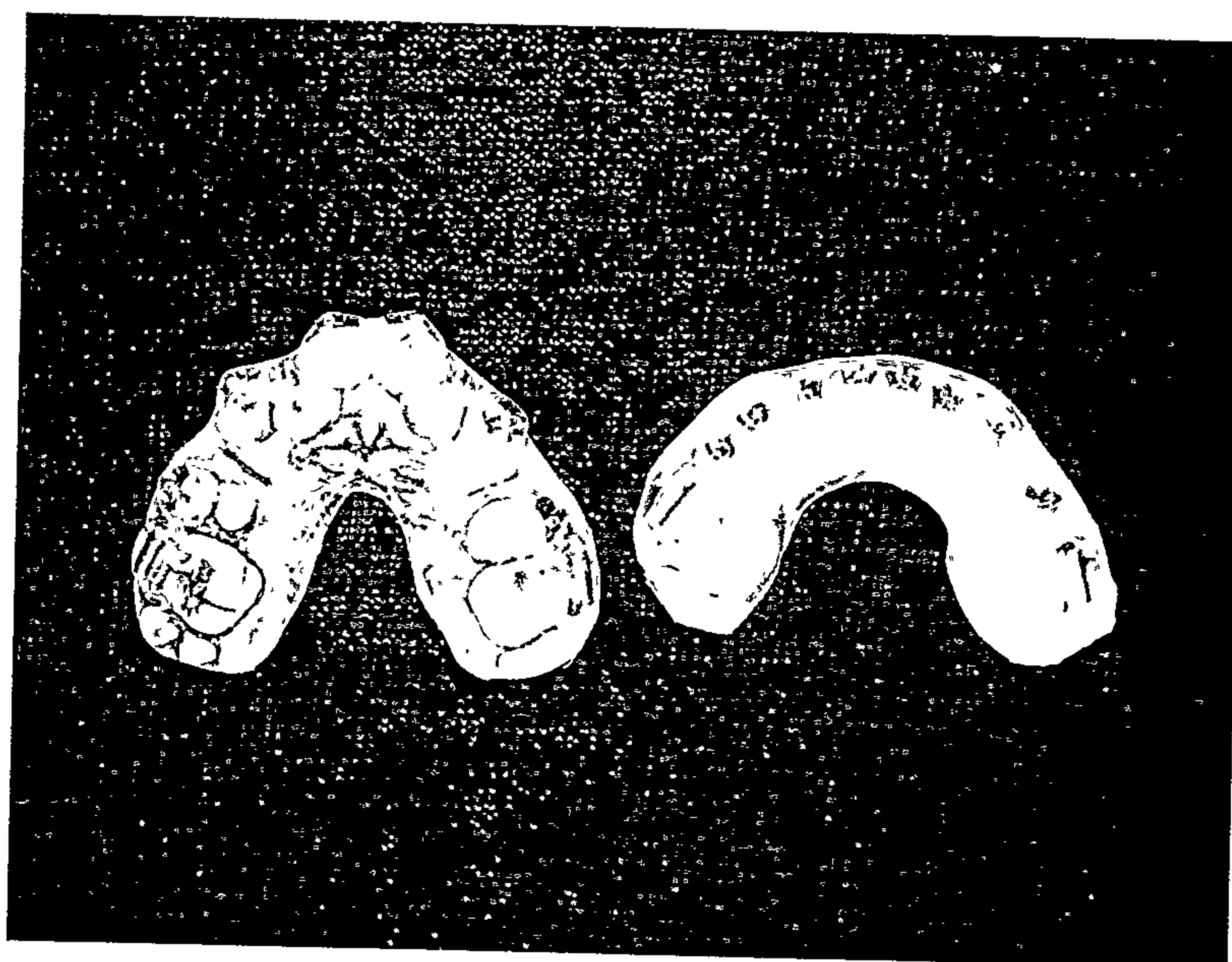


Fig. 6 - Adapted positioner or tray.

3.1.2 Clinical Method of Indirect Bonding

- a. The teeth in both arches were given a prophylaxis with a rubber cup and paste of pumice and water. At the same time, care was taken not to damage the gingival tissues.
- b. The patient was then allowed to rinse with ordinary tap water.
- c. TheOrmco Cheek Retractor was placed as in fig. 7. This operated in such a way as to give excellent access to almost all surfaces, while at the same time retracting the cheeks from the buccal surfaces of all the teeth.
- d. The mouth was cleared of saliva with a high volume evacuator. Virilium dry guards of suitable size were placed buccally over the opening of the parotid ducts. Cotton rolls were placed in the maxillary and mandibular buccal sulcus as well as in the lingual area. fig. 8. A disposable-type saliva ejector was placed in the disto-lingual to remove any saliva. Upper and lower teeth were then dried with a triplex syringe.

- e. With the teeth now thoroughly air dried the 50 per cent solution of buffered phosphoric acid (as supplied with the Auto-Tach adhesive) was applied to buccal and labial surfaces of all teeth in the maxillary arch, by a cotton pellet. The application was by gentle dabbing, rather than a rubbing motion, beginning at the upper left molar and continuing to the upper right molar. (fig. 8) The lower arch had the etching solution applied in the same manner, immediately after application to the maxillary arch.

The etching process was allowed to continue for 2½ minutes, as all patients were drawn from an area of fluoridated water supply.

This is longer than the etching time recommended by the manufacturer, but is the etching time recommended for similar etchants in the Pedodontic Department at Sydney University.

- f. The teeth were again thoroughly washed with water from a triplex syringe, which was being used in conjunction with a high volume evacuator to remove all fluid from the vicinity. All cotton rolls and dry-guards, were very carefully removed, so as not to come in contact with any of

the newly etched surfaces. After removal of any remaining areas of fluid new cotton rolls and "dry guards" were again replaced; in the same manner as in section e. A portable hair dryer (fig. 9) with a flexible hose was used to dry any moisture from the etched enamel surfaces. The flexible hose of the drying apparatus also allowed the addition of an evacuator tip which facilitated the precise placement of a warm air stream anywhere in the oral cavity. (fig. 10) The warm airflow was continually moved to avoid any dental or gingival trauma and was at all times maintained at the lowest warm setting.

It was thought necessary to use the hair drying apparatus as seen in fig. 10 as the hospital compressed air facilities were found to have both moisture and oil contamination. If the air supply from triplex syringes could be guaranteed to be free of moisture or oil contamination then the use of the hair dryer system would be negated.

- .g. The catalyst paste of the adhesive (refrigerated when not in use) was mixed in equal proportions on a thick cold glass slab for ten to fifteen

seconds. The slab was kept under refrigeration until ready for mixing and wiped to eliminate any condensation. The lower temperature allowed the operator to mix the two proportions of the Auto-Tach material and load all the brackets without undue haste as the setting time was over three minutes. Only a small amount of adhesive was required for each bracket as the area which had previously been occupied by the double-sided adhesive tape was very thin. The amount was judged in such a way as to be in excess of the amount required for the bracket. At the same time the amount had to be less than the amount required to fill the spillways.

- h. The etched surfaces were then given a final 30 second drying with the hair dryer to eliminate any chance of moisture contamination. (This also had the added benefit of warming the tooth structure slightly, thereby speeding up the setting reaction of the adhesive once the tray was seated).

The tray was positively seated and held for a period of four minutes to allow the material ample time to set. It should be stressed that at no time after the tray was correctly seated was it allowed any movement. The upper tray

remained in this position until the lower tray had been positioned and its adhesive set.

- i. The lower tray was placed in exactly the same manner as the upper. Prior to seating it the etched surfaces of the lower teeth were once again dried for a further 30 seconds. (see fig. 11 and 12)

If there was any direct moisture contamination of any etched surface in the lower arch during the process of positioning the upper tray all dry guards and cotton rolls were carefully removed and the area re-etched for a period of ten seconds. The teeth were then washed, evacuated, isolated with cotton rolls and "dry guards" as in section f. The tray and adhesive were then seated as in the maxillary arch.

- j. After the adhesive of the lower arch had set the upper tray was then removed. This was accomplished by sectioning the tray in the midline with crown and collar shears from the vicinity of the labial frenum to the palatal midline. (fig. 13) The tray was then carefully peeled off in the two halved sections leaving the brackets in their correct position on the teeth. (fig. 14)

- k. After the removal of the lower tray, all excess material which was bonded to the teeth (as a result of the spillways) was removed with a hand scaler or a flat fissure tungsten carbide bur (size No. 4). When all excess adhesive had been removed the interproximal regions were tested for bridging by the adhesive. This was achieved by passing dental floss between all teeth. If any bridging was present it was removed by Horico metal abrasive strips.
- l. The patient was again allowed to rinse. The cheek retractors were then reapplied, the mouth evacuated, upper and lower arches isolated and dried according to section 3. A topical application of acidulated fluoro-monophosphate of concentration 1.23 per cent was then given. (fig. 15) This remained in position for five minutes. After this application the patient was not allowed to rinse for a period of 1 hour.
- m. Arch wires were not placed for ten minutes after bonding was complete. (fig. 16)



Fig. 7 - Patient with Ormco cheek retractor in place.



Fig. 8 - Teeth isolated with "dry guards" and cotton rolls. Etching process is in progress while saliva ejector is in place.

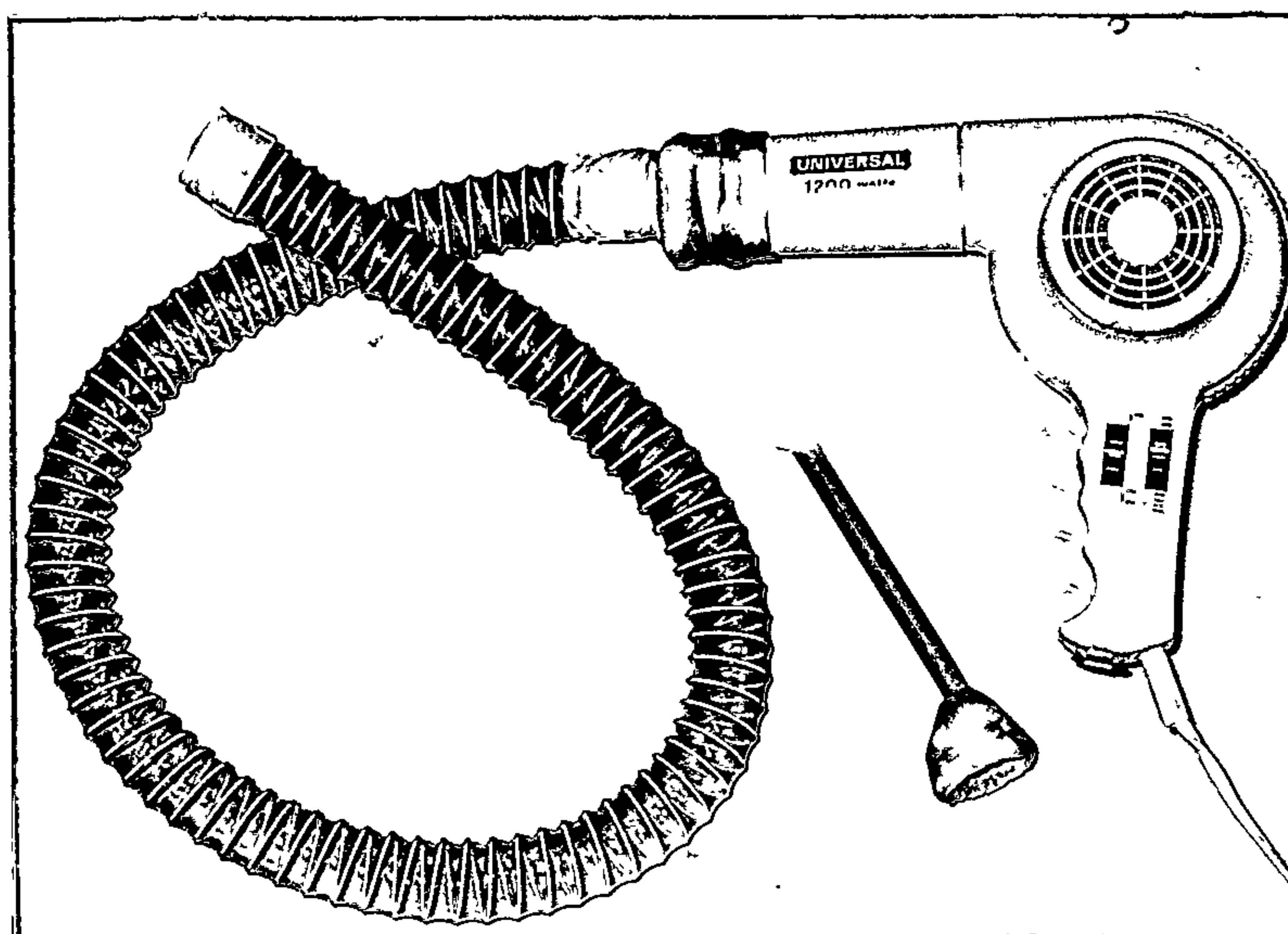


Fig. 9 - Hair dryer with flexible tubing and attachable evacuator tip.



