Decalcification occurring during banded orthodontic treatment and its prevention.

Robert Alexander Smith B.D.S. (Hons) - Syd. Uni.

A thesis submitted in partial
requirement for the degree of
Master of Dental Science.

Department of Preventive Dentistry,
Faculty of Dentistry,
University of Sydney,
New South Wales,
Australia.
1981.

DEDICATION

This thesis is dedicated to my wife Jan, for her love and understanding during its preparation, to my son, Bradley, and to my family for their support always.

In loving memory of Pop (24.12.1901 - 26.10.1981)

ACKNOWLEDGMENTS.

Appreciation is extended to the following for their assistance in the preparation of this thesis:

To Associate Professor K. Godfrey, Department of Preventive Dentistry, University of Sydney for his supervision and helpful advice.

Many thanks are due to Dr. G.G. Craig, Senior Lecturer in Preventive Dentistry, University of Sydney for his guidance in the preparation of the original work.

Also I would like to acknowledge the help afforded by Associate Professor P.D. Barnard, Department of Preventive Dentistry, University of Sydney in the statistical evaluations.

I wish to express my sincere gratitude to Dace Freijs, John Brabant, Ian McNeill and Jim Smyth for their comradeship and help throughout the two years of our studies.

I am grateful for the assistance of Mrs. I. Starrett in typing the original draft of this thesis.

Financial assistance from the Health Commission of N.S.W. and the Commonwealth Postgraduate Course Awards Scheme was invaluable.

Finally I wish to thank the librarians, Joan Thwaite and Rod Joynes and the photographers Robert Johnson and Robert Van Luyn for their contributions.

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INTRODUCTION.

Although direct bonding of orthodontic attachments is replacing conventional banding in the anterior region of the mouth, it appears that banding of the teeth has distinct advantages in the posterior regions (Zachrisson, 1978a; Zachrisson, 1978b). Orthodontic patients have an increased risk of decalcification of dental enamel occurring under and around conventional banding (Shannon, 1972; and Shannon and Miller, 1972). Obviously the magnitude of any iatrogenic damage will influence an assessment of the need for orthodontic treatment. If the injuries to teeth are considerable, a reluctant attitude to orthodontic therapy would be recommended. Consequently the aim of all operators should be to minimise any such treatment-induced changes (Zachrisson, 1976).

Few well-controlled clinical studies have reported on the incidence of decalcification occurring during orthodontic therapy - for review, see Shannon, St. Clair, Pratt and West (1977). The results of these studies have shown widely varying figures depending on the methods of scoring lesions and the effects, if any, of preventive measures employed in the study. The reports range from very minimal to 58% of patients receiving orthodontic treatment being affected (Stratemann and Shannon, 1974). All the studies reported have been carried out in areas where the communal water supply contains less than optimal levels of fluoride. No reports appear on the incidence of decalcification occurring during orthodontic treatment in areas of optimally fluoridated water.

A number of procedures, used in combination, are necessary if decalcification is to be reduced to the lowest possible levels during orthodontic therapy - see Fitzsimons (1969) for review. The most widely accepted procedures to reduce the incidence of the caries process in the general population is the use of fluoride-containing materials. It would appear appropriate that the incorporation of a programme of preventive dentistry involving the use of fluorides might be effective in reducing the process during orthodontic treatment. In vitro testing by Tillery, Hembree and Weber (1976) showed that single application of fluoride solutions was less effective than coatings in preventing decalcification under loosened orthodontic bands. It appears, however, that the majority of authors consider that constant re-exposure is necessary to gain maximum benefits from the use of fluoride materials (Ericsson, 1977).

The purposes of this study are twofold:

i) To gain some idea of the incidence of decalcification occurring on maxillary and mandibular molar teeth which have been banded during orthodontic therapy, in patients who have had thirteen years exposure to optimal levels of fluoride in drinking water.

ii) To examine by in vitro testing whether constant re-exposure to low concentration fluoride solutions will prevent the formation of decalcification under loosened orthodontic bands.

CHAPTER 1.

DECALCIFICATION OCCURRING DURING ORTHODONTIC TREATMENT.

1.1 HISTORICAL BACKGROUND.

Early workers concerned about the "etchings" which showed following the removal of orthodontic bands focused attention on the possible effects that the materials used to secure the bands to the teeth may have on the underlying enamel. Lefkowitz and Bodecker (1938) showed that dyes penetrated the enamel of the teeth of dogs only in areas which were subjected to the action of oxyphosphate cement.

Later Lefkowitz (1940), utilised the teeth of adults that were anatomically intact and were to be extracted for reasons other than caries. He cemented orthodontic bands on the teeth in vivo. Seven days later the teeth were extracted and ground sections were made and examined by means of Grenz rays. Of eighteen cases in which cement was used, fifteen showed evidence of decalcification in localised areas. Two cases cemented with silicate cement were most marked whilst the three cases sealed with gutta percha showed no decalcification. Lefkowitz concluded that the dental cement decalcifies enamel.

In a later article by Docking, Donnison, Newbury and Storey (1952) the results of Lefkowitz (1940) were questioned. They noted that, in the experiments, although the bands were placed around the complete tooth, etching is shown only on the proximal surfaces. They contend that although the author does not indicate whether this was true of the tooth sections not shown in this paper there is a possibility that being on teeth of adults (thirty five years and over), the sites of etching may correspond to incipient or arrested caries or repeated attack by acids formed by plaque in interproximal areas. Thus the enamel may have been rendered more susceptible to attack by the acid cements as a result of these conditions. Lefkowitz himself suggested the appearance of decalcification in localised areas is due to either the loss of cuticle in certain areas or due to variations of natural resistance of the tooth to caries.

Castello, Massler, Monteleone and Suher (1948) supported the findings of Lefkowitz (1940). They investigated the effects of zinc phosphate cement on enamel surfaces. They demonstrated that all enamel surfaces exposed to the action of various mixes of cement were more or less affected, the etching being more pronounced in the ground surfaces than unground ones, and that the cement liquid alone etched the enamel markedly and uniformly. The variation between ground and unground enamel they explained as being due to a "protective film" which prevents, to some extent, the decalcifying action of the cement mix.

Gross (1951) believed that the work of Lefkowitz (1940) and Castello et al (1948) was not satisfactory in that no attempt was made to control the mixing of cements for band cementation (and hence did not reflect the means usually used to cement orthodontic bands). He also noted that the experiments were carried out on adult teeth with more mature, acid-resistant teeth than those of adolescent children.

Gross used pairs of teeth of orthodontic patients requiring extractions, leaving one of each pair as the control and banding the other for seven days. He found no new areas of decalcification in any of the twenty teeth studied and concluded that cement, when mixed according to the controlled method recommended, did not cause decalcification. Unfortunately he did not try the effect of using cements mixed according to presumably unsatisfactory techniques but suggested that this should be done in future experiments, along similar lines.

Docking, Donnison, Newbury and Storey (1953) also assessed the effects of cementing orthodontic bands on underlying enamel. By the use of a surface finding meter and/or a replica method they found that orthodontic cements generally did not attack the surface of sound tooth enamel. Only very thin mixes with a consistency of 0.5 gm./ml. showed definite evidence of surface decalcification. This very thin mixture would be useless in practice, however, because it sets very slowly, if at all.

They did find, however, that a 1.0 gm./ml. mixture, which did not etch the enamel surface, did cause the enamel to take up dyes such as methyl violet. This may indicate that although the surface enamel remains intact, as shown by the experiments, subsurface decalcification may result from the use of these thin cement mixes.

Seniff (1962) reported in very subjective terms on the results of his experiments to determine the effects of "thin, medium and thick" mixes of zinc phosphate cement. He found that all surfaces were more or less etched. No data, however, is given and only small samples of teeth were used (32 teeth in the complete trial).

Fitzsimons (1969) examined the effects of silicophosphate, zinc phosphate and black copper cements on the etching of enamel. He found that all cements failed to produce etching of intact enamel when mixed in clinically acceptable liquid/ powder ratios.

Wisth (1970) used a P^{32} uptake method to evaluate the degree of decalcification occurring in thirty experimental teeth. He first cemented a pinledge-retained gold plate to the mesial half of the buccal surface of teeth to be tested. These remained in place for three months. At the completion of this time the plates were removed, cement scraped off, retention holes filled with amalgam, and orthodontic bands fitted, but not cemented to the teeth. The idea was to encourage the process of decalcification as would occur under a loose band. The bands remained in place for four weeks. The P^{32} uptake method was used to examine the amount of decalcification occurring in the mesial and distal halves of the teeth. He found that less decalcification was found in the areas which had been covered by cement. He concludes:-

"Under certain conditions it appears that the cement in some way protects the enamel from decalcification".

Skibell and Shannon (1973) found that placing zinc phosphate cement in contact with enamel produced a reduction in the enamel solubility by 30.9%. They contend that this apparent solubility reduction is simply a matter of fragments of the set cement remaining on the tooth surface after bulk cement removal. This would reduce the amount of tooth surface available to the decalcifying solution and thus lower the amount of mineral withdrawn. The extreme difficulty of removing cement from the treated enamel surface has been reported by Docking, Donnison, Newbury and Storey (1953). Skibell and Shannon thus believe that this effect may also be the cause of the apparent reductions noted in the decalcifications on the side receiving the pinledge plate in the Wisth (1970) experiment.

Thus it appears that the early reports of the deleterious effects of cements on enamel surfaces have been refuted. Recent findings indicate that the cements, mixed in the consistency routinely used in the clinic, do not predispose decalcification of enamel. The major emphasis in the prevention of decalcification both under and around bands to-day centres on the dual processes of increasing the enamel resistance to acid attack by cariogenic bacteria, and the continual efficient removal of plaque deposits around the appliances.

1.2 INCIDENCE OF DECALCIFICATION OCCURRING DURING ORTHODONTIC TREATMENT

Sved (1946) stated that:-

> "In many instances the orthodontist is held responsible for these decalcifications, not only by the public but also by the dental profession in general."

This concern by the general public and the family dentist that orthodontic therapy causes an increase in the number of cavities, led researchers to investigate caries incidence in orthodontically treated patients.

Noyes (1937) studied patients between the ages of eight and fifteen years who were receiving orthodontic treatment. Caries assessment was based on radiographic evidence that the enamel had been penetrated. The average number of cavities in eighty three children examined prior to treatment was 2.65 per child. The seventy patients examined subsequent to the completion of treatment (an average 3.8 years later) had an average of 3.75 cavities. Thus the caries increase was approximately 0.25 new cavities per year. Noyes concluded that the average 0.68 cavities per year found during the treatment and retention period was only slightly higher than the 0.62 cavities per year observed in the same children occurring before they were subjected to orthodontic therapy. Noyes however, lacked an adequate control group.