Fig. 10 - Etched and isolated teeth being dried with extension tip on hair dryer.



Fig. 11 - Isolated teeth with upper tray in position.

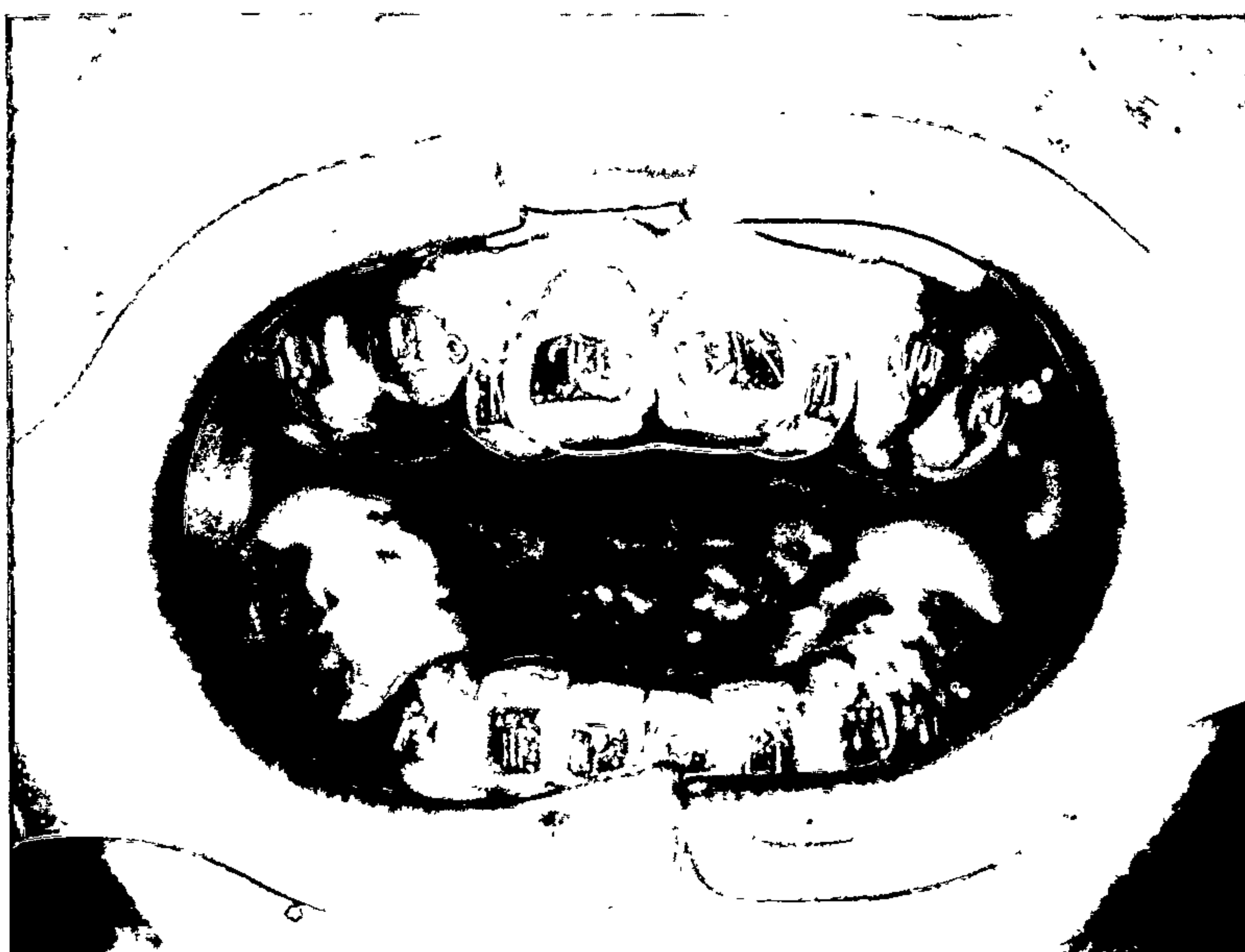


Fig. 12 - Both upper and lower trays in position
after setting of the adhesive.



Fig. 13 - Sectioning of positioner with crown and collar shears.

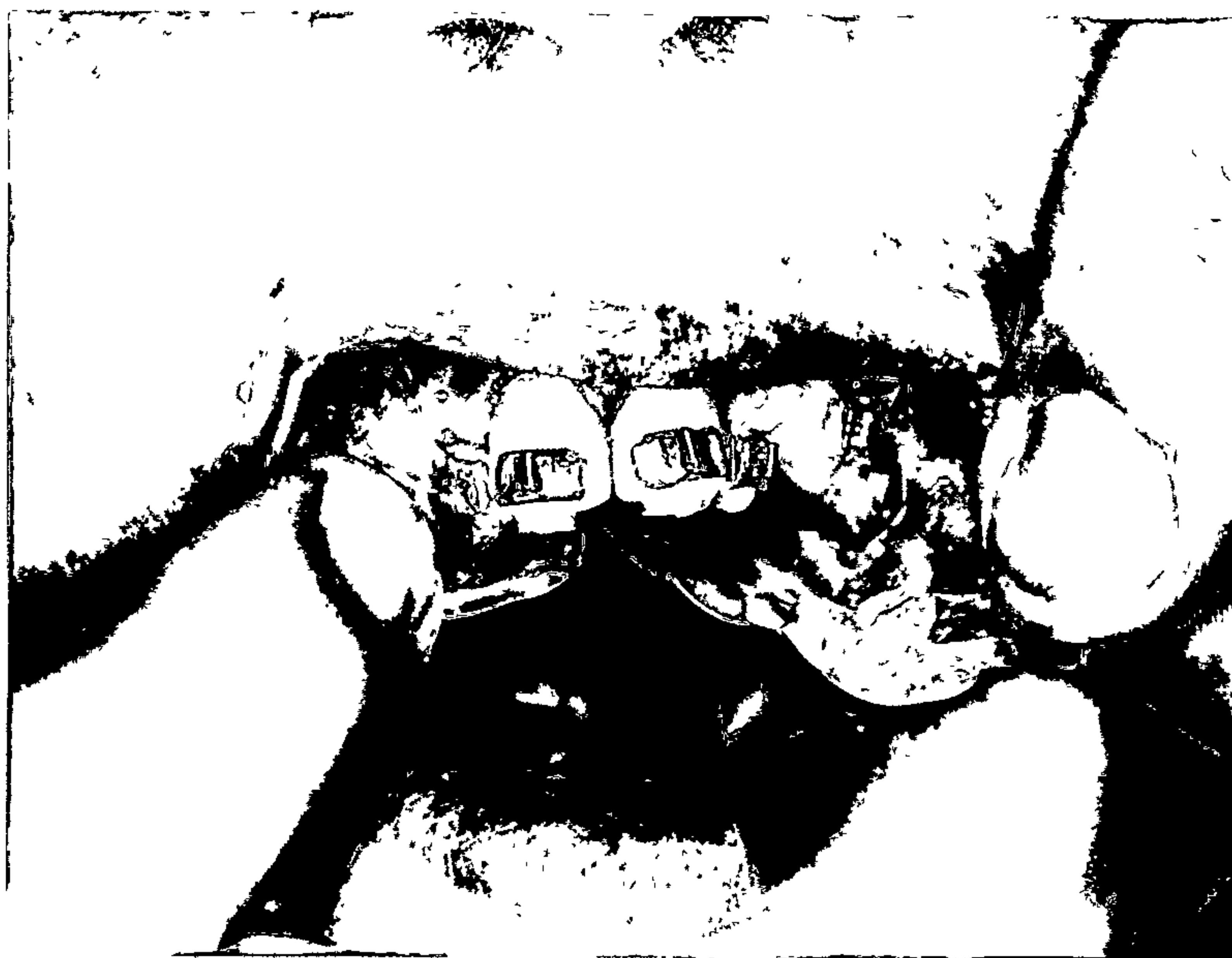


Fig. 14 - Removing positioner after sectioning.



Fig. 15 - Topical fluoride application after isolation with Ormco cheek retractor.

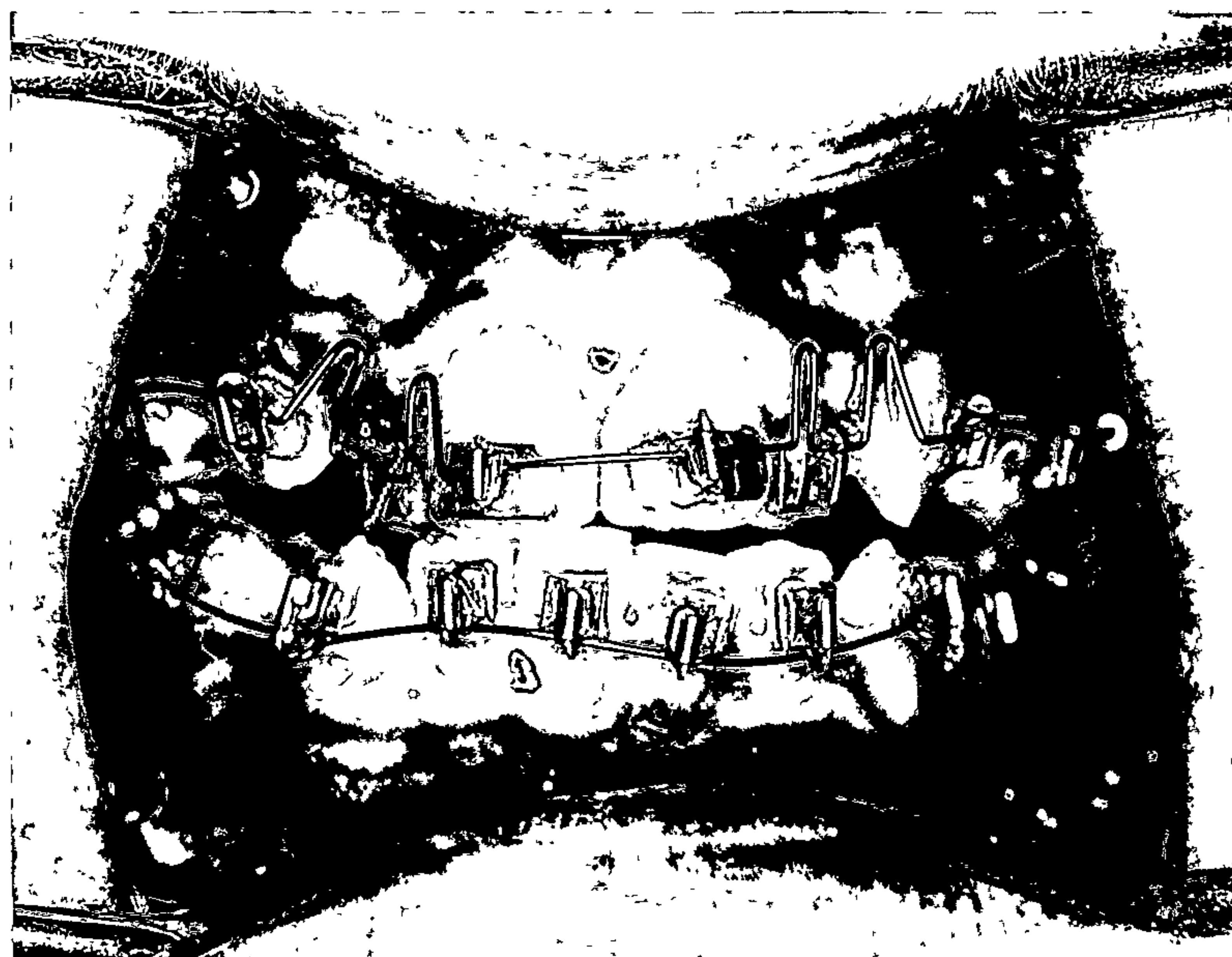


Fig. 16 - Bonding completed with arch wires in place.

3.2 Direct Bonding

Direct Bonding was conducted in a similar fashion to the indirect technique without the laboratory stage. i.e. Stages a to g were identical to those of the clinical procedure of the indirect technique.

Then the adhesive was mixed in the same manner as in Section g. The only difference was the smaller quantities of adhesive mixed for each batch.

All brackets had previously been selected and contoured with great attention being paid to the fact that any moisture contamination of the mesh on the bracket backing would result in adhesion weakness or failure. Enough adhesive was mixed to secure three or four brackets. The brackets had the adhesive mixed on a refrigerated slab according to Section g. For direct bonding the mixing was done by a chairside assistant who passed the attachment with the adhesive in position to the operator with tweezers. The brackets were then positioned for height and correct rotational displacement according to the judgement of the operator.

The sequence of bracket placement followed the pattern

```

UL6  )
      )
UL5  )
      )      1st  mix
UL4  )
      )
UL3  )

```

```

UR6  )
      )
UR5  )
      )      2nd  mix
UR4  )
      )
UR3  )

```

```

UR2  )
      )
UR1  )
      )      3rd  mix
UL1  )
      )
UL2  )

```

A similar pattern was followed in the lower arch with the posterior segment having the attachments placed prior to the anterior segment. This routine was adopted to decrease any possibility of moisture contamination as it was found that this was most likely to happen in the lower posterior segments. After each mix the hair dryer was used to accelerate the setting reaction prior to the next mix.