Dolce (1950) came to similar conclusions to Noyes. He studied replies to questionnaires sent to dentists who had referred 102 patients for orthodontic treatment. Answers indicated that caries incidence during orthodontic therapy was not generally increased. It must be noted that both these studies only concerned lesions that required restoration, smaller defects were not recorded.

Meyers (1952) studied 548 teeth clinically before treatment and subsequently after six months of orthodontic banding, to ascertain the incidence of new decalcification. Prior to treatment the teeth were dried and all marks of any type including etchings or precarious lesions were charted. 275 of the teeth on the right hand side of the mouth were coated with copalite varnish before the bands were cemented. The 263 teeth on the left hand side of the mouth had no varnish applied. All bands were cemented with zinc oxyphosphate cement.

When the bands were removed six months later the teeth were dried and any additional etchings were recorded on the master chart. Meyers found that overall 79 teeth were found to have new areas of decalcification (14.4%). Of the uncoated teeth, 63 showed new marks. Meyers quotes this as 27.4% but I calculate it to be 23.9%. The 275 coated teeth had only 16 affected by new decalcifications (5.9%).

This experiment may have been better designed if right and left sides had been mixed for control and experimental groups in alternate mouths to prevent any bias that having all test groups on one side of the mouth may induce. Unfortunately, only a small number of the first molars were tested in this report. Thirteen control and test upper first permanent molars showed that 38.4% of the control and 7.6% of the test teeth had increased areas of decalcification. These new marks were found mostly on the lingual side. 45.4% of the eleven control lower first permanent molars and 0% of the twelve controls were similarly affected. All these new areas were found on the vestibular (buccal) side. By far the greatest incidence of new decalcification was found on the lingual side of maxillary laterals.

Bach (1953) studied a large number of teeth (4,468) prior to banding and found an average of 1.3 defects per tooth.

These defects included caries, restorations and various types of decalcification. After the completion of orthodontic therapy, he reports an increase of 0.75 lesions per tooth. However, I believe this calculation to be incorrect. Rather, there is an increase of about 0.18 lesions per tooth which is a 13.4% increase per tooth. There was no non-orthodontic control group included in this study.

Ingervall (1962) attempted to study caries frequency in orthodontic patients by comparing a control group with sixty patients who were under fixed banding therapy (consisting of at least three bands in one or both jaws). In addition to the fixed appliances, most of the patients had also been treated with removable and/or functional appliances. The control and treatment groups were matched to eliminate as far as possible age and sex differences. No fluoride applications were reported in either group.

Ingervall found that caries frequency was significantly higher among those children who had received orthodontic treatment when precarious lesions were included in the registration. When precarious lesions were excluded, the caries increase became less and was not statistically greater than the control. It must be pointed out that the fixed appliances were only in place for a relatively short period of twelve to eighteen months, and also that only twenty nine patients had any fixed appliances in the lower arch.

Ingervall also noted that the distribution of carious lesions was influenced by the presence of the orthodontic appliances. He considered that generally bands helped protect the teeth from caries development. He did, however, point out the danger under loosened bands, and emphasised the importance of careful examinations for this defect at each patient visit.

Muhler (1970) studied caries incidence in 697 children over a two year period. He allotted the children to three groups. One group, who had no orthodontic treatment, acted as controls. One orthodontic group, who were treated by thirty five different orthodontists, used a non-tin - non-fluoride dentifrice during treatment. The other group received a stannous fluoride prophylaxis prior to banding and also used a stannous fluoride containing dentifrice. At the conclusion of the study it was found that orthodontic treatment did significantly increase the DMFS scores in the group not using the stannous fluoride dentifrice. Further, it was found that the lesions were found more on the buccal surfaces in the orthodontic groups whilst the proximal surfaces were seemingly protected.

Zachrisson and Zachrisson (1971a) found that an orthodontic group receiving a topical application of sodium fluoride prior to treatment, using 0.2% sodium fluoride mouthrinses twice a week and receiving thorough toothbrush instruction throughout treatment had no greater caries increments after the completion of treatment than a non-orthodontic, non-fluoride receiving control group. They did, however, note a shift in the distribution of lesions from mainly proximal in the control group to being more on the partially covered vestibular and lingual surfaces in the orthodontic group. The authors conclude that orthodontic therapy does not greatly increase the incidence of carious lesions but may cause a change of position in their occurrence.

The design of this report is somewhat misleading, because the experimental and control groups have two variables distinguishing them. The first is that aspect which the authors are attempting to evaluate i.e. one group has orthodontic bands, the other has none. The second is that the experimental group has continuous fluoride applications and the benefit of oral hygiene instructions which the control group does not. Consequently the results gained may indicate either the banding has little effect on the overall caries incidence, as indicated by the authors, or it may suggest that fluoride therapy in conjunction with oral hygiene programmes can reduce caries incidence during orthodontic therapy to a similar level as non-treated groups.

Shannon (1972) and Shannon and Miller (1972) in a review of the literature consider that although points of view are controversial, it appears clear that orthodontic treatment brings about a significant caries risk.

Stratemann and Shannon (1974) report in a control group of 110 orthodontic patients who were given oral hygiene instruction prior to and during treatment 58% showed areas of decalcification, mainly in the gingival areas.

Wisth and Nord (1977) reported the caries experience of all children living on an island outside Bergen, Norway who were born in 1957 and 1958. They compared the DMFS increments of the twenty six boys and twenty six girls who had received orthodontic treatment with fixed appliances in both jaws to the remaining fifty eight girls and fifty three boys who received no orthodontic treatment. The DMFS counts were recorded eighteen months to two years after removal of fixed appliances. The orthodontic patients were instructed in toothbrushing with the horizontal scrub technique at the time of band cementation, and were given 0.05% sodium fluoride mouthrinses daily. They also brushed their teeth with a 0.2% sodium fluoride solution three times a year at school. The control group received no systematic tooth-brushing instruction, but brushed their teeth with 0.2% sodium fluoride three times per year at school. They found, under these conditions, that caries experience was somewhat less in the orthodontically treated group. Unfortunately this study does not report the caries experience of the group before treatment. It may be, as reported by Hollander and Ronnerman (1978), that the two groups had significant differences in caries increments prior to treatment. Also, once again, the possible effects of the fluoride therapy and oral hygiene, as noted by the authors, may have been the factor that caused the level of carious lesions recorded.

Magness, Shannon and West (1979) quote an unpublished study which reports the incidence of decalcification occurring in an orthodontically treated group as being 64.1% of the 39 patients studied.

It is evident from the above reports that investigators disagree on the effects of orthodontic therapy in relation to the incidence of caries and decalcification. Much of this disagreement may be related to the differences in the protocol of the studies. For example some studies looked at the incidence of lesions immediately after removal of appliances, some years after retention. Some studied only the carious lesions requiring filling, whilst others included decalcified areas not requiring restoration. All the reports reviewed were carried out in areas where communal water supply contained less than optimal levels of fluoride. No reports were found on the incidence of decalcification and/or caries in orthodontically treated patients who had exposure to optimally fluoridated water supplies.

1.3 CLASSIFICATION OF DECALCIFICATION.

In referring to tooth structure, it is impossible to define decalcification and caries separately. Gould Medical Dictionary (1979) defines decalcification as:-

> "Withdrawal or removal of the mineral salts of bone or other calcified substance."

Dental caries is defined as:-

> "A localised progressive and molecular disintegration of teeth believed to begin with the solution of the tooth structure by lactic and pyruvic acids which are the product of enzymatic action of oral bacteria upon carbohydrates."

Thus basically the two terms are describing different stages of the same process. Noyes (1937) states that decalcification is a pre-carious lesion. Bach (1953) agreed and said that:-

> "decalcified areas are potential caries and caries preclude fillings."

Bach predicted from his study that one of the ten decalcified areas would be filled within three to five years of its appearance. Burnett and Sherp (1962) simply state:-

> "Decalcification is the initial and crucial step of the carious process."

Many attempts have been made to classify decalcifications. Most authors attempt to classify the pheonomenon in terms of position on the tooth in which the lesion is found or alternately try to institute a scale of severity. Some early authors such as Noyes (1937) and Meyers (1952) simply determined if decalcification was present or absent.

Sved (1946) noted that decalcification differed in character and appeared in different form in various locations on teeth.

He devised an eight class decalcification system. By using this classification Sved believed both the probable cause as well as the prevention of each could be determined.

Sved noted that the incisal third of the tooth seldom becomes decalcified and believed that this was because of the cleansing action of the incised food. However, the middle and cervical thirds represent the danger zones which may be very severely affected. The classification is based on attempting to further define the position of the etching on smooth enamel surfaces. The classification is:-

a) Class I - occur on the cervical third of the labial or buccal surfaces of teeth, where the enamel is exposed to the fluids of the mouth and food accumulations. The prevention of this type of decalcification Sved believed, was largely in the hands of the patient, by the institution of proper oral hygiene procedures - see Fig. 1.

b) Class II - occur under bands - see Fig. 2 and Fig. 3. Any part of the tooth covered by the band may be affected when a band comes loose or the cement is dissolved from under it. Sved believes that well cemented bands act as a protection to the enamel, but a loose band represents the gravest danger. The prevention of Class II decalcification is entirely in the hands of the orthodontist.

c) Class III - occur under bands through the action of phosphoric acid in the cement. As we have seen, at one time all decalcifications were thought to be caused by cement. Sved, however, believed that this was a rare type of decalcification seen only in 0.1% of cases.

d) Class IV - occur under bands on the lingual surface of maxillary anterior teeth - see Fig. 4. They are brought about by the forces of mastication crushing the cement

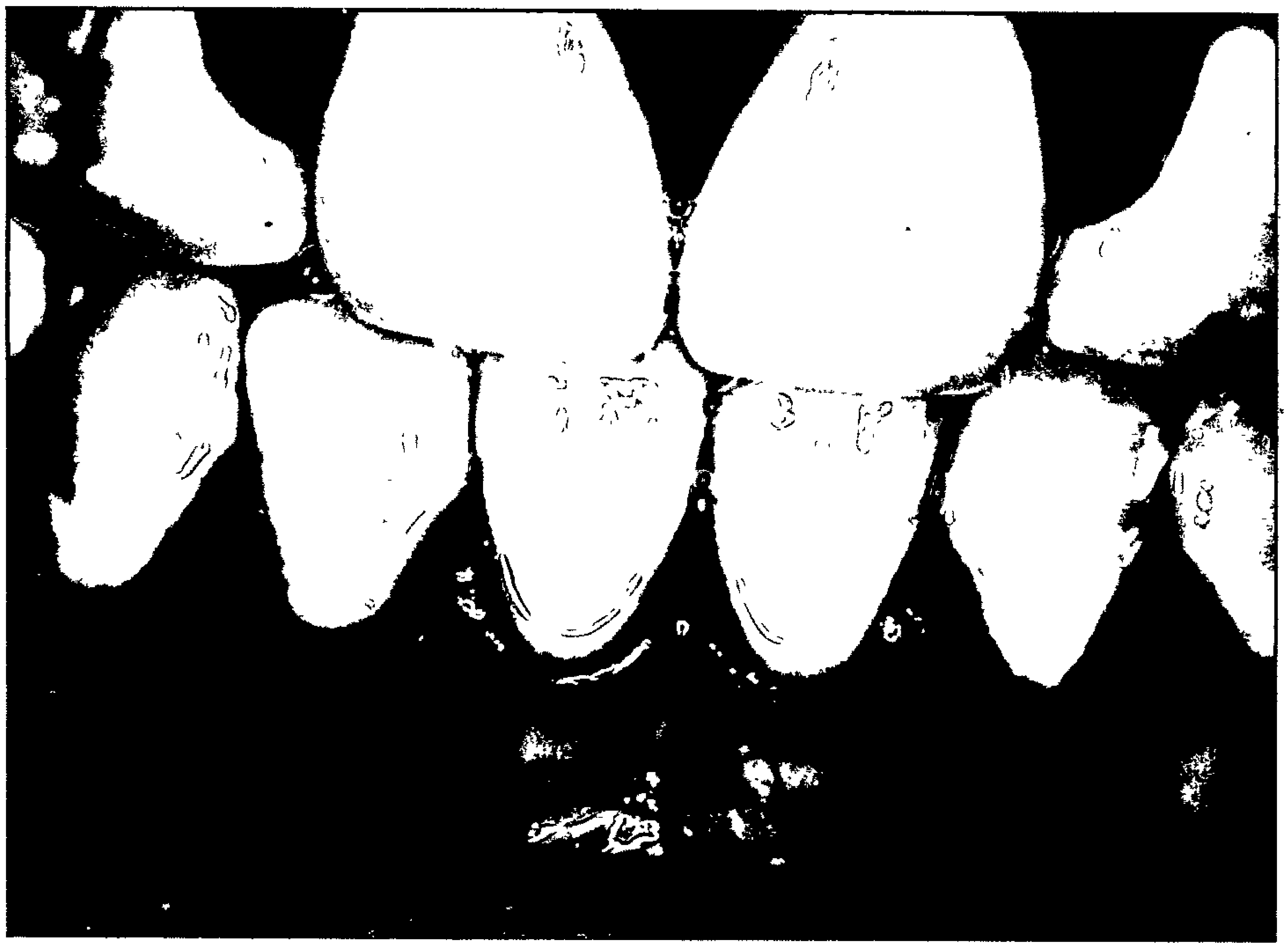

Fig. 1 Class I decalcification on lower incisor teeth.

Fig. 2 Class II decalcification on a lower molar.

Fig. 3 Class II decalcification on an upper cuspid.

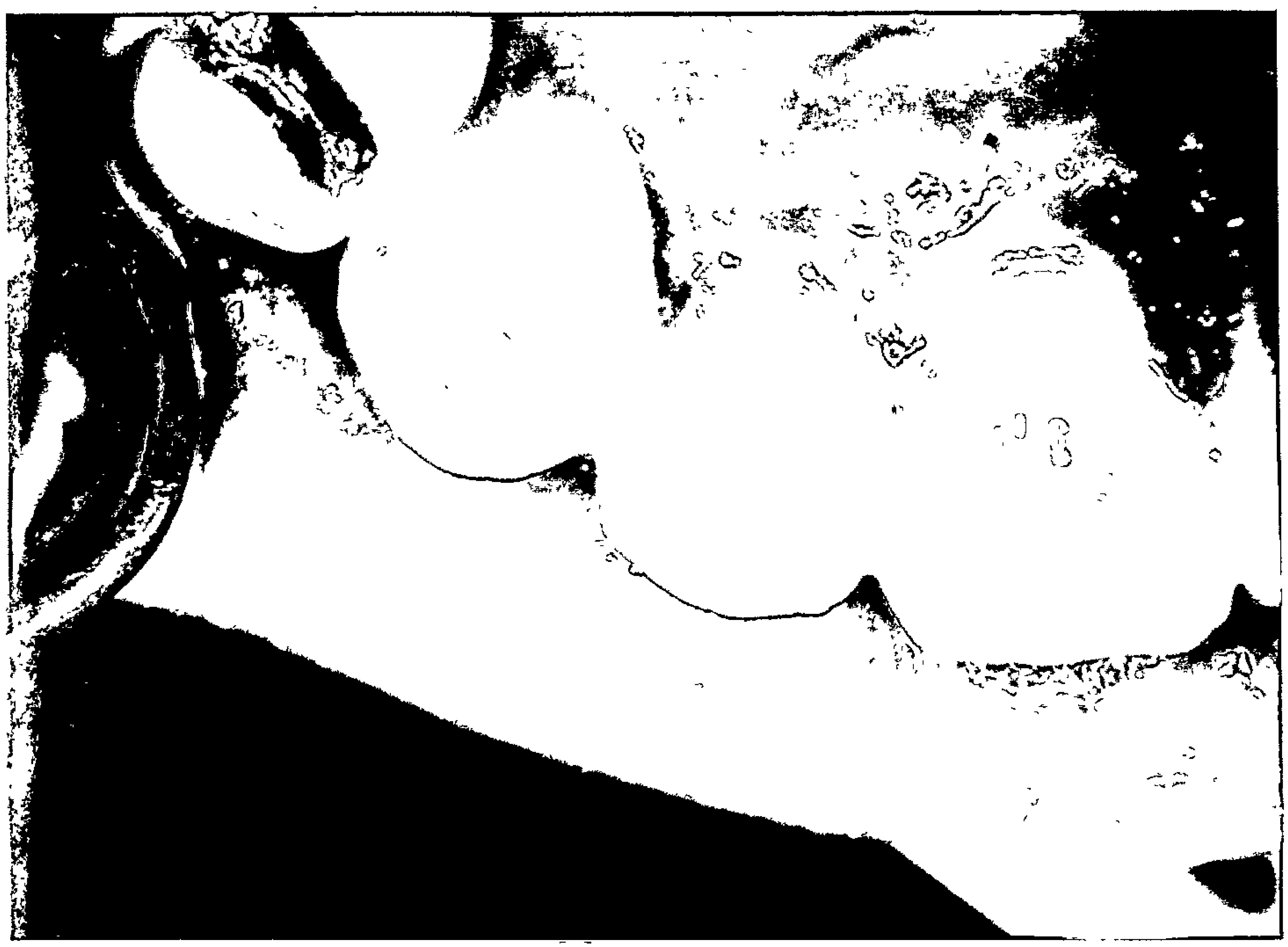

Fig. 4 Class IV decalcification on an upper lateral incisor.

under the band. The prevention of this class of decalcification depends upon the elimination of masticatory stresses on the anterior bands.

e) Class V - occur at the cervical edges of bands. They are caused by the accumulation of food particles (we might consider more likely plaque to-day) along the edges of bands - see Fig. 5. Meticulous care by the patient is needed in order to prevent this decalcification.

f) Class VI - occur on the lingual of maxillary molars and buccal of mandibular molars along the occlusal edges of bands. They appear as white lines or triangular areas and are due to the crushing of cement by occlusal stresses - see Fig. 6. These decalcifications may be prevented by properly constructed bands. Sved believed the occlusal edges should be trimmed low enough to prevent bite interference.

g) Class VII - occur along cervical and occlusal edges of bands in mouths receiving meticulous care. These, Sved believed, were not true decalcifications but the grooving of enamel by heavy toothbrushing. Again he believed that these may only be seen in about 0.1% of cases.

h) Class VIII - occur under the various kinds of removable bite plates and retaining appliances. They may be found anywhere on the tooth but generally on the lingual surfaces. Again proper toothbrushing is needed to prevent Class VIII decalcifications.

I think that, if Class III, and Class VII decalcifications are removed from this classification then even to-day it probably represents the most clinically useful method for looking at the "cause" and means of prevention under and around orthodontic banding.

Most other classifications of decalcification tend to focus

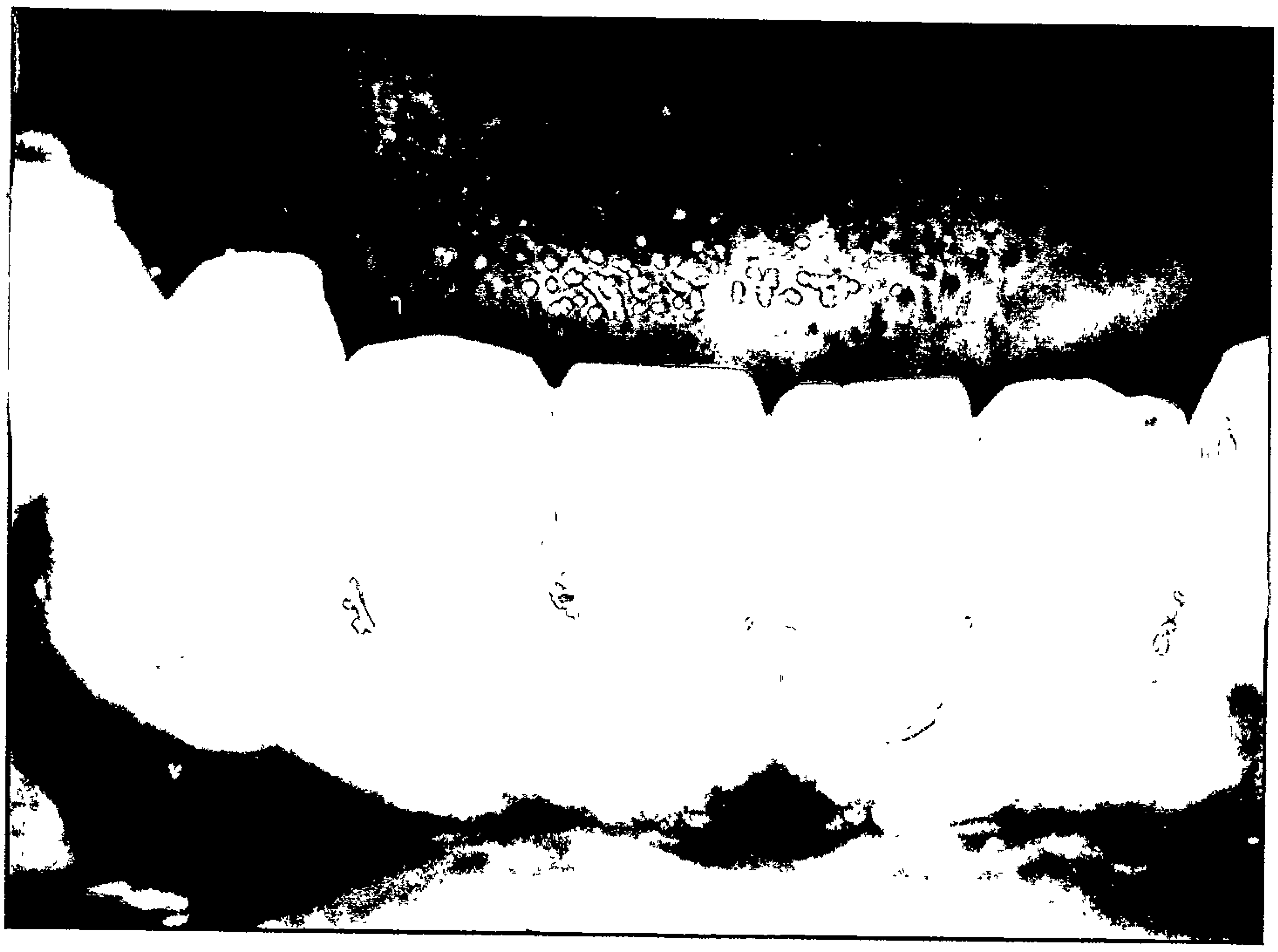

Fig. 5 Class V decalcification on lower incisor teeth.