It must be stressed that with the direct bonding technique only the upper arch was etched, isolated dried and bonded. On completion of the bonding of the upper arch theOrmco cheek retractor was removed, the patient allowed to rinse and rest for a short time prior to repeating the procedure in the lower arch.

Clean-up and fluoridation procedures were identical to those in Sections k and l.

materials were used on opposite sides of the mouth and where one material was used on the upper premolar on one side it was used on the lower premolar on the opposite side.

The teeth were extracted after one week with great attention being paid to not dislodging or disturbing the brackets. Each tooth with the attached brackets then had its root carefully removed with a high speed air rotor. The crowns of the treated teeth with the brackets attached were suspended by .010 inch stainless steel ligature wire in 2M. hydrochloric acid for a period of 10 days. There was no agitation of the teeth or the solution as this could possibly result in the fracture of the very fine adhesive tags.

After 10 days there appeared to be no remnant of tooth structure. Subsequently the brackets with the composite surface attached were transferred to a beaker of distilled water where they were individually moved through the water very carefully in an attempt to remove any debris which was still attached to the composite surface. The brackets were then allowed to air-dry on filter paper while being covered with a large beaker to prevent any contamination of the composite surface with dust particles prior to coating.

3.3 Scanning Electron Microscopic Examination of the Composite Surface of the Enamel Interface.

As explained in the review of literature the penetration of the adhesive into the enamel surface is of great interest, as this would appear to influence the amount of potential post-treatment discolouration. The longer the adhesive tags, which are entrapped in the enamel surface after debonding, the greater the amount of adhesive; thereby increasing the prospect of potential discolouration.

The scanning electron microscopy study undertaken was only a pilot study. It was above all an attempt to allay fears held for the future appearance of the enamel surfaces of teeth of the 23 patients which were going to be treated clinically with direct and indirect bonding.

3.3.1 Methods for S.E.M Study Investigation

A total of 8 light wire Ormco brackets were bonded to eight first premolar teeth. Four of these brackets were bonded in vivo, 2 with Auto-Tach and 2 with Concise (this appears to be the most popular direct bonding adhesive amongst practising Orthodontists in responding to a recent survey) ⁽¹⁴⁹⁾. Both of the

The same sequence of events was adopted with four brackets on four premolars in an in vitro situation.

Surface Examination:

The composite surfaces which had previously been in contact with the enamel surface were coated by a Synavac E 12/14 coating unit (Manufactured by Synavac High Vacuum Pty Ltd (Aust.)). fig. 17 All specimens were coated with carbon and then gold or gold-palladium alloy. This gave a total coating thickness between 300 and 400A⁰.

The coated surfaces were examined by a scanning electron microscope (-Cambridge Stereoscan S600) (fig. 18). Accelerating voltage of 7.5, 15 and 25 K.V. were used.

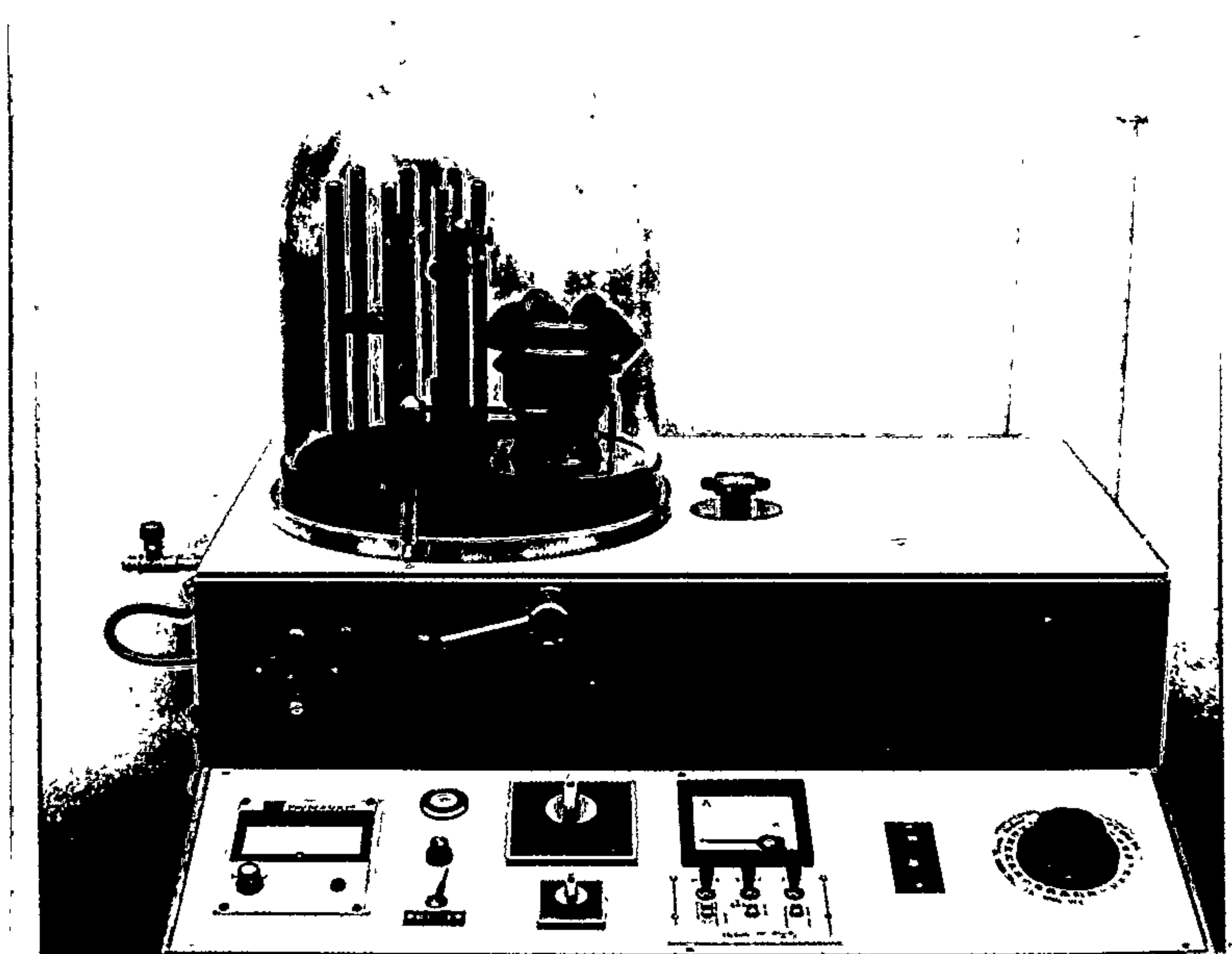


Fig. 17 - Synavac E 12/14 coating unit

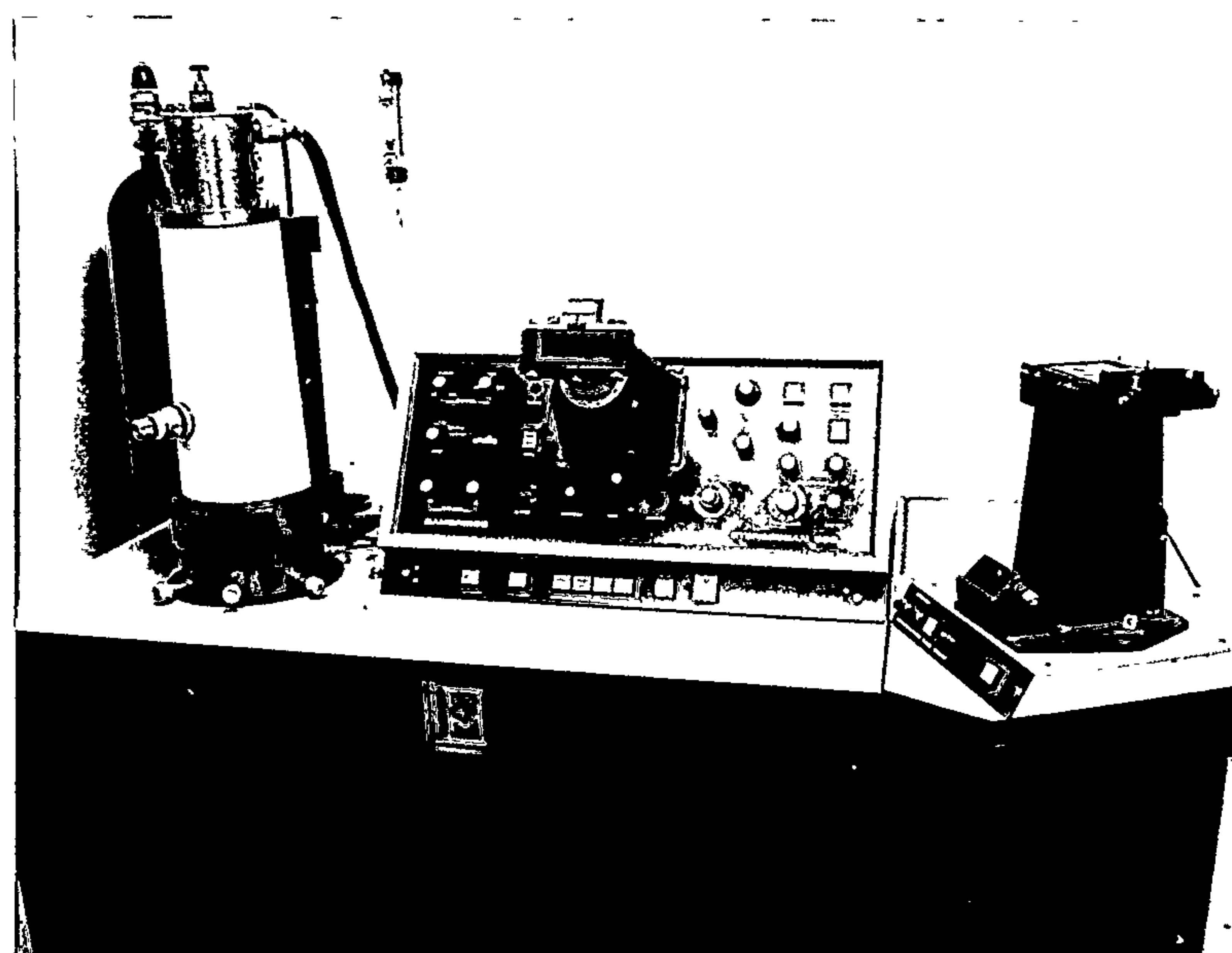


Fig. 18 - Cambridge Stereoscan S600 scanning electron microscope.

CHAPTER 4RESULTS AND DISCUSSION4.1 Statistical Analysis of the Failure Rates
for the Direct and Indirect Techniques

From the outset of this investigation it was understood that the number of brackets to be bonded for either technique would have to be restricted, due to the limited clinical time available. However, the results for individual tooth categories, together with significantly relevant tooth groups, are presented in Tables 1 (Direct Technique) and 2 (Indirect Technique).

The statistical analysis of the results obtained was achieved by a chi square analysis. This analysis was according to Lancaster's Methods⁽⁶⁰⁾. To cater for the non-orthogonal nature of the data it was processed by a Cyber 72 computer in the Biometry department at Sydney University, with a programme by Dr. M. O'Neil according to the format laid down by him⁽⁹³⁾.

One chi square analysis was done of the entire set of data. Following this, both jaws were analysed separately. The complete computer readout is shown in Table 3.

The sample size for individual teeth was too small to test for failure rates comparing the two techniques. However, as the interaction of the technique and tooth groups is not significant, conclusions drawn from the main effect would apply to both the direct and indirect technique.

The results of this evaluation showed that:

- a) There was no difference in the failure rate between the indirect and direct technique overall.

Chi square = 1.6946 with 1 D.F.*

$0.50 > p > 0.10$

On the basis of this analysis it was found that irrespective of the technique:

- b) Molars were significantly different from premolars in terms of failure rates.

- Maxilla -

Chi square = 8.4641 with 1 D.F.*

$p < 0.01$

- Mandible -

Chi square = 11.1657 with 1 D.F.*

$p < 0.01$

* Degrees of Freedom

- c) The grouping of molars and premolars combined was significantly different from anterior teeth, i.e. canines and incisors as a group.

- Maxilla -

Chi square = 16.5254 with 1*

$p < 0.01$

- Mandible

Chi square = 8.0679 with 1*

$p < 0.01$

- d) The group comprised of first permanent molars (M) was significantly different from the group comprised of first premolars and second premolars ($PM_1 + PM_2$), and as the group ($M + PM_1 + PM_2$) was significantly different from the group comprising anterior teeth, i.e. central incisors, lateral incisors and canines (1, 2, 3), then it can be concluded that group (M) is significantly different from group (1, 2, 3).

- e) It was shown that there was no difference between maxilla and mandible.