Fig. 6 Class VI decalcification on a lower molar.

on the extent or severity rather than the site of the lesion. For example Bach (1953) divides the decalcifications recorded in his study into white lines, white spots and white surfaces.

More recently Zachrisson and Zachrisson (1971a)(1971b) have devised a classification of severity.

Score

0 - surface appears intact.

1 - whitish demineralisation without cavitation.

2 - whitish demineralisation with beginning cavitation of enamel.

3 - cavitation that cannot be removed by cautious grinding.

Dimitriadis, Sassouni and Draus (1974), Shannon, St. Clair, Pratt and West (1977) and more recently Magness, Shannon and West (1979) all use their own classifications which are more or less variations of that of Zachrisson and Zachrisson (1971a) (1971b) presented above. Others such as Hirschfield and Johnston (1974) simply use an ordinal scoring system of severity from zero to three in half unit increments and take the average score of four separate observers. Even the authors admit the drawbacks of using this rather subjective scoring system. However, they contend that this is the method most nearly approximating that used by clinicians in their everyday practice.

Dimitriadis, Sassouni and Draus (1974) found that severity scoring based on a similar classification to that of Zachrisson (1971a) (1971b) did not show good agreement with demineralisation scored by radioisotope uptake of the lesion by P^{32}.

Thus although recognising the inadequacies of the visual scoring method it would appear that this is the most widely used and accepted approach for scoring the severity of decalcified lesions in vivo.

CHAPTER 2.

THE PREVENTION OF THE CARIES PROCESS BY THE USE OF FLUORIDES.

Decalcification under and around orthodontic banding may be considered to be the initial stage of the carious process - Noyes (1937); Bach (1953); Ingervall (1962); Burnett and Scherp (1962) and Zachrisson (1978a). Many authors have suggested that this increased risk of attack is best offset by a programme involving the use of fluorides. Indeed Shannon, St. Clair, Pratt and West (1977) and Skibell and Shannon (1974) consider that all orthodontic patients require an individual preventive programme in order to eliminate the incidence of decalcification and decay.

Very soon after Dean's discovery of the correlation between the fluoride content of water and the prevalence of caries, it was thought that topical application of fluoride to the surface of the teeth would have a corresponding prophylactic effect. Hundreds of clinical and laboratory studies since then have been conducted to evaluate the effectiveness of different methods of fluoride administration. These investigations have led to the development of the various fluoride application methods available to-day. Although topical fluorides are in widespread use, in general dentistry, there still remains considerable clinical investigation to be carried out before the full value of these agents can be assessed precisely. Conclusive evidence is still lacking as to whether or not a particular regime is superior to others. In particular, very few well controlled studies have been reported on the relative benefits to be obtained from different techniques during orthodontic therapy. No orthodontic studies have reported possible benefits in areas where optimal water fluoridation is present, as in the Sydney area. The planning of a rational fluoride therapy for the orthodontist anxious to introduce optimal preventive programmes in his practice is further complicated by the continuous development of new techniques and products.

In reviewing possible means of preventing decalcification during orthodontic treatment by the use of fluorides, studies ranging over a two to three year period will be emphasised. This is the average period of time that an orthodontic patient would be subjected to increased caries risk. Unless otherwise stated all studies cited were carried out in areas in which the communal water contained low fluoride i.e. less than 1 p.p.m.

Basically protection by fluorides may be utilised:-

1) Prior to banding of teeth:
   a) Professional use of fluoride-containing prophylaxis pastes prior to topical fluoride applications.
   b) Professionally applied solutions and gels containing fluoride.
   c) Patient administered fluoride-containing dentifrices.

2) During banding procedures:
   a) Use of fluoride-containing cements.
   b) Use of fluoride-containing varnishes.

3) During active treatment:
   a) Patient administered solutions and gels containing fluoride.
   b) Professionally administered solutions and gels containing fluoride.

2.1 PRIOR TO BANDING OF TEETH

2.1.1 Professional use of fluoride-containing prophylaxis paste prior to topical fluoride applications.

Before the application of most professionally applied topical fluorides plaque is removed. Gron and Brudevold (1967) and Tinanoff, Wei and Parkins (1974) believe the presence of debris and salivary films prevent fluoride penetration into the enamel and hence advocate its removal prior to topical applications. Other studies by Bruun and Stoltze (1976) and Joyston - Bechel, Duckworth and Braden (1975) have shown that the amount of fluoride incorporated into the surface layers of enamel is independent of the presence of plaque. Undoubtedly, the use of cleaning and polishing pastes lead to the removal of thin layers of surface as shown by Vrbic, Brudevold and McCann (1967). Moreover, this outer layer is usually richest in fluoride content.

Studies by Bixler and Muhler (1966), Vrbic and Brudevold (1970) and DePaola and Mellberg (1973) have shown marginal reductions in caries increments associated with the incorporation of fluoride (in various forms) in prophylaxis pastes. Other reports by Horowitz and Lucye (1966) and Scola and Ostrom (1968) failed to find any caries reducing effects of fluoride containing prophylaxis pastes. A most dramatic reduction of dental caries was reported by Axelsson and Lindhe (1974). Children were given a dental prophylaxis with a paste containing five per cent monofluorophosphate every two weeks. After two years they were found to have virtually plaque-free teeth, negligible gingivitis and practically no new caries. Unfortunately fluoride application based on polishing with rotary instruments appears little suited to orthodontic treatment once fixed appliances are placed.

As pointed out by Brudevold and Naujoks (1978), although it is not clear whether a fluoride prophylaxis paste enhances the effect of topical application, especially in an area with optimally fluoridated water supplies, there appear to be no contraindications to using a fluoride-containing paste as long as the two agents are not incompatible. Indeed, studies by Shannon (1970a), Shannon (1971), Shannon and Charlton (1974) and Shannon and McFarland (1974), indicate that sequential application of acidulated phosphate fluoride followed by stannous fluoride may in fact give added caries resistance to the enamel surface. This may suggest that the prophylaxis paste should contain acidulated phosphate fluoride and the subsequent topical solution contain stannous fluoride. Barenie, Ripa, Trummel, Mellberg and Nicholson (1976), however, failed to find any caries reduction in a study involving semi-annual applications of an acidulated phosphate flouride prophylaxis paste over a two year period.

2.1.2 Professionally applied solutions and gels containing fluoride.

Solutions.

A great number of studies have been undertaken to assess the effects of different fluoride containing solutions on caries increments. These studies report the results of various solutions at different concentrations, for varying periods of time and with different time intervals between application. The three most commonly used topical solutions are:-

i) 2% neutral sodium fluoride.

ii) 8-10% stannous fluoride.

iii) acidulated phosphate fluoride at pH about 3 and containing 1.2% fluoride.

i) Neutral sodium fluoride.

A survey of the literature (for reviews see Muhler, 1959; Weisz, 1962; Horowitz and Heifetz, 1970; Marthaler, 1971; and Horowitz and Heifetz, 1975) indicates that the recommended procedure and scheduling for the application of sodium fluoride as a topical agent has changed very little from that first developed by Knutson, Armstrong and Feldman (1947). They tested different fluoride solutions, concentrations and frequencies of application in a series of large scale studies that involved thousands of school children. In summary the major results of these studies were that a series of four applications with a 2% sodium flouride solution appears to give a maximum effect. Increasing the interval between individual applications in the series from about one week to three to six months decreases the effectiveness of treatment. Overall they found a reduction of about 40% in new carious teeth. They suggested reapplication after a three year period.

With some variation, 30% to 40% reductions in dental caries incidence in permanent teeth have been reported quite consistently. The major advantage of its use is that it is relatively stable and hence requires no fresh preparation for each patient. The taste is not unpleasant and hence is well accepted by most patients. The solution is non-irritating to the gingiva and does not cause discolouration of the teeth. The major disadvantage in its use as a professionally applied topical is that the patient must take four trips to the dentist within a relatively short time. This inconvenience, more than any other, has led to the more wide acceptance of other solutions for use in private dental offices.

ii) Stannous Fluoride.

The recommended application technique for stannous fluoride involves the isolation of the teeth with cotton wool and drying, following a prophylaxis. The solution is applied for four minutes. The recommended frequency of application depends on the patient's susceptibility to dental caries. Generally speaking, six monthly reapplications are suggested for caries-prone individuals and once yearly for others.

Much of the early work on the effectiveness of stannous fluoride was conducted by Muhler and his associates. Muhler (1959) in a series of clinical studies showed that 8% stannous fluoride applied annually was significantly more effective than four applications of sodium fluoride reapplied once each three years.

Mercer and Muhler (1961) compared three groups of children - a control, one receiving a single application of 2% sodium fluoride and the other a single application of 8% stannous fluoride. After twelve months the DMFS increments showed no significant difference between the control, and the group receiving the sodium fluoride application. The stannous fluoride group, however, had a DMFS reduction of 50% which was found to be statistically significant. The same authors examined the same solutions applied semiannually over a two year period (Mercer and Muhler, 1972). In this study they found sodium fluoride did have some caries reducing effect, but that this was still significantly less than the effect of stannous fluoride. It must be observed that the sodium fluoride was applied as a single application in each of these trials. As noted previously it was found by Knutson, Armstrong and Feldman (1947) that sodium fluoride should be administered in four successive applications to produce optimal effect. Thus the experimental design of these studies, I feel, favours the stannous fluoride solution.

Gish, Muhler and Howell (1962) examined the difference in DMFS and DMFT increments in groups of children receiving annual applications of 8% stannous fluoride and three yearly applications of 2% sodium fluoride. The sodium fluoride group received four applications of the solution within one week. They found over five years that the group receiving annual applications of stannous fluoride had 35% fewer DMF surfaces than the sodium fluoride group.

Other investigators have found stannous fluoride to be effective in reducing caries. However, the magnitude of the benefits reported by these workers has generally been less than that obtained by Muhler and his co-workers.

Jordon, Snyder and Wilson (1959) observed at the end of two years the effect of a single application of 8% stannous fluoride. They found a caries reduction of 37.85% in 420 children. Peterson and Williamson (1962) reported a 26% reduction of DMFT after two yearly applications with an 8% stannous fluoride solution over a control group. Harris (1963) similarly found a 23% reduction in dental caries in a half-mouth application of 8% solution semiannually. This study was carried out in an optimally fluorided area.

In contrast to the many favourable reports, a few studies have shown stannous fluoride to produce little or no anti-cariogenic effect. A study by Wellock, Maitland and Brudevold (1965) of children given a single application of 8% stannous fluoride solution failed to show reductions in incremental dental caries after one year. No reduction in DMFS was noted when 10% stannous fluoride was used as part of a two year study by Torell and Ericsson (1965). Horowitz and Lucye (1966) also failed to demonstrate any decay-preventive effect after one or two years in children treated annually with 8% stannous fluoride.

As can be seen the results obtained by various investigations are not consistent. It is important to remember when comparing results of different studies to note the conditions under which the tests were performed. For example, differences (in standard) may exist between observations made as part of a service programme and those carried out meticulously as a research project.

Certainly very extensive laboratory studies by Shannon (1970b), Shannon (1971), Shannon and Wescott (1976) and Shannon and Charlton (1974) indicate that stannous fluoride is very effective in reducing the solubility rate both of intact and partly demineralised enamel. However, as pointed out by Brown, Gregory and Chow (1977) and Gron (1977), although reduction of enamel acid solubility seems to be a desirable feature, it may not be equated with inhibition of dental caries. In fact, some highly effective rate-reducing agents against enamel etching do not inhibit dental caries.

When initially introduced stannous fluoride had several disadvantages compared with other topical solutions available. In aqueous solution the material was not stable; it underwent rapid hydrolysis and oxidation. These reactions reduce or eliminate the agent's effectiveness (Horowitz and Heifetz, 1975). Much of the inconvenience of needing to mix fresh solution for each treatment has now been overcome by the development of a procedure for stabilising stannous fluoride in solution with glycerine - Shannon (1969). Now stannous fluoride is available in a solution which does not require individual preparation.

A number of authors such as von Ehrenheim (1959), Hyde and Muhler (1963) and Harris (1963) have reported pigmentation of teeth following topical application with stannous fluoride. Indeed Wellock, Maitland and Brudevold (1965) considered that staining of the teeth treated with 8% stannous fluoride was of such proportions (60% of patients receiving the solution) that treatment was discontinued after one year of use. Muhler (1960b) and Hyde and Muhler (1963) were of the opinion that the brown pigmentation is an indication of arrested caries in decalcified zones. A further disadvantage of the use of stannous fluoride solutions is the rather unpleasant, astringent taste.

The major advantage, as reported by Horowitz and Heifetz (1975), in the use of stannous fluoride appears to be that the recommended interval of six to twelve months between re-application conforms well with the usual recall appointments of most practicing dentists.

iii) <u>Acidulated Phosphate Fluoride.</u>

The recommended procedures for applying acidulated phosphate fluoride (APF) solution is the same as that for applying stannous fluoride.

Initial testing by Brudevold, Savory, Gardner, Spinelli and Speirs (1963) indicated that powdered enamel acquired more fluoride from a solution of fluoride acidulated with phosphoric acid than from an equivalent solution of stannous fluoride or neutral fluoride. These findings prompted Wellock and Brudevold (1963) to carry out clinical tests on the effects of a single topical application of the substance. At the end of the two year study with annual applications, children in the test group demonstrated a 70% reduction in DMF surfaces compared with untreated controls. Further investigations were carried by Pameijer, Brudevold and Hunt (1963) who treated one side of the dentition with four topical applications of neutral 2% sodium fluoride and the other half with four applications of this solution dissovled in 0.15 M orthophosphoric acid. They found that less than half as many new carious surfaces were noted on the side treated with acid solution over a period ranging from three to fifteen months.

The beneficial effects found in later studies that have evaluated topically applied solutions of APF, have tended to be smaller than those obtained in the initial studies. Wellock, Maitland and Brudevold (1965) reported that at the end of two years, children treated annually with APF solution had developed 52% fewer DMF surfaces compared with children in a control group.

In a series of reports by Horowitz (1968), Horowitz (1969) and Horowitz and Doyle (1971) it was shown that annual applications of an APF solution reduced the DMF surface increments by 28% over a control group during a three year period. Seminannual applications reduced DMFS values by 41% compared to the same control group. Subsequently, Horowitz and Kau (1974) re-examined the group thirty and thirty six months after treatment had ceased. They found that the group which had received annual topicals still had 31% - and the group receiving semiannuals, 49% - less DMF surface lesions than the control group. Thus they maintained that an anticaries effect had been retained some three years after treatment.

Cartwright, Lindahl and Bawden (1968) obtained a 49% reduction of DMFT increments in children who had received four semiannual applications of APF solution. Unfortunately no DMFS increments were reported.

More recently laboratory tests by Shannon (1971) indicate that the enamel solubility reductions produced by enamel teated with topical applications of solutions of APF and stannous fluoride were similar in degree. This was confirmed by Shannon and Wescott (1976). They also found that the APF-treated teeth retained more of this solubility reduction than those exposed to stannous fluoride when the teeth were reintroduced into an acid environment.

The major advantages in the use of APF over stannous fluoride is that the material does not discolour hypomineralised tooth surfaces and the taste is more acceptable.

Gels.

Fluoride-containing gels for topical application in the dental office were developed because it was believed that the added viscosity would make them easier to use than fluoride solutions. These gels are usually administered in plastic, wax or foam trays.

Most reports on the clinical effectiveness of gels in reducing caries increments have been with those containing APF. Essentially these have the same ingredients, concentration and pH as APF solutions. In addition, a gelling agent is introduced, usually methyl cellulose or hydroxyethyl cellulose. Often the gels are thixotrophic, that is, under isothermal conditions they tend to convert to a solution when agitated or placed under pressure.

Swejda, Tossy and Below (1967) reported no difference in incidence of carious lesions among children treated by

APF gel compared with controls after one year. The children were seven year olds.

In two reports by Bryan and Williams (1968) and Bryan and Williams (1970) the effectiveness of APF gel applied by the use of foam trays in reducing caries increments was evaluated. The annual topical application was preceded by a prophylaxis. After one year they reported a reduction of 33% in DMFS over a control group receiving only annual prophylaxes. After two years the reduction was reported to be 37%. Both reductions were statistically significant.

In the study by Horowitz and Doyle (1971), mentioned previously, a group receiving annual applications of APF gel administered in wax trays over three years had a reduction of 24% in DMFS increments compared with the control group. The protection was comparable to that received by children in the same study who were given annual applications of a solution of APF.

Shern, Duany, Senning and Zinner (1976) failed to show any reduction in DMFS scores in a group of children receiving five daily applications of an APF gel. This test group was compared to a control who received five daily applications of a placebo gel. The results were evaluated after a two year period.

Beal and Rock (1976) state that APF gel was the most popular form of professionally applied preventive agent in the United Kingdom at the time of writing of their study. They tested a number of gels applied in trays and found all were well accepted by both patient and operator. Thixotrophic gels were considered to have advantages in handling over others.

Mainwaring and Naylor (1978) found that seminannual professional applications of APF gel produced a statistically significant reduction in DFS increments over a control group receiving applications of a non-fluoride gel. The study was carried out over three years in a high caries experience group of eleven and twelve year olds.

It is evident from the above review that APF gel used as a professionally administered topical gives substantial protection in populations experiencing high increments of caries - Bryan and Williams (1968) (1970) and Mainwaring and Naylor (1978). It is apparent, however, that APF gel is of little or no value in populations experiencing a low incidence of dental caries - Szwejda et al (1967) and Shern et al (1976).

The incorporation of stannous fluoride into glycerine by Shannon (1969) allowed the stabilisation of the material. Although Cowan and Shannon (1972) have shown that as a gel the agent is effective in reducing the enamel solubility rate there are no reported clinical studies using the gel as a professionnally applied medium.

In summary most studies show the effectiveness of fluoride solutions and gels as being effective in preventing the carious process. Results seem to be more consistent when treatments are given semiannually rather than annually.

Studies Involving Orthodontic Treatment.

Although much has been reported on the effects of various fluoride materials in reduction of caries increments, generally, little has been reported on the effects of professionally applied topical fluoride treatments in relation to protecting enamel during orthodontic treatment.

Seniff (1962) reported an 8% stannous fluoride solution applied for four minutes "reduced markedly" the etching of enamel found in his experiments in cementing bands with various mixes of cement (thin, thick and medium). However, no statistical data is presented.

Muhler (1970) studied the effects of giving a stannous fluoride prophylaxis and topical stannous fluordie application prior to placement of fixed appliances. He found that the group who received this treatment and also brushed their teeth daily with a stannous fluoride-calcium pyrophosphate dentifrice had significantly less dental caries after completion of treatment than an orthodontic group who did not receive the fluoride treatment.

Indeed the group who received orthodontic treatment had less caries increments than a control group who had no orthodontic treatment and no fluoride applications. Unfortunately this study does not evaluate the relative protective effects of the prophylaxis, topical application, use of the dentifrice or a combination of any or all of these agents.

Zachrisson (1971a) reports that a group undergoing orthodontic treatment and given a 2% topical application of sodium fluoride prior to banding, as well as sodium fluoride mouthrinses daily during treatment, had no greater caries increments than a non-orthodontic, non-fluoride supplemented control group. Again, unfortunately, it is not possible to determine if any protective effect was due to the topical application prior to treatment, mouthrinses during treatment, or as is more likely a combination of the two.

Dimitriadis, Sassouni and Draus (1974) studied the use of a single application of APF solution prior to banding. They found that this inhibited the amount of decalcification induced under orthodontic bands which were purposely loosened, over a six week period. They thus suggest that a topical application of APF solution prior to orthodontic banding may be a valuable preventive measure against demineralisation.

Hirschfield and Johnston (1974) used a similar experimental design to test the relative effectiveness of stannous fluoride, APF and an organic fluoride (Elmex) in reducing decalcification under banding. Using a visual scoring method, they found that both the APF and Elmex significantly reduced the amount of visual decalcification, whereas stannous fluoride did not. They thus recommended the use of either of the former solutions prior to banding.

Shannon and Charlton (1974) studied the effects of treating enamel surfaces with APF, stannous fluoride and sequential applications of the two solutions prior to placement of cement. They found that a sequential process involving the application of APF followed by stannous fluoride reduced the enamel solubility more than either solution by itself in in vitro testing.