- Chi square = .4574 with 1*

- $0.50 > p > 0.10$

* Degrees of Freedom

TABLE 1

DIRECT TECHNIQUE			
Teeth Bonded	No. of Attachments	No. of Failures	% Failures
Maxilla			
First Permanent Molars	23	8	34.8
Second Premolars	17	2	11.8
First Premolars	15	1	6.7
Canines	24	0	0
Lateral Incisors	20	0	0
Central Incisors	24	0	0
Mandible			
First Permanent Molars	23	9	39.1
Second Premolars	15	3	20.0
First Premolars	15	1	6.6
Canines	24	2	8.3
Lateral Incisors	24	3	12.5
Central Incisors	24	1	4.0
Significant Groupings			
Maxilla and Mandible Combined			
All Teeth Combined	248	30	12.1
Molars	46	17	36.9
Premolars	62	7	11.3
Anteriors	140	6	4.3
Molars and Premolars	108	24	22.2
Maxilla			
Molars	23	8	34.8
Molars and Premolars Combined	55	11	20.0
Premolars	32	3	9.4
Anteriors	68	0	0
Mandible			
Molars	23	9	39.1
Molars and Premolars Combined	53	9	16.9
Premolars	30	4	13.3
Anteriors	72	6	8.3

TABLE 2

INDIRECT TECHNIQUE

Teeth Bonded	No. of Attachments	No. of Failures	% Failures
Maxilla			
First Permanent Molars	20	4	20.0
Second Premolars	17	2	11.7
First Premolars	14	2	14.0
Canines	20	1	5.0
Lateral Incisors	20	2	10.0
Central Incisors	20	0	-
Mandible			
First Permanent Molars	20	4	20.0
Second Premolars	17	1	5.8
First Premolars	17	1	5.8
Canines	20	0	-
Lateral Incisors	20	1	5.0
Central Incisors	20	1	5.0
Significant Groupings			
Maxilla and Mandible Combined			
All Teeth Combined	225	19	8.4
Molars	40	8	20.0
Premolars and Molars	105	14	13.3
First and Second Premolars	65	6	9.2
Anteriors	120	5	4.2
Maxilla			
Molars	20	4	20.0
Premolars and Molars	51	8	15.7
Premolars	31	4	12.9
Anteriors	60	3	5.0
Mandible			
Molars	20	4	20.0
Premolars and Molars	54	6	11.1
Premolars	34	2	5.9
Anteriors	60	2	3.3

TABLE 3

A = Teeth
B = Methods
C = Jaws
R = % Failure Rate

a) Maxilla & Mandible

		Chi	Degrees of	
Group		Square	Freedom	Significance
AR	=	44.6593	5	P<0.001
BR	=	1.6946	1	0.20>P>0.10
BAR	=	6.4992	5	0.30>P>0.20
CR	=	.4574	1	0.50>P>0.45
CAR	=	.9324	5	0.975>P>0.90
CBR	=	2.6594	1	0.20>P>0.10
CBAR	=	1.2010	5	0.95>P>0.90
Total	=	57.8152		

B) Maxilla

AR	=	25.6419	5	P<0.001
BR	=	.0640	1	0.90>P>0.80
BAR	=	4.9125	5	0.55>P>0.60
Total	=	30.3744		

c) Mandible

AR	=	20.4622	5	0.005>P>0.001
BR	=	3.9836	1	0.050>P>0.025
BAR	=	3.0876	5	0.700>P>0.059
Total	=	27.3348		

4.2 Comparison of Direct and Indirect Bonding Techniques

The comparative failure rates of direct and indirect technique are summarised in Tables 1 and 2. The complete statistical evaluation is given in Section 4.1. This shows that there is no statistical significance between either technique.

An analysis was done to compare the clinical time required for both techniques. The summary of these findings are presented in Table 4 together with the results of the analysis.

A student t test was used to ascertain if there was a statistically significance difference between the clinical times required for each technique.

This test gave a t value of $t = \pm 2.7$ with 21 degrees of freedom. i.e. $0.025 > P > .01$

Therefore, the clinical stage of bonding is significantly quicker with the indirect technique when compared to the direct technique.

It should, however, not be forgotten that considerable time is required to manufacture the bracket positioner in the indirect technique. The

TABLE 4

CLINICAL TIMES RECORDED (minutes)

	Direct	Indirect
	(n = 12)	(n = 11)
	45	55
	75	39
	39	55
	72	60
	82	34
	44	47
	48	41
	44	31
	74	41
	44	31
	65	40
	63	
Average Time	57.9	43.1
Standard Deviation	15.4	9.97

average laboratory time to manufacture the positioner was 36.7 minutes with a standard deviation of 3.9 minutes.

It is true that the manufacture of the bracket positioner could be carried out by technical personnel but this does entail a cost factor which may offset the time gained at chairside.

Furthermore, it should be stressed that the stated times for both direct and indirect techniques were calculated from the time prophylaxis was commenced, to the time that all bonding and clean-up procedures were completed. The clean-up procedures were generally more extensive with the indirect technique than with the direct method. When the latter technique was employed, any excess adhesive material was removed with a hand scaler before it had completely set. It is also important to note that the amount of excess adhesive was very small with the direct method.

The extended clean-up process for the indirect technique can be attributed to the fact that:

- a) The spillway areas incorporated to prevent excess adhesive moving interproximally and gingivally resulting in the adhesive in these

areas bonding to the enamel. This had to be removed with a tungsten carbide bur. Such a process is time-consuming, as great care has to be taken not to damage the enamel.

- b) Despite the spillways, there were a small number of cases where some adhesive was forced over parts of the tooth structure which was not covered by the bracket base. Occasionally the adhesive even covered parts of the attached gingiva and in one case there was interproximal bridging by adhesive in the lower right premolar area. In these cases the excess adhesive was effectively removed with a Morse scaler and any rough edges (these were generally close to the bracket base) were then smoothed over with a number four round bur.

The positioning of bracket attachments was found to be easier with the indirect method. With more experience using the direct method it was found that anterior attachments presented no problem to the operator but it became progressively more difficult to position attachments towards the distal aspects of the arches. This difficulty with

positioning attachments more distally varied from patient to patient but was never evident with the indirect method. The failure rates for posterior teeth (molars and premolars) in the indirect technique was 13.3 per cent while that for the direct method was 22.2 per cent but a Chi square analysis showed this difference not to be significant.

Therefore, in cases where it is necessary to bond attachments to the posterior teeth, e.g. where there is a space shortage, or epileptic patients taking dilantin, then the indirect method would probably be the method of choice.

The degree of trauma suffered by the patient seems to be identical for either technique. Patients questioned after bonding found both processes easy to tolerate and their reactions were much more favourable than those who had undergone conventional banding. The speed of the indirect method made it very acceptable but this advantage was slightly offset by the more extensive clean-up procedure required.

4.2.1 Gingival Condition

The gingival condition was assessed by subjective observation. In retrospect, this aspect

should really have been studied by an independent operator who did not know if the patients were bonded directly or indirectly. This independent operator should also have assessed the results in terms of numerical indices such as a plaque index and a gingival index. After one year these could have been analysed in terms of the type of bonding.

The subjective evaluation conducted during treatment indicates that there was no difference between either technique. It should also be remembered that a thorough clean-up was conducted after every patient was bonded.

In general, it can be said that gingival responses were excellent in both techniques provided that the oral hygiene was good and that no portion of the bracket base or adhesive was in contact with the gingival margin. Patients who used dental floss (all were instructed to do so) showed excellent gingival responses. As an overall observation the gingival responses of patients treated with either technique appeared to be better than comparable patients who had conventional bands, especially in the posterior segments.

4.2.2 Individual Tooth Groups

4.2.2.1 Molars

The failure rates of molars for both techniques is high enough to suggest that all molars should be banded. Even if the failure rates were not as great, I would still recommend banding. This stems from the fact that in the Begg technique the role of the molar is fundamental to the success of the technique. Therefore, if a molar attachment becomes loose it necessitates the immediate return of the patient to the orthodontist. This can be inconvenient for the patient, not to mention inconvenient and embarrassing for the orthodontist. Apart from this, trauma to the patient's tissues may be caused from the free end of the arch wire. Even more serious than this is the prospect of the patient inhaling the molar tube attachment if it should somehow come off the arch wire. In such cases the orthodontist is never sure if the patient swallowed or inhaled the attachment and a precautionary chest X-ray does nothing to increase the esteem of the orthodontist in the eyes of his patient. Other bonded attachments remained attached to the arch wire in all but one case of bracket dislodgement.

The placement of molar attachments can be very difficult with the direct technique particularly in

cases of restricted access. Even with good access it was often very difficult to obtain precisely the desired bracket positioning.

There was also considerable gingival irritation in the gingival tissues of near 35 per cent of patients' bonded molar attachments.

This irritation was no worse than that found in banded cases and was only restricted to the buccal surface whereas with bands it pertains to four surfaces in many cases.

A further point in favour of bonding molar attachments was the fact that in no cases was there the formation of decalcified surface areas, or the appearance of new carious lesions.

4.2.2.2 Premolars

No distinction could be drawn between first and second, upper and lower, and direct or indirectly bonded premolars.

The comment that it is generally more difficult to bond second premolars than first premolars is justified in most cases where direct bonding was used.

Contraindications to the bonding of attachments to upper or lower premolars are basically in three categories:

- a) In cases where the clinical crown is too short, which in most cases is due to the tooth not being fully erupted.

In such cases the bracket impinges on the gingiva resulting in gingival irritation. Another effect of this lack of clinical crown is that attachments seem to be easily lost from such premolars. This is probably the result of gingival crevice fluid contaminating the etched enamel. It could also be a result of the enamel not being etched properly due to the escape of gingival crevice fluid during the etching process.

It should also be said that such premolars should not be banded because of the possibility of permanent gingival damage not to mention the pain and discomfort inflicted on the patient in such circumstances.

- b) In cases where the crowns of premolars are rotated. This necessitates the bonding of a lingual as well as the buccal attachment. At times the process of bonding on lingual buttons can be

difficult and time-consuming. This is not to say that they cannot be placed but rather that this is an extra step which can often be tedious on premolars. Apart from the time factor some of the advantages of direct bonding are lost when a lingual attachment has to be placed. Firstly an extra surface has to be etched and secondly three sides of the tooth may become covered with foreign objects i.e. buccal lingual and one of the interproximals (due to the rotation elastic).

There are however instances where bonding of premolars can be of great help and the chance of loosening attachments or having to bond lingual attachments is definitely worthwhile. Such cases are the borderline non-extraction cases. By bonding and not banding premolars the chances of treating such patients by a nonextraction procedure is greatly increased due to the extra amount of space available (space which is normally occupied by band material and cement). Also proximal surfaces are accessible to interproximal stripping if required.

c) The third contraindications to bonding attachments to premolars in areas where they will be subject to occlusal interference. This interference

can be in the positions of centric occlusion, centric relation or in the path of laterally excessive movements. In the present study, 7 of the 13 premolar attachments lost were lost because of suspected occlusal interference.

Such occlusal interference may be due to a number of reasons, the most common being buccal or lingual cross bite or unfavourable inclination.

4.2.2.3 Anterior Teeth

As stated previously, the Chi square analysis showed that statistically there was no difference between upper and lower anteriors irrespective of whether direct or indirect techniques were applied (The respective failure rates being shown in Table 1 and 2).

Normally one would assume that the failure rate would be higher amongst groups of lower anterior teeth than uppers. This was found not to be so and therefore it must be assumed that occlusion in cases of deep bite is not as great a limiting factor as would be expected. When bonding (directly or indirectly) cases with deep overbites the attachments were whenever possible, placed to avoid contact with the opposing dentition. Where this was not

possible the patient was instructed to avoid placing excess pressure on the attachments. The low failure rates on lower anterior teeth indicates that this procedure worked very well, as these figures compared very favourably with the failure rates quoted for conventional bands⁽⁷⁹⁾.

Another point favouring the bonding of anterior brackets is the improvement in aesthetics. The bracket bases used in this investigation were rather large. Since commencement of this investigationOrmco has marketed the "mini pads" (Other manufacturers have comparable products). These mini pads are a definite improvement as far as aesthetics are concerned and work now in progress tends to indicate that their retentive capacity with an identical adhesive is comparable to the products used in this investigation.

Another important advantage observed so far is that there has not been any demineralization staining after attachment removal. This is only to be expected as leakage caused by ill-fitted bands or cement leaching out from under bands cannot occur with bonded attachments. If bonded attachments is deficient in adhesive to any extent then the attachment generally dislodges. This process of total bracket failure is preferable to

to leaching loose or ill fitting bands.

Perhaps the greatest advantage found with the bonding of anterior attachments was the ease of securing attachments when compared to the fitting and cementing procedure used with conventional banding. This ease and comfort are felt by the operator and much more importantly by the patient. The comfort is especially noticeable in extremely crowded teeth as the need for separation is eliminated in all instances. This saves time for the operator not to mention the confidence and comfort of the patient.

Another important factor was that the degree of discomfort in the week after debonding of attachments seemed nowhere as severe in patients who had bonded attachments as in those who had conventional bands. This can be attributed to not having the thickness of band metal and cement forced interproximally.