Most authors agree that topical fluoride application is necessary prior to cementation of fixed appliances. Generally the patient is referred to their private practitioner for application. Zachrisson (1975) and Bounoure and Vezin (1980) both suggest a convenient means of application of fluoride gel may be the use of a set of impressions prior to banding and the application of gel to the inside of the alginate. Recently Speicher and Spedding (1980) have suggested the use of disposable dual arch trays for the application of gel topicals. These two methods may be amenable to use in the orthodontic office as they both require little chair time and may be readily performed by auxiliaries.

2.1.3 Patient administered fluoride-containing dentifrices.

A large number of fluoride-containing dentifrices have been introduced - for review see Heifetz and Horowitz (1970), Marthaler (1971), Horowitz and Heifetz (1975) and von der Fehr and Möller (1978). The interest in fluoride dentifrices stems from the fact that most people in industrialised countries regularly use a dentifrice, and topical fluorides (as we have seen) have been demonstrated to have a caries-preventing effect. Thus, dentifrices constitute a practical means of providing orthodontic patients with a regular supply of fluoride. The benefits may be gained before, during and after the placement of the fixed appliances. Even in areas where the drinking water contains optimal levels of fluoride a significant reduction in caries above that provided by the water, is obtained by the use of a fluoride containing dentifrice as shown by Gish and Muhler (1965).

Chemically, fluoride dentifrices can be divided into four main groups, although considerable variation is found within each group in relation to the concentrations of active ingredient as well as the type of abrasive used. The major groups are:-

i) Sodium fluoride
ii) Stannous fluoride
iii) Monofluorophosphate
iv) Amine fluorides

One Australian study reported by Homan and Messer (1969) found that dentifrices containing stannous fluoride calcium pyrophosphate, sodium fluoride acid orthophosphate and stannous fluoride sodium metaphosphate gave caries reductions of 64, 42 and 40% respectively when compared to a group using a non-fluoride-containing control dentifrice. The study extended over a twenty month period.

There can be little doubt that most fluoride dentifrices are effective as far as reducing caries is concerned, but considerable uncertainty exists as to which composition has the greatest caries inhibiting effect. Much of the variation is attributable to the fact that any study on the use of a dentrifrice involves not only the caries inhibition produced by the dentifrice but also the plaque removal by the toothbrush. Thus good toothbrushing may hide the effectiveness or otherwise of the agent being tested in the dentifrice. Thus, although the variation in reported caries preventing effects has been great, a 25-30% reduction in DMFS has been regularly reported in non-fluoride areas. The obvious recommendation is that orthodontic patients be advised to use a fluoride-containing dentifrice prior to, during and subsequent to orthodontic treatment.

2.2 DURING BANDING PROCEDURES.

2.2.1 Use of Fluoride-Containg Cements.

The idea of incorporating fluoride into cements used to attach orthodontic bands is an attempt to provide a supply of fluoride close to the enamel which may provide chemical protection against decalcification where the seal between the cement and tooth has been violated.

Gross (1951) dismissed the possible inclusion of sodium fluoride in cements to reduce caries. He states:-

> "Sodium fluoride can do only harm in a dental cement. Sodium of any kind is not permissible because sodium phosphate is very soluble in saliva. The fluoride will form insoluble fluorapatite and thus the fluoride radical is not available".

Phillips and Swartz (1957) demonstrated that certain dental restorative materials significantly affected the solubility of both powdered and intact enamel and dentine. Solubility was reduced appreciably after contact with some of the materials, and this reduction appeared to be associated with the presence of fluoride.

Norman, Phillips and Swartz (1960) subsequently found that fluoride was in fact released from these materials and that if stored with powdered enamel, the fluoride concentration of the powdered enamel increased. There appeared to be a definite relationship between the quantity of fluoride contained in the material, the amount of fluoride taken up by the powdered enamel and the decrease in solubility. Further studies by Norman, Platt, Phillips and Swartz (1961) confirmed that, with few exceptions, fluoride uptake and enamel solubility was markedly affected, in intact enamel as well as powdered enamel. Unfortunately in these studies it was found that zinc phosphate cement, utilised with 10% calcium fluoride, although increasing the fluoride content of teeth treated, did not increase the solubility.

These initial studies, however, encouraged others to examine if incorporation of other fluorides in dental cements might in fact reduce decalcifications and etchings under orthodontic bands. Gursin (1965) studied the effects of substituting a 30% stannous fluoride solution for the like amount of water in the liquid of a zinc oxyphosphate cement. The resultant composite cement would contain 750 p.m.m. fluoride ion. He examined the physical properties of the resultant set cement. The variables studied were compressive strength and setting time. He also examined the surface hardness of the enamel beneath the test cement and a regular zinc oxyphosphate cement by use of a Knoop indenter.

Gursin found that neither the compressive strength nor setting time of the cement was affected by the addition of the stannous fluoride. He did, however, find that the enamel exposed to the stannous fluoride-containing cement showed less loss of hardness when exposed to acid than that exposed to regular cement. Gursin then used these results to conclude that this reduction in hardness after acid exposure was equivalent to a reduction in the solubility of the enamel.

Wei and Sierk (1971) examined the fluoride uptake in underlying enamel when various materials were employed to cement orthodontic bands. They used regular zinc phosphate cement and a zinc phosphate cement containing 10% stannous fluoride. A third group received an application of 10% stannous fluoride prior to band cementation with a regular zinc phosphate cement. They found that a significantly higher fluoride concentration was found in the enamel under bands cemented with the zinc phosphate cement containing stannous fluoride. The teeth treated with stannous fluoride prior to banding were not found to have higher fluoride content than a control group or the enamel exposed to zinc phosphate cement. Wei and Sierk further found that the increase in fluoride content was not significantly different one day, or seven days after band cementation. Quite sensibly the authors note that the higher fluoride content may impart reduced solubility and anticariogenic properties to the enamel under orthodontic bands, but further studies would be required to confirm this. No attempt was made to evaluate any changes in the physical characteristics of this greatly increased fluoride containing cement.

Ram, Gedalia and Reisstein (1973) set out to determine the effect of adding higher fluoride concentrations to zinc phosphate cements than those studied by Gursin (1965). 2, 5 and 10% stannous fluoride was added to zinc phosphate cement to determine the effect on the characteristics of the cement. In particular they examined compressive strength, consistency, setting time, solubility, film thickness and degree of disintegration. They found that the addition of 5 and 10% stannous fluoride significantly increased the setting time, solubility, film thickness and degree of disintegration and significantly decreased the compressive strength and consistency. Incorporation of 2% stannous fluoride to zinc phosphate cement did not cause deterioration in the physical and mechanical properties overall. There was a significant increase in the film thickness but this still remained within the A.D.A. specifications. Significant release of fluoride to the underlying enamel was found when 2% stannous fluoride (resulting in 3.5 p.p.m. fluoride in the final cement) was added.

Skibell and Shannon (1973) examined the effect of the addition of varying percentages of stannous fluoride to zinc phosphate cement. They tested the solubility in 0.25M lactic acid of enamel, after exposure to the cements. The stannous fluoride in this instance was added to the powder of the cement by incorporating stannous fluoride crystals in amounts appropriate to provide 0.4%, 1.0%, 2.0% or 4.0% stannous fluoride in the final set cement. The set cement was kept in contact with enamel for periods of twenty four hours, and one week. Statistical analysis revealed that the length of time the cement remained in contact with the enamel, did not effect the results significantly. This is consistent with the findings of Wei and Sierk (1971).

The enamel exposed to zinc phosphate cement with no added stannous fluoride showed reduction in enamel solubility by 30.9%. This finding is of course at variance with authors such as Lefkowitz (1940), Castello, Massler, Monteleone and Suher (1948) and Seniff (1962) who believed that the acidity of zinc phosphate cement, in fact, increased the solubility of enamel and caused etching of the surface. The results, however, are in keeping with those recorded by Norman, Platt, Phillips and Swartz (1961) and Wisth (1970). A possible explanation for the apparent decrease in solubility is provided by Docking, Donnison, Newbury and Storey (1953). They considered that the effect was simply a matter of fragments of the set cement remaining on the tooth surface and thereby reducing the amount of tooth surface available to the acid.

The important findings of Skibell and Shannon are that the 0.4% and 1% stannous fluoride-containing cements did not significantly add to the protective effect of the regular cement noted above. Cement containing 2.0% and 4.0% stannous fluoride in the final mix reduced enamel solubility significantly more than the results for lower concentrations (64.2% and 58.8% reductions respectively). These values were not significantly different one from the other. It would appear, therefore, that no further protection is afforded by the 4% over the 2% fluoride containing cement.

The relative effectiveness of zinc phosphate cements containing sodium fluoride and stannous fluoride in reducing solubility and increasing microhardness was examined by Shannon (1980a). He used zinc phosphate cements containing 1000, 2000, or 4000 p.p.m. of fluoride ion incorporated as both stannous and sodium fluoride. Stannous fluoride containing cements produced significantly greater reductions in enamel solubility than sodium fluoride containing cements when they were used to coat the surface of teeth in vitro. Stannous fluoride, at 4000 p.m.m. fluoride ion, gave significantly greater solubility reductions than either of the two lower conentrat-ions. Further, Shannon found that sodium fluoride, at 4000 p.p.m. fluoride, and stannous fluoride, at 4000 p.p.m. and 2000 p.p.m. fluoride ion, incorporated into cement increased the micro-hardness of the enamel surface to which they were exposed. Other concentrations did not increase microhardness above pretreatment values. Shannon noted that although the similarity in response patterns for the enamel solubility and microhardness is striking in the present study, there is no assurance that a cause-and-effect relationship actually exist. This is contrary to the assumptions made by Gursin (1965), however, it appears a more scientific attitude.

Further confirmation of the beneficial effects on the enamel surface induced by cementing bands with a cement containing stannous fluoride is found in the recent work of Sadowsky, Retief and Bradley (1981). They found that cementing orthodontic bands to maxillary central incisor teeth with a zinc phosphate cement containing 5% stannous fluoride for twenty one days resulted in the underlying enamel surface acquiring greater levels of fluoride than control enamel which was covered with bands cemented with regular zinc phosphate cement. Further, they were able to show that the greater the fluoride uptake, the more resistant the enamel was to demineralisation when exposed to an acidified gel.

The "Shofu Dental Company" of Japan has recently introduced new polycarboxylate and zinc phosphate cements. Both these products contain a preparation that the manufacturers have called "Hy-Agent." Hy-Agent consists basically of tannic acid, zinc fluoride, strontium fluoride and a pH adjuster. The development of this preparation was due basically to research carried out in the Osaka University Dental School. In an report by Tani aki and Inoue (1979) it was found that the tannin-fluoride preparation was effective in reducing artificially induced secondary caries in dentine. The authors believe this caries reducing action was due to the:-

> "inhibiting effect on the dissolution of organic matter in dentin"

and an:-

> "obturating effect on the dentinal tubules."

L.K.B. Dental Products International, who market the cements in Australia, list the cementing of orthodontic bands as one of the indications for use of both products. However, as yet no research has been performed to investigate any caries inhibitory effects of Hy-Agent on enamel surfaces.

Overall, it would appear from the findings reviewed, that a zinc phosphate cement containing 2% stannous fluoride would represent an optimal concentration to be used clinically as little variation in physical and mechanical properties result , and yet enamel solubility is reduced with this agent. Long term clinical studies need to be carried out to evaluate the benefits to be derived from the use of fluoride containing cements, in cementing orthodontic bands.

2.2.2 Use of Fluoride-containing Varnishes.

Varnishes containing fluoride and coatings for teeth that either incorporate fluoride or are placed on the teeth following the application of fluoride are used in an attempt to maintain intimate contact between the tooth enamel and fluoride for a longer period of time than is achieved by traditional methods of application. Due to the relatively recent introduction of these products only a small number of studies have been devoted to their long term cariostatic effects. A number of the reports on the use of these materials are in foreign languages. Reviews by English writers will be used to evaluate these studies.

Koch and Petersson (1975) report that Heuser and Schmidt (1968) found a 30-40% caries reduction fifteen months after a single treatment with Duraphat (a varnish containing sodium fluoride suspended in an alcoholic solution of varnish. One ml. of varnish contains 50 mg. of sodium fluoride). They also report the results of a two year study by Maiwald and Geiger (1973) as finding that one application a year of Duraphat was ineffective in reducing caries increments, but that if three applications were performed the results showed a 45% caries reduction. A further study of Hetzer and Irmish (1973) is quoted by the same authors, in which an 18% caries reduction was obtained as a result of two applications per year during a three year period.

Koch and Petersson (1972) showed that contact with Duraphat did increase the fluoride content of the underlying enamel and that longer contact led to higher levels in the outer layers and greater depth of penetration of fluoride. This may suggest that if the varnish was placed under orthodontic bands prior to cementation, then very high levels and great depth of penetration may be attained as the varnish would be protected from mechanical traumatisation. In a later study, Koch and Peterson (1975) found a reduction in DMFS of 75%, over a control group, by patients given two semiannual applications of varnish. Protection against caries was not observed amongst children initially classified as having a high caries prevalence, although this observation was made on only a few participants.

A clinical study on diabetic children reported by Wegner (1976) involved the application of Duraphat twice yearly. After two years he found a 50% reduction in DMFT increment in the group receiving the applications over a control group.

In vitro tests by Edenholm, Johnson, Koch and Peterson (1977) showed that fluoride uptake in enamel of primary teeth after application of fluoride varnishes was initially very high. This level, however, was reduced after storage in saliva for one week.

Arends and Schuthof (1977) also used in vitro testing to demonstrate the differences in enamel solubility after exposure of APF solution, Duraphat and Fluor-Protector (a urethane lacquer containing the equivalent of 0.35% fluoride ion in liquid lacquer). They found that the varnish-treated enamel resisted acid attack far better than that receiving the topical APF solution. Also Duraphat was found to release more fluoride ion during in vitro testing that Fluor-Protector. The authors postulate that the increased protection noted in varnishes, may stem from the fact that the fluoride is in contact with enamel for extended periods of time (at least twenty four hours). This may predispose to the formation of fluoridated hydroxyapatite rather than calcium fluoride. If so, this would confer greater durability to the protective effect of the varnishes.

Using very young subjects (five year olds) Murray, Winter and Hurst (1977) could find no significant reduction in caries increments over a two year study with Duraphat used in a half-mouth technique. Holm (1979) studied the use of Duraphat on three year olds. In contrast to Murray et al, he found a siginificant reduction, amounting to 1.6 less DMF surfaces, in a test group (44%), over a control group. This study also lasted two years.

Koch, Petersson and Ryden (1979) found that six monthly treatments with Duraphat gave better caries protection than the use of weekly mouthrinses with 0.2% sodium fluoride at school. After two years they found a difference of 1.1 average less decayed surfaces in the varnish group than the mouthrinse group. This represented about a 30% greater protection in the varnish group.

Significant increases in fluoride ion concentration of enamel were found by Bruun,Givskov and Stöltze (1980) after in vitro treatment with Fluor-Protector. Further, they found that most of this was maintained during the first week of the study. However, after six months about 70% of the acquired fluoride was lost in the oral environment.

Pugnier (1972) reported that the sealing of teeth with cyanoacrylate resin after topical application of 1.23% APF solution reduced carious surfaces by 53% after two years. In the study, half of the mouth was sealed, half was not. Freidman, van der Merwe, Bischoff, Fatti and Retief (1976) examined the use of APF topical solutions following the acid-conditioning of the tooth and the effect of subsequently sealing the tooth with cyanoacrylate. They found that the topical application following acid-conditioning did significantly increase the fluoride content of enamel in nineteen to twenty three year olds over a one year period. The subsequent coating of cyanoacrylate was not found to enhance fluoride retention. Horowitz (1980) reviews the use of sealants to bind fluoride to enamel and considers that its main application lies in sealing pits and fissures.

No studies have investigated the protective effects of fluoride varnishes used under orthodontic bands. As noted previously it might appear that the covering of the varnish by the orthodontic band may protect the varnish from being removed by the process of mastication and hence allow greater benefits to be derived by the enamel.

2.3 THROUGHOUT ACTIVE TREATMENT.

2.3.1 Patient-administered solutions and gels containing fluoride.

Solutions.

The use of patient-applied fluoride in the form of solutions generally refers to the use of mouthrinses. However, a few studies have been reported on the efficacy of using fluoride solutions in brushing programmes at school. Volker (1939) originally showed that exposure of enamel to sodium fluoride reduced its dissolution in acid and, since the carious process involves such dissolution, it was thought that application of this solution may help reduce the caries incidence. Later, this cariostatic effect of topical application of fluoride was reported by Bibby (1942), Cheyne (1942) and Knutson and Armstrong (1943). These findings initiated studies with fluoride mouthrinses. Many reports have since clinically evaluated the benefits of various solutions, used under a variety of conditions and with different results. Basically the only solutions of fluoride that have been adopted by the dental profession for patient application have been:-

i) Sodium Fluoride
ii) Acidulated Phosphate Fluoride
iii) Stannous Fluoride.

i) Sodium Fluoride.

Weisz (1960) reported that children in his pedodontic practice who used a 0.25% sodium fluoride mouthwash, twice daily, experienced an 80-90% reduction in DMF surfaces over a control group. The observation period ranged from two to ten years. It must be noted, though, that the control and test groups were not really similar groups. The test group was instructed in oral hygiene procedures and was given strict dietary advice, whilst the control group was not. Further, the test group was charged a fee for the instructions and mouth-rinsing programme.

One of the first school programmes of mouthrinses was reported by Torell and Siberg (1962). They showed that monthly three minute rinsing with o.2% sodium fluoride produced statistically significant reduction in caries on the proximal surfaces of incisors after twelve months. Because of the unconventional means of using only proximal lesions of anteriors to evaluate the effects of treatment, it is difficult to interpret fully the reported benefits.

In a very large study by Torell and Ericsson (1965) sodium fluoride mouthrinses were evaluated against several other preventive agents and methods. Included in the study was a group of children who engaged in daily, unsupervised rinsing at home (after every toothbrushing) with a neutral 0.5% sodium fluoride solution and another group who, under supervision of dental nurses, underwent a fortnightly rinsing at school with a neutral 0.2% sodium fluoride solution. At the conclusion of the two-year study, children in the daily mouthrinsing group showed 50% reduction in new incremental caries scores compared with children in the control group. Lesser benefits, a 21% reduction in average new DMF surfaces, were found in children who rinsed fortnightly. Compared with the findings for other groups in the study who received professionally administered fluoride applications or fluoride dentifrices, the daily mouthrinsing procedure also yielded significantly better results.

These findings were further corroborated by Koch (1967) who, amongst other tests on caries preventive measures, examined the effects of fortnightly supervised rinsing with 0.5% sodium fluoride, over a three year period. He found a

23% reduction in DMF surfaces. Interestingly, he found that the effects were more marked in lower than upper teeth.

Horowitz, Creighton and McClendon (1970) reported similar anticaries effects from weekly rinsing with an 0.2% sodium fluoride solution. Participants in Grade 1 and Grade 5 carried out the mouthrinse procedure under the supervision of classroom teachers. After one year, children in Grade 1 and Grade 5, who rinsed with the fluoride solution developed 30 and 28% fewer DMF surfaces respectively, than children in the control group. After twenty months the percentage differences had dropped to 16% for Grade 1 children, but had risen to 44% for children in Grade 5.

Aasendon, DePaola and Brudevold (1972) examined a group who were given sodium fluoride (containing 0.02% fluoride) mouthrinses, daily at school, as part of their study. They could find no statistically significant difference in DMFS increments from a control group given placebo mouthrinses after one year. However, the average increments in the test group were smaller. After two years, the reductions were found to be statistically significant, and after three years the reduction of 27% in DMF surfaces was also significant.

A much stronger sodium fluoride mouthrinse (containing 0.3% fluoride) was used weekly at school in a study by Heifetz, Driscoll and Creighton (1973). They found that, after two years, the children who had rinsed with the solution had lower incremental caries scores (38% less DMFS) than the children who rinsed with a placebo solution. However, the reduction was not found to be statistically significant due mainly to the large number of participants who left the study (56%). The more concentrated solution, thus, did not appear to give any better results than previously reported solutions. However, the taste of the solutions became quite unpopular and, in fact, caused the intended three year study to be reduced to two.

Rugg-Gunn, Hollaway and Davies (1973) found a reduction of 36% in DMF surface lesions in a group of eleven to twelve year olds using a 0.05% sodium fluoride mouthrinse at school daily. The control group used a placebo rinse and the final increments were recorded after three years. They were able to show greater reduction in caries on the anterior proximal and free smooth surfaces than on pit and fissure lesions.

Using a 0.4% sodium fluoride mouthrinse weekly at school, Gallagher,Glassgow and Caldwell (1974) demonstrated a 13% reduction in DMF surfaces over a control group using a placebo mouthrinse. The study extended over a twenty six months period.

In a series of reports Ripa, Leske and Levinson (1978), Ripa and Leske (1979) and Ripa, Levinson and Leske (1980) showed that a weekly programme of 0.2% sodium fluoride mouthrinses at school produced significant reductions in both the deciduous dentition and in older children (eleven to thirteen years). They found a reduction of 20% in DFS in a two year study with deciduous dentitions. In a three year report, a reduction of 30.9% DMFS was found in the rinse group. In both studies it was noted that better protection was afforded on the proximal surfaces than on others.