Bonding of attachments to upper or lower canines, partially erupted anteriors and odd shaped teeth e.g. peg shaped laterals or shovel shaped centrals. This was at all times accomplished in a very short time provided the bases were correctly contoured prior to bonding. The ease with which such teeth were treated was of great benefit to the patient and eliminated the frustration

which such teeth can cause the operator.

The benefits in border-line non-extraction cases as expressed in the previous section on premolars was even more evident for anterior teeth. Bonded attachments allowed interproximal stripping while treatment was in progress. This meant that stripping could be undertaken in progressively small increments thereby allowing the correct setting of teeth prior to any further stripping. This process was of particular value in those cases where "stage IV Begg" mechanics were employed as it allowed the more accurate prediction of the final result due to a reduction in the amount of post-treatment settling.

4.3 Scanning Electron Microscopic Evaluation

Scrutiny of the scanning electron micrographs, depicting the composite surfaces, which prior to demineralization of the tooth structure had physically contacted the etched enamel, revealed that there was no discernible difference in the appearance of a particular brand of composite, bonded in vivo or in vitro.

4.3.1 Auto-Tach (Fig. 19 to 26)

The fact that Auto-Tach closely reproduces

the etched enamel surface is displayed in fig. 19 (magn. 20X). This micrograph depicts the periodicity of the perikymata. This periodicity is also shown in fig. 20 (magn. 100X). It becomes apparent from the micrograph that the lines which characterise the periodicity of the perikymata represent two different types of surface structure of the counter die:

- Relatively smooth surface areas.
- Areas showing a rough nodulated type of surface structure.

These rough nodulated areas are better illustrated in fig. 21 to fig. 25 (magn. 500X to 5000X). The surfaces depicted in these micrographs do not resemble a counter die of an etched enamel surface, the nodular structures being too irregular and coarse N.B. fig. 24.

The relatively smooth areas between the rough nodular extrusions as shown in figures 21 to 25 look as though they could closely follow the topography of the etched enamel surface. At this early stage of investigation it seems feasible to assume that the evenly textured surfaces shown in figs. 19 to 26 represent areas of direct contact with the etched enamel surface.

The material composition and origin of the nodular extrusions are at this stage a matter of theoretical speculation. Suggested explanations are:

- a) That they are artefacts of the demineralization process. This would seem unlikely as they follow the perikymata too closely and occupy the entire composite surface at regular intervals.
- b) That they are the result of unevennesses in the etch pattern. This again seems unlikely as etch patterns generated by 50 per cent phosphoric acids are generally of a very even nature.
- c) That they are the result of air inhibition of polymerization. As composite sets there is an opening of the carbon-carbon double-bond. Then instead of joining to another carbon atom a bond is formed to an oxygen atom. This may result in a whole area of composite not setting. This phenomenon is frequently observed in areas of air entrapment in composite restorations.
- d) Auto-Tach has a relatively high viscosity when compared to the sealant phase of Concise. This

higher viscosity of Auto-Tach may result in the adhesive not being able to contact the etched enamel in the depressions between the perikymata on seating of the bracket. Under these conditions the adhesive in these areas would then occupy a state of minimal free energy i.e. rounded or spherical in shape. The spherical shape however can, not be completely smooth due to the large inorganic filler particles which break the surface.

4.3.2 Concise

Concise showed that it, like Auto-Tach, replicated the periodicity of the perikymata fig. 26 (magn. 20X). However, at a magnification of 100X (fig. 27) surface looks completely different to that of Auto-Tach in that the areas which appear smooth are in actual fact considerably rougher than that of Auto-Tach. In this area the low viscosity resin material has in sections taken an exact impression of the enamel prisms.

Fig. 28 (magn. 500X) exemplifies an increasing dissimilarity between Auto-Tach and Concise at higher magnifications. Breaks in the continuity of the low viscosity resin layer become apparent only to reveal the granular structure of the two

paste composite system (the granular appearance emanating from the very large filler particles). This observation tends to indicate that the probability of a constant contact area between the high viscosity filled paste system and the low viscosity resin system is unlikely.

Figs. 29 to 32 (magn. 2000 → 5000X) further exemplify the extremely rough nature of Concise which appears to extend over the entire surface. More importantly they show the thin spinous sheet like structure of the Concise resin tags.

The composite surfaces shown in the scanning electron micrographs of this investigation are curved as they follow the curvature of the premolar teeth to which they were bonded. This means that any measurement of length of extrusions from the base of these surfaces can only be an estimation of the actual length. These estimations are however a reasonable guide to the extent of penetration of the respective adhesives into the enamel. On the basis of this guide the apparent penetration of resin into the enamel would appear to be:

- Auto-Tach

- .5 to 1 μ m when considering the

smooth surfaces. (fig. 25)

- 4 to 6 μm (fig. 24) when considering the rough extrusions. It should however be remembered that these nodular extrusions are of such a cross-sectional shape and dimension that it seems improbable that they could ever have penetrated into the etched enamel surface.

- Concise

Appears to penetrate into the etched enamel to a depth of 12 to 16 μm (fig. 31 and 32.) This depth of penetration appears consistent over the entire surface.

The degree of penetration of adhesive into the enamel surface carries with it a potential problem. Theoretically the deeper the penetration of adhesive into the enamel, the more adhesive will be left in the enamel, as some adhesive always remains in the enamel after debonding⁽²⁷⁾ (51). The greater the amount of adhesive left in the enamel the greater the risk of post-treatment discolouration. There may in actual fact be no risk of discolouration

but the potential risk cannot be stressed enough. At the moment the longest documented post-treatment evaluation is 1 year⁽¹⁴⁴⁾.

If there was post-treatment discolouration and this discolouration did only extend to the depth of the resin tags (16 μm) then there would be no harm in removing this amount of contaminated enamel. It should however be remembered just how hard it is to remove only 16 μm over an uneven surface under clinical conditions and have an end product which is identical to a natural tooth surface.

It seems reasonable to assume that in order to avoid discolouration the material which penetrates the least distance into the enamel would be the obvious choice, provided it gave adequate strength.

Therefore on the basis of this very limited scanning electron microscope study and the clinical results obtained over a 1 year study with Auto-Tach, the adhesive strength properties of which have been verified⁽⁴¹⁾. This would appear to be the adhesive of choice as it indicates a reduction in the potential discolouration.

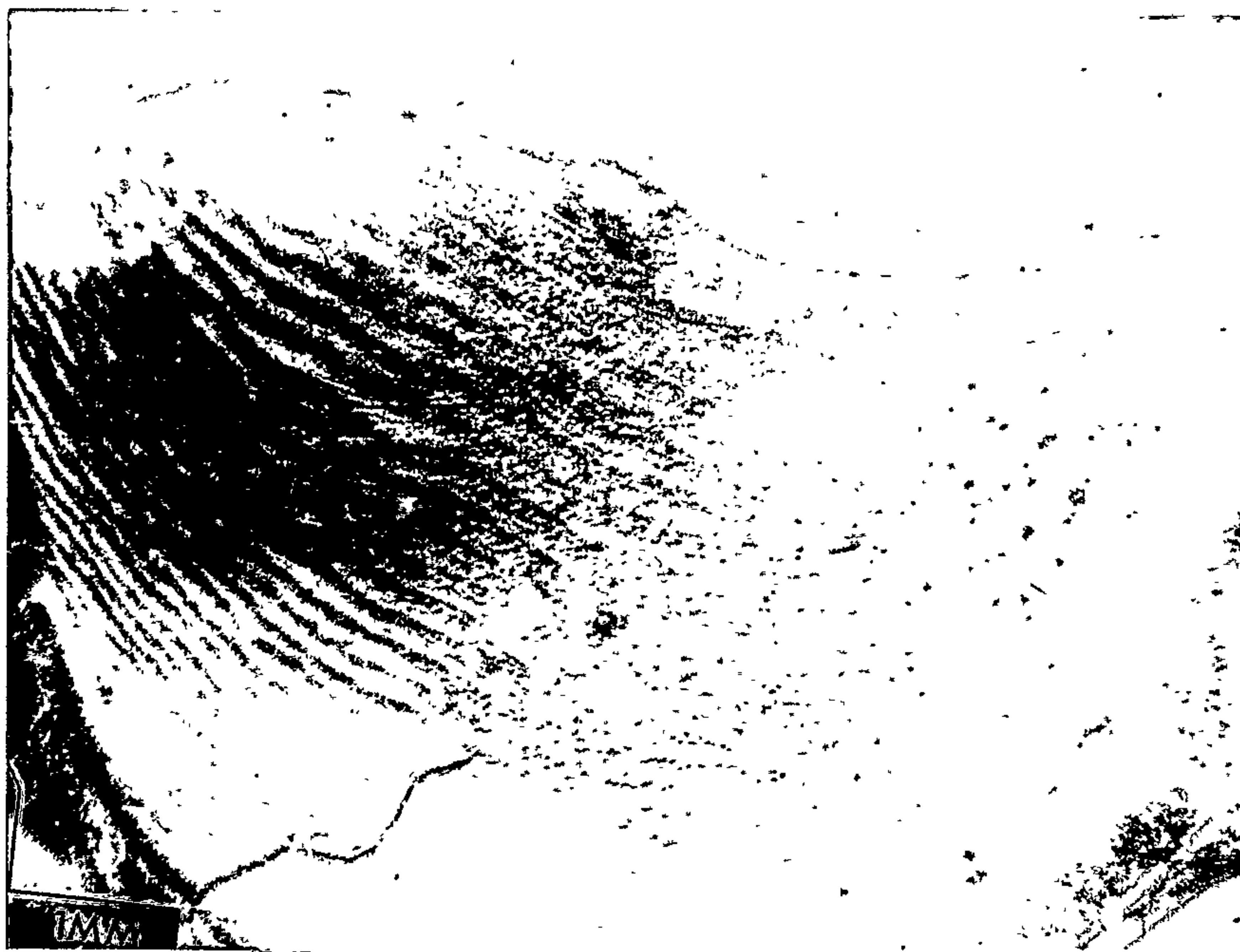


Fig. 19 - Auto-Tach Magnification 20X.



Fig. 20 - Auto-Tach Magnification 100X.

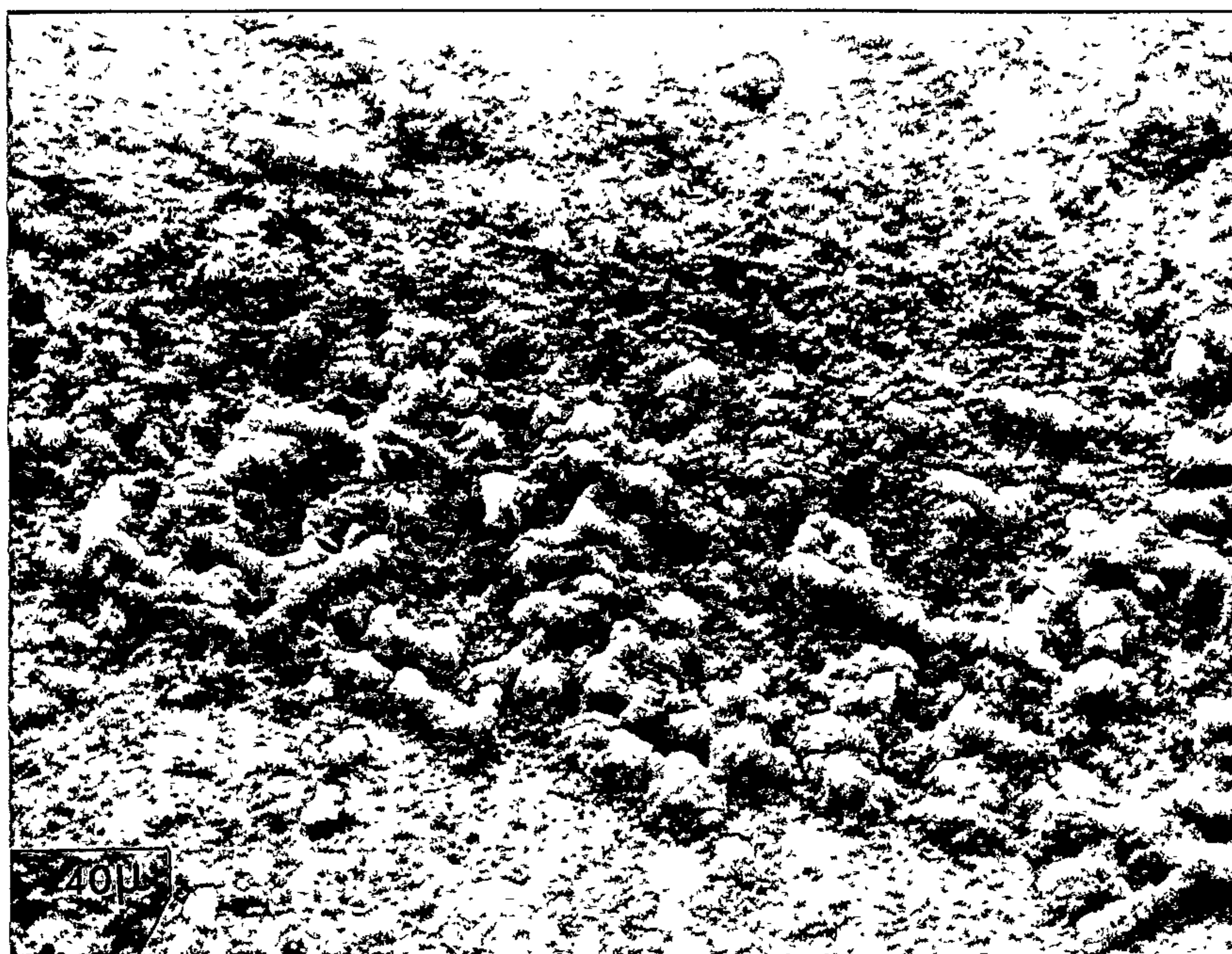


Fig. 21 - Auto-Tach Magnification 500X.

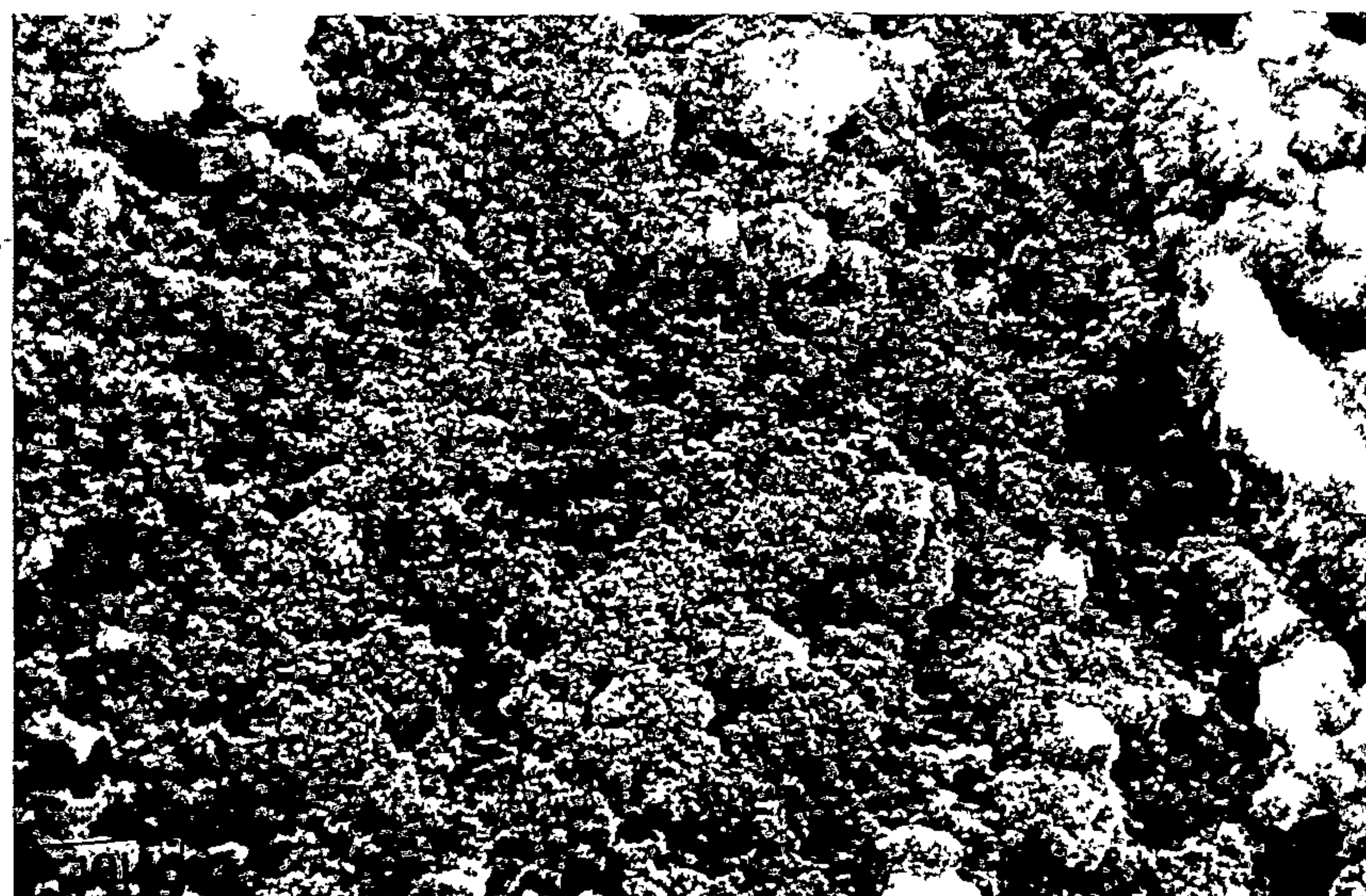


Fig. 22 - Auto-Tach Magnification 2000X.

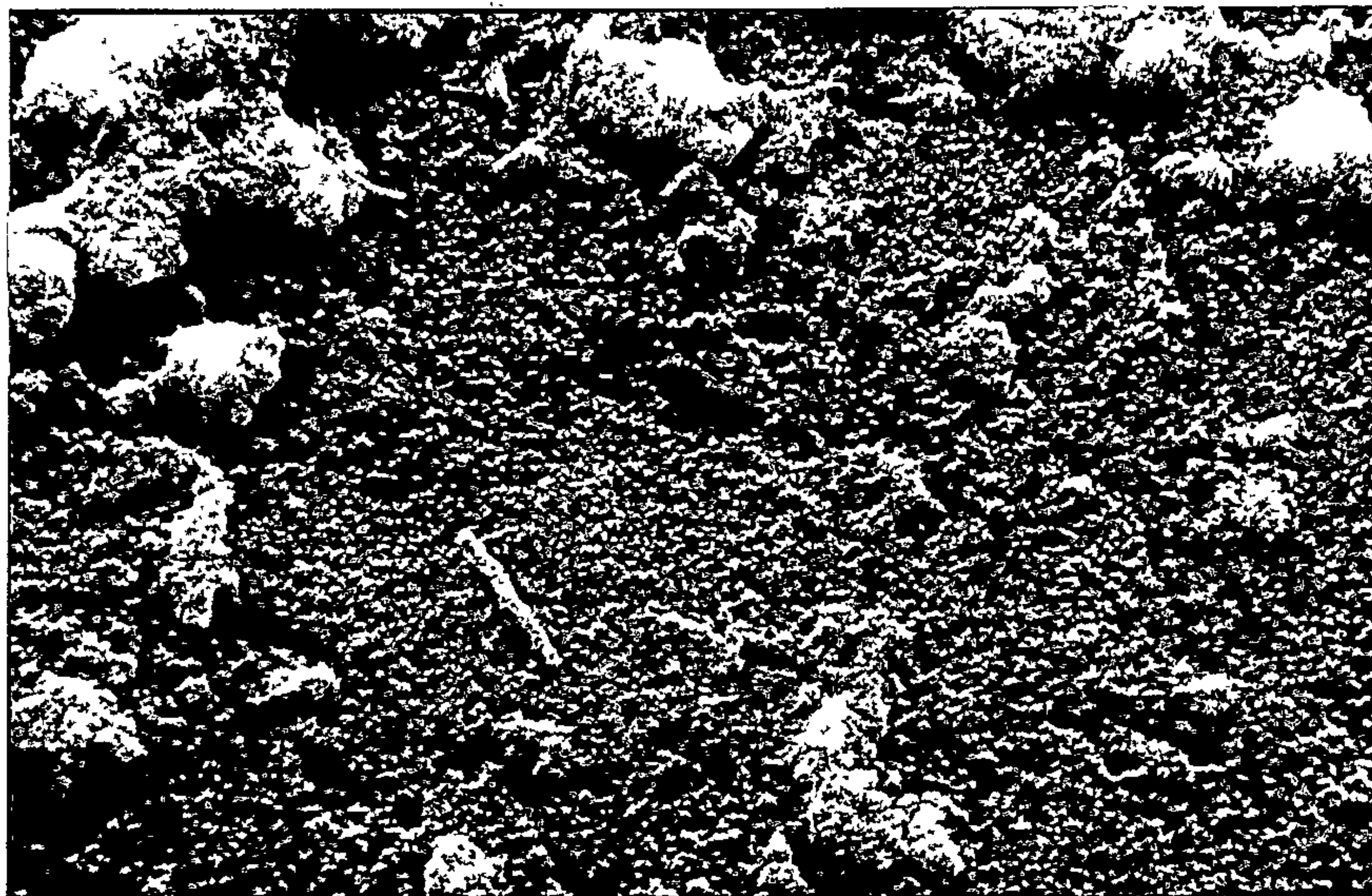


Fig. 23 - Auto-Tach Magnification 2000X.

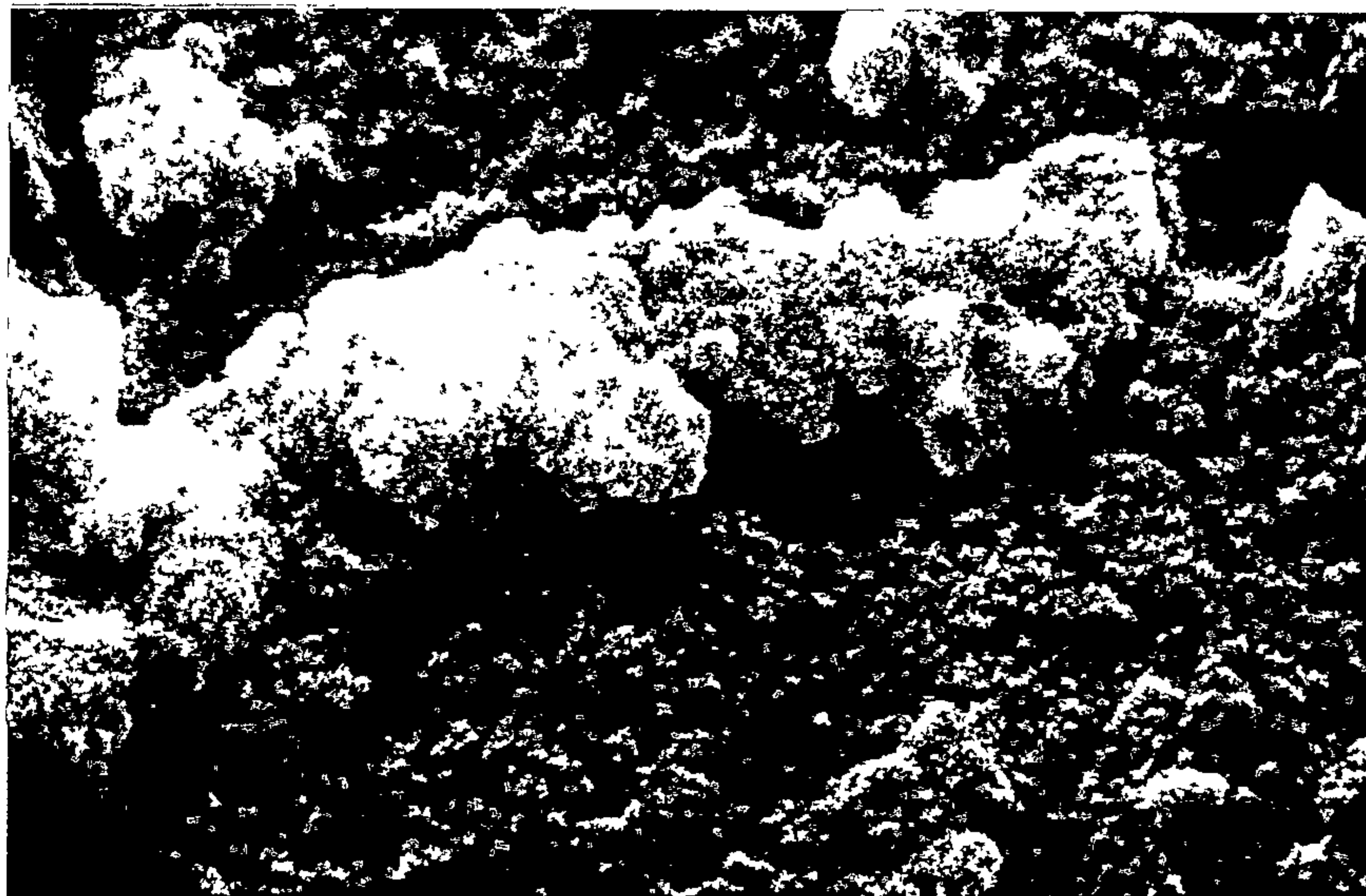


Fig. 24 - Auto-Tach Magnification 5000X.

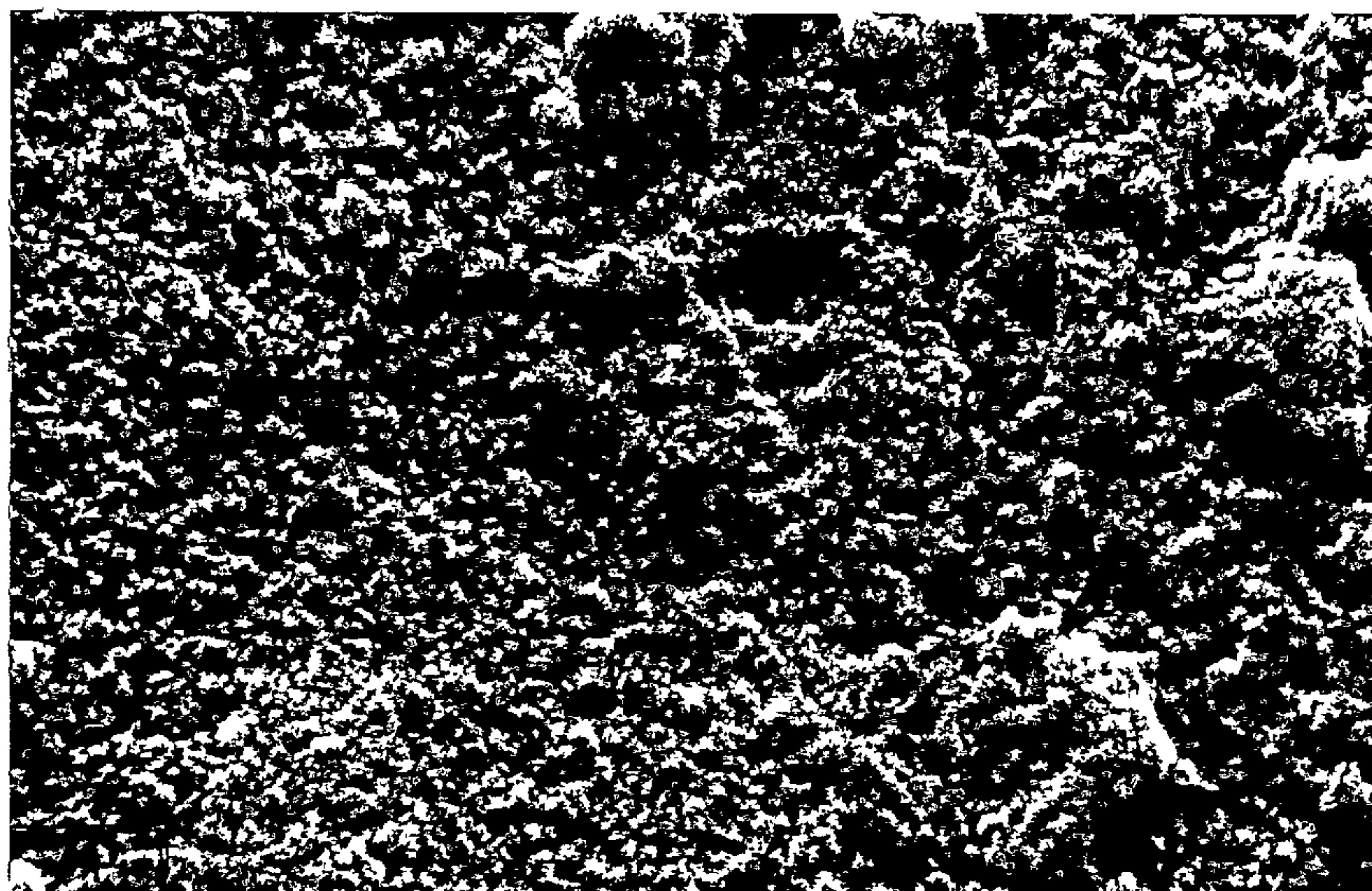


Fig. 25 - Auto-Tach Magnification 5000X.

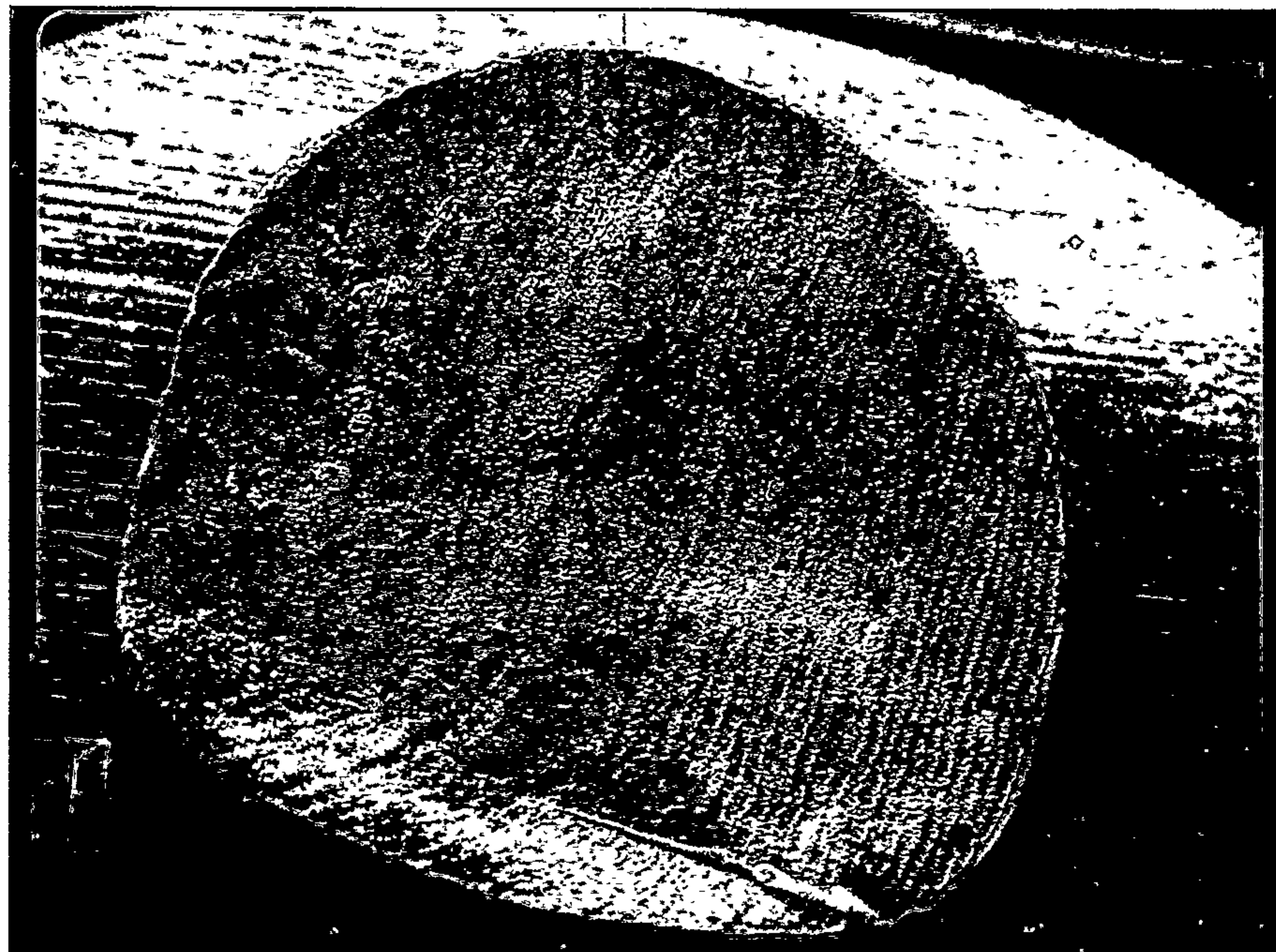


Fig. 26 - Concise Magnification 20X.

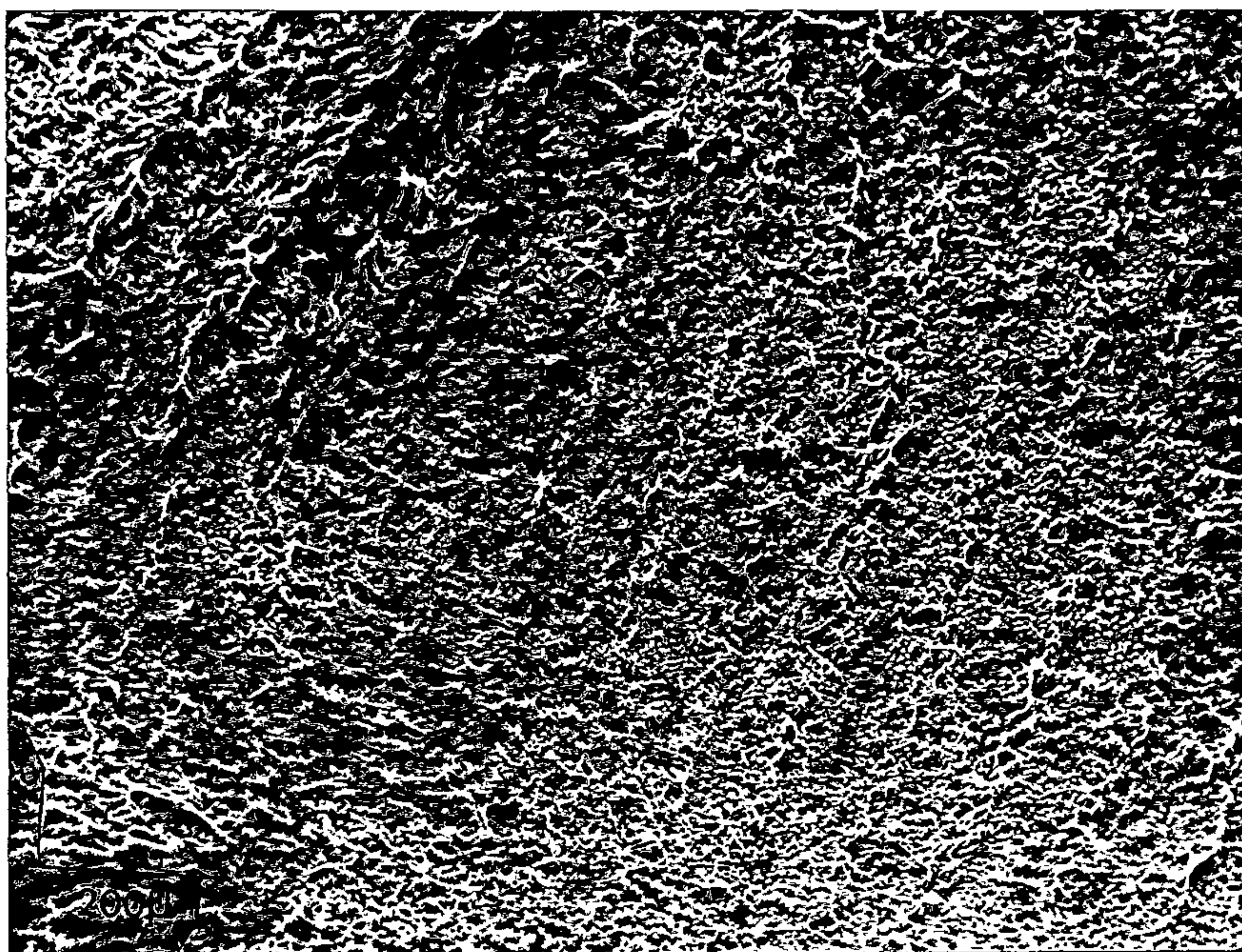


Fig. 27 - Concise Magnification 100X.

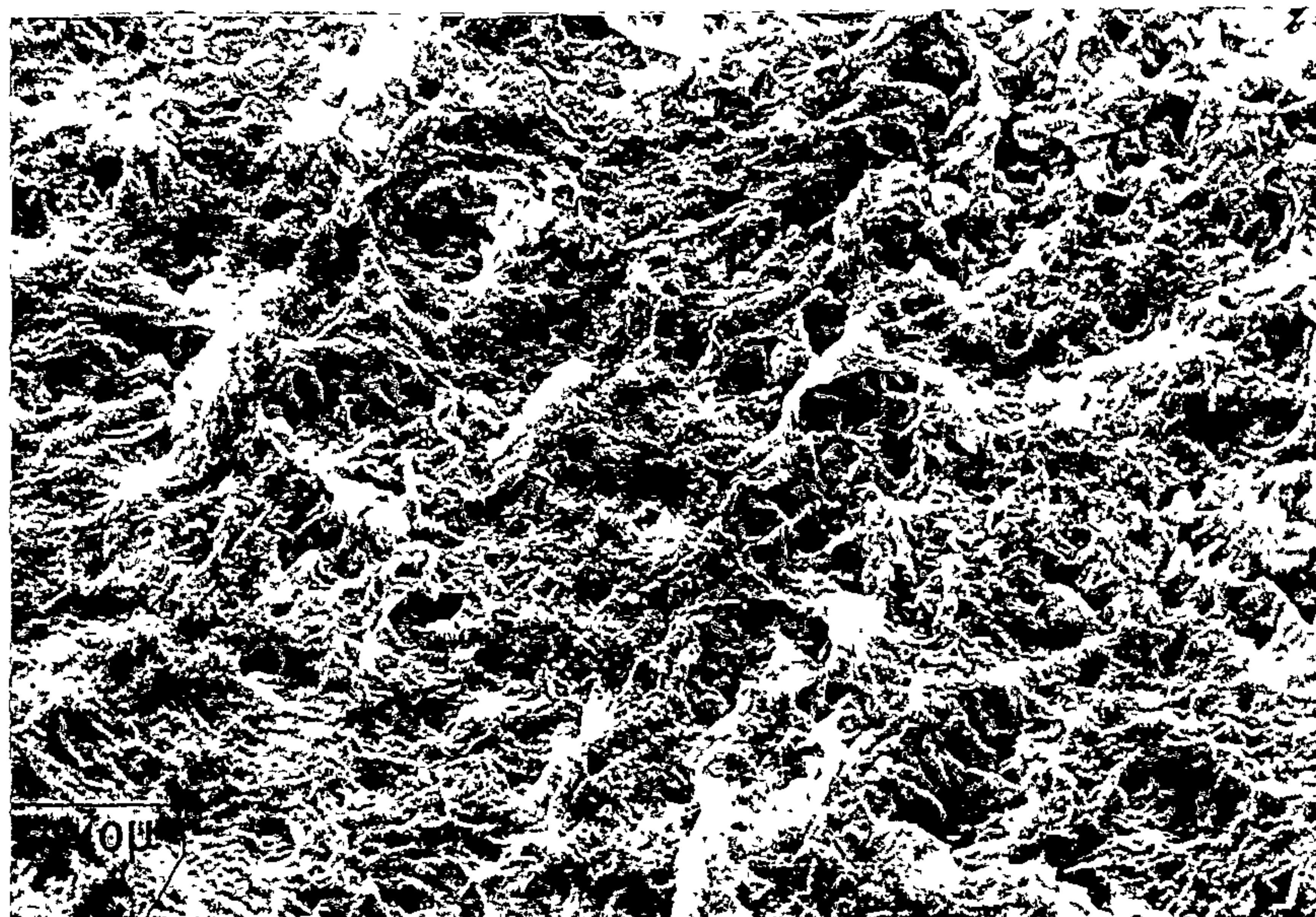


Fig. 28 - Concise Magnification 500X.

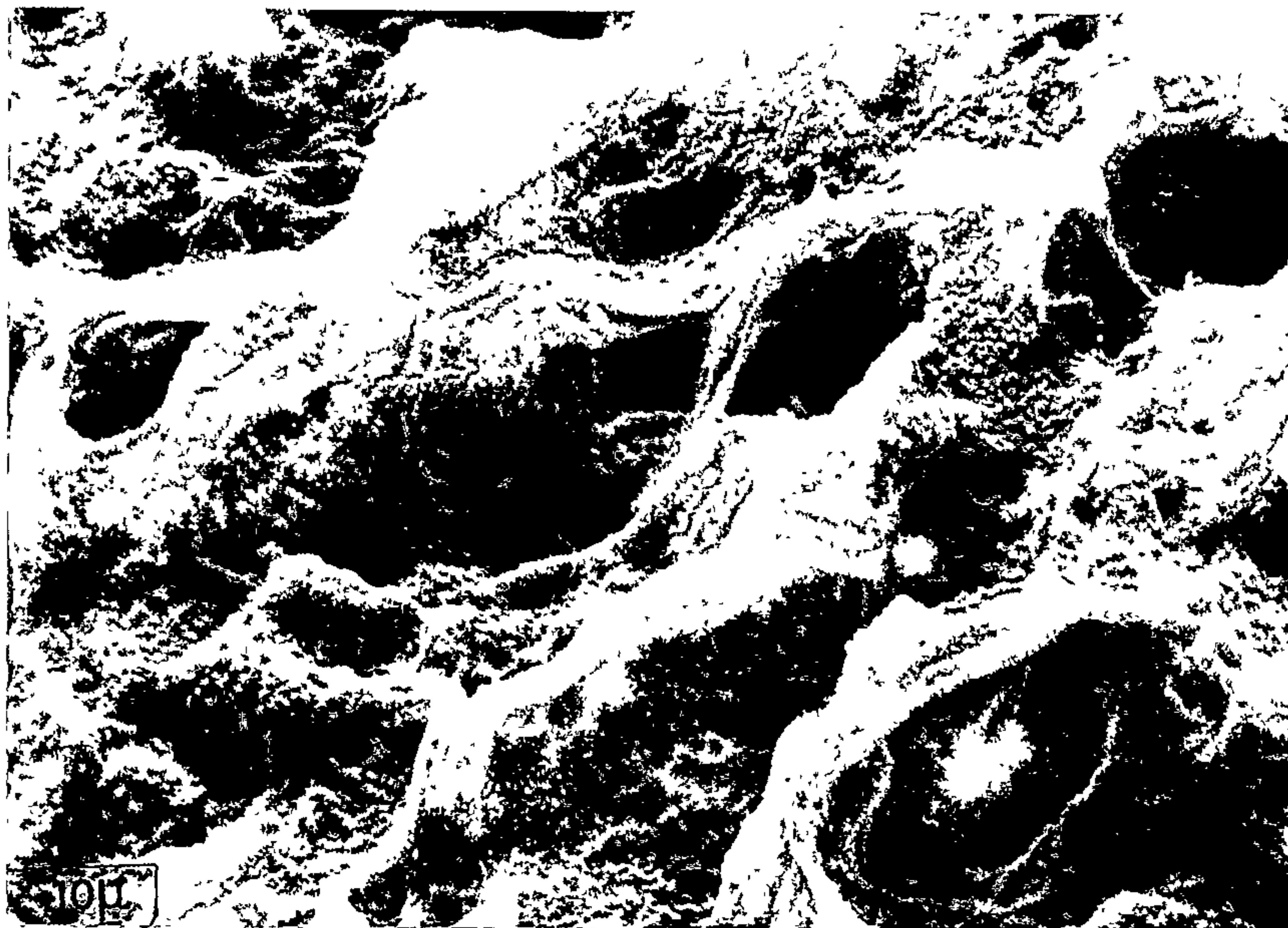


Fig. 29 - Concise Magnification 2000X.

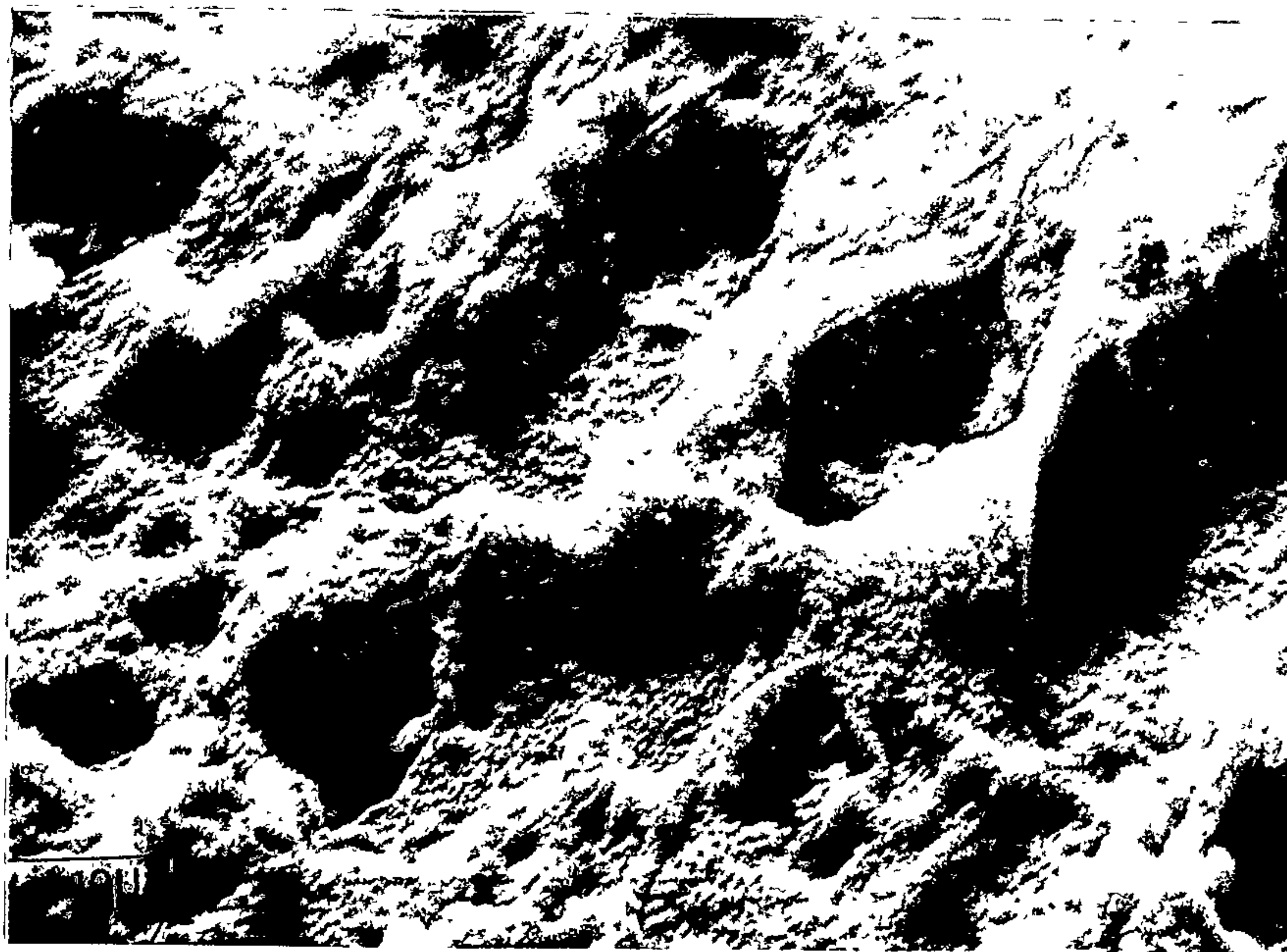


Fig. 30 - Concise Magnification 2000X.



Fig. 31 - Concise Magnification 5000X.



Fig. 32 - Concise Magnification 5000X.

CHAPTER 5SUMMARY AND CONCLUSIONS

The bonding of orthodontic attachments to dental enamel shows a development from a situation of experimentation to one of clinical feasibility and predictable consistency. These qualities are obtainable from a number of chemically and physically different adhesive materials provided that the enamel surface is adequately pretreated.

This investigation was undertaken to evaluate any differences in:

- Bracket failure rates
- Gingival response.
- Caries rate
- Patient acceptability
- Clinical time required

between the direct and indirect bonding techniques.

The results showed that:

- a) There was no difference in failure rate between either technique;
- b) molar attachments failed more readily than those of premolars;

- c) molar attachments failed more readily than those of anteriors;
- d) premolar and molar attachments as a group failed more readily than those of anterior teeth;
- e) there was no difference in failure rates between the maxillary and mandibular dental arches irrespective of the technique.
- f) clinically, the indirect technique was approximately 25 per cent faster than the direct bonding technique. This was measured from the time of prophylaxis commencement to the completion of clean-up procedure.
- g) the gingival response was identical with both techniques.
- h) the caries rate over a twelve month period was found to be almost negligible and identical for both techniques. It should be stressed that regular fluoride applications were given and that the patients were drawn from an area where the water supply was fluoridated.

- i) the indirect technique was easier for the operator especially in the posterior segments but involved a more extensive clean-up procedure than the direct technique. It should be stressed that both techniques were readily accepted by the patient.
- j) it was advisable not to bond attachments to molars due to the significant failure rate which resulted in inconvenience to both the patient and the operator while at the same time jeopardising the success of the treatment.
- k) it was advisable to bond premolars in non-extraction cases and cases where the necessity to rotate premolars was not anticipated. Bonding to premolars was found to be contraindicated where short clinical crowns were evident or occlusal interferences present.
- l) it was preferable to bond all anterior teeth as the failure rates for either technique were considerably lower than those experienced with conventional banding. More importantly, the bonding of anterior teeth was found to be preferred by both the patient and the operator for reasons of aesthetics, convenience, comfort

of the patient and avoidance of need for separation.

The pilot scanning electron micrograph (S.E.M.) study showed a greater penetration of the enamel surface by an adhesive which used a low viscosity sealant than an adhesive which did not employ a low viscosity sealant. Therefore, one has to question the use of adhesives which employ a sealant stage because the residual adhesive which is left in the tooth structure after debonding increases the possibility of potential discolouration. This potential for discolouration would appear to be further increased by the use of a methyl methacrylate adhesives as these are less colour stable than the BIS-GMA resins especially if they employ a low viscosity sealant stage.

Although it can be concluded that bonding of orthodontic attachments is practical, convenient and predictable for anterior and in most cases premolar teeth, there remain a number of questions which further investigations have to answer before bonding becomes the routine procedure of orthodontist:

- a) The long and short term effect of debonding on the enamel surface?

- b) The best method of debonding for a particular type of adhesive on a particular type of tooth?
- c) The long term effect of depth of adhesive penetration into the enamel surface?
- d) The long term colour stability of the various types of adhesive used?

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