Berggren and Welander (1960) evaluated the effectiveness of a 1% sodium fluoride solution applied by brushing at school. Test groups who brushed nine times in the two years of the study were found to have about 16% less DMF teeth than the control group. A second study by Berggren and Welander (1964) tested the caries inhibition produced by 0.5% sodium, 0.25% zirconium and 0.56% ferric fluoride solutions used with brushing. They found that five applications of sodium, ferric and zirconium fluoride produced significant reductions of 29, 33 and 17% respectively in the proportion of previously sound permanent teeth becoming carious. After two years, little or no reduction was found after two applications with any of the solutions.

ii) Acidulated Phosphate Fluoride.

Earliest studies with acidulated fluoride solutions used as mouthrinses by Bibby, Zander, McKelleget and Labunsky (1946) showed no caries-inhibiting effect in a small group of thirty one dental students compared to a control group of eighteen. In a larger follow-up study by Roberts, Bibby and Wellock (1948) the same agent had a caries promoting effect. The agent used in these two studies differs from the currently used acidulated solutions in that the latter contain phosphate. In theory, the phosphate provides a "common ion effect" to inhibit the demineralisation of the enamel in the presence of low pH.

Frankl, Fleisch and Diodati (1972) studied mouthrinsing with an APF solution containing 1 mg. of fluorine at pH4. The rinses were given daily at school for one minute to children whose average age was fourteen years. Little change in DF surface values was noted compared with a group rinsing with a placebo solution after the first twelve months. However, the 25% reduction found after two years was found to be statistically significant.

This lack of statistical change during the first twelve months was also noted in the APF- (containing 0.02% fluoride at pH4) rinsing group in the Aasenden, DePaola and Brudevold (1972) study. After three years of daily rinsing at school, however, the 30% reduction in DMF surfaces was found to be significant statistically. Although when comparing the caries-inhibiting effects of the neutral and acidulated solution in this study, a similar result was obtained, the authors found a higher fluoride content in teeth exposed to APF mouthrinses.

The similar effectiveness of APF and neutral sodium fluoride used as mouthrinses was also found in the Heifetz, Driscoll and Creighton (1973) study. As noted earlier, the sodium fluoride group showed a 37.5% reduction in DMF surfaces. The reduction was 27.4% for the APF rinsers over the group using a placebo mouthwash.

Finn, Möller, Jamison, Ragattier and Manson-Hing (1975) examined the use of two low-concentration APF rinses used twice daily. The solutions used contained 100 p.p.m. and 200 p.p.m. fluoride and the changes in DMFS increments were compared with a group rinsing with a placebo mouthwash after a twenty six months period. The reductions, after making allowances for reversals of diagnosis, were found to be 17.9% and 28.6% for the 100 and 200 p.p.m. solutions respectively. Both reductions were found to be statistically significant over the control. However, there was not a significant difference between the two groups.

Bullen, McCombie and Hole (1966) conducted a two year study to examine the effects of four or five brushings per year with APF solution (1.23% fluoride) at school. A reduction of 15% in caries increments was found to be statistically significant. In another Canadian study Conchie, McCombie, Hole and Com (1969) found a reduction of 25% in DMF surfaces, over a control group, after nine brushings with the same APF solution. The brushings were conducted over a two year period and final examinations were performed twenty months after the last brushing.

iii) <u>Stannous Fluoride.</u>

Stannous fluoride became a candidate for use as a mouthrinse when laboratory and animal experiments by Muhler and van Huysen (1947) and van Huysen and Muhler (1948) showed enamel solubility to be reduced far greater by the use of stannous fluoride than by sodium fluoride. Ericsson (1950) also found greater solubility reduction in laboratory experiments. These early results led to human clinical studies and stannous fluoride, as we have seen, became a very popular topical treatment.

Unfortunately, there were many problems associated with its use as a mouthrinse. High concentrations, as used in topical treatment, caused some gingival irritations, stained decalcified areas, tasted terrible and were unstable in aqueous solution. As noted previously, this problem of stability was obviated by Shannon (1969) in the development of a system for forcing stannous fluoride into solution with glycerine at high heat. As a result of these disadvantages the number of reported tests with stannous fluoride mouthrinses are far fewer than those reported with other solutions.

Swerdloff and Shannon (1969) demonstrated the feasibility of using stannous fluoride mouthrinses (0.1%) as part of a school preventive programme. Although these investigators worked with a small group of children (168 total for both test and control groups), they found an apparent benefit, and could demonstrate the safety of the procedure. They found a reduction of 35% in DMFS increments over the five months of the study. However, this was not found to be statistically significant either due to the reduced length of time of the experiment or lack of adequate numbers.

A large study by Radike, Gish, Peterson, King and Segreto (1973), over three years, evaluated the effects of a 0.1% stannous fluoride mouthrinse used daily at school. They found a reduction of 33 and 43% in DMF surface lesions, as measured by two independent operators, over a control group using a placebo rinse. A notable aspect of this report was that it was carried out with children who had been exposed to optimal concentrations of fluoride in the communal supply for all their lives. Some discolouration of the teeth was noted in the test group.

Shannon (1980b) studied the solubility reduction of enamel, dentine and cementum, in vitro, after subjecting the test surfaces to mouthrinse concentrations of sodium and stannous fluoride solutions. Two concentrations of each solution were tested containing 225 p.p.m. and 900 p.p.m. fluoride. He found both concentrations of stannous fluoride gave significantly greater enamel solubility reduction than either sodium fluoride solution. Also the enamel solubility was reduced significantly more with the more concentrated stannous fluoride solution. Shannon thus contends that serious consideration should be given to stannous fluoride containing mouthrinses. As Brudevold and Naujoks (1978) point out, however, there may be little or no correlation between solubility-reducing effects in vitro and anti-caries effects in vivo.

It is apparent that insufficient clinical trials have been reported which would support the recommendation of the use of stannous fluoride for use as a frequent mouthrinse over other solutions. The danger of staining of hypomineralised areas would also temper any recommendations for its use.

Gels and Pastes.

In contrast to the use of self-applied solutions, patient-administered fluoride gels are generally applied by the use of a toothbrush. Once again a number of active ingredients have been evaluated, used in a variety of regimes.

Marthaler, Konig and Muhlemann (1970) evaluated the use of an amine fluoride gel containing 1.25% fluoride over a three year period. The brushings were conducted weekly at school (thirty two sessions) for the first year and fortnightly during the second and third years (sixteen sessions per year). At the conclusion of the study, the children who brushed with the fluoride gel experienced 40% fewer DF surfaces than the control group brushing with a placebo gel. The reduction was found to be statistically significant.

Large reductions in DMFS increments were demonstrated by Lang, Thomas, Taylor and Rothaar (1970) by the use of zirconium fluoride prophylactic paste at six monthly intervals. These reductions ranged from 37.8 to 42.1% when evaluated by three independent examiners after an eighteen month observation period. These large reductions are even more dramatic when it is realised the study was carried out in an area with an optimally fluoridated water supply.

Heifetz, Horowitz and Driscoll (1970) failed to show any significant reduction in caries increments in patients brushing five times a year with a 0.6% fluoride containing APF solution or a 1.23% APF gel at school. The study was conducted over two years.

In contrast, Trubman and Crellin (1973) found a reduction of 24.8% in DMF surfaces in a group using a 1.23% APF gel four times per year. This was found to be a statistically significant reduction. They did note, however, that the reduction recorded after twelve months was not statistically significant.

In Sao Paulo, Brazil, Horowitz, Heifetz, McClendon, Viegas, Guimaraes and Lopes (1974) used a very similar design to the experiment of Heifetz, Horowitz and Driscoll (1970), including the same concentration of APF solution (0.6%) and gel(1.23%). They found reductions in DMF surfaces ranging from 26-33% with different combinations of prophylaxis paste followed by either APF solution or gel, self-administered. They concluded that, to be effective, the APF gel required the prior use of a prophylaxis paste.

Mellberg, Peterson and Nicholson (1974) reported 21% fewer DMF surfaces in children using an APF paste (0.4% fluoride) applied by brushing than a control group using a placebo paste. The pastes were applied semiannually over a three year period. Greatest protection was afforded on bucco-lingual surfaces.

Semiannual self applications of a paste containing 9% stannous fluoride were evaluated in a study by Gish, Mercer, Stookey and Dahl (1975). The children using the paste were lifetime residents in an optimally fluoridated area. They found a reduction of 24.7% in DMF surfaces over a three year period.

The incorporation of stannous fluoride into a water soluble gel by Shannon (1969) opened the way for investigation into its use as a patient-applied topical. Cowan and Shannon (1972) found that various concentrations of this gel all gave reductions in enamel solubility of teeth treated. They also found that acid exposure rapidly decreased the solubility reductions. They thus recommended frequent exposure to the gel. With this in mind, Landry and Shannon (1973) tested the use of a 0.4% stannous fluoride gel in a home care programme. They found that brushing with the gel daily over one week reduced enamel solubility by an average of 12.1% and a highly significant increase in effectiveness was found after longer periods. They suggested that the daily use of such a gel would be a valuable preventive adjunct in orthodontic treatment.

Shannon and McFarland (1974) confirmed this enamel solubility reduction found by the use of daily self-administered 0.4% stannous fluoride gel. In addition, however, they used weekly office administration of APF and stannous fluoride mouthrinses. Using these procedures they found a 27.3% reduction in enamel solubility after twenty eight days of treatment.

The use of sodium fluoride and APF-containing gels used daily at school in polyvinyl mouthpieces was examined by Englander, Keyes, Gestwicki and Sultz (1967). Very substantial reductions in DMFS scores of 75% and 80% were recorded in children using the sodium fluoride and APF-containing gels respectively for six minutes daily over a control group receiving no applications. The period of applications lasted twenty one months. Twenty three months after ceasing treatment Englander, Carlos, Senning and Mellberg (1969) re-evaluated the patients. They still found 55% and 63% reductions in the DMFS increments of the sodium fluoride and APF groups compared to the controls. Further studies by Englander, Sherrill, Miller, Carlos, Mellberg and Senning (1971) showed that the use of mouthpiece-applied APF gel three times a week gave a 29% reduction in DMFS after thirty months in a community with an optimally fluoridated water supply.

Studies involving orthodontic treatment.

Ingervall (1962) advocated the use of fluoride mouthrinses daily during orthodontic treatment to help prevent caries, but presented no evidence to substantiate this advice. The main advocate of the use of mouthrinses during orthodontic treatment has been Zachrisson. In studies on patients using 0.2% sodium fluoride mouthrinses twice weekly along with frequent toothbrushing instruction and review, Zachrisson and Zachrisson (1971a) and Zachrisson and Zachrisson (1971b) found no increase in caries index scores over a non-orthodontic, non-fluoride using control group. Zachrisson (1975) advocated the use of 0.05% daily sodium fluoride rinses during treatment and recently Zachrisson (1978a) even increases the rinses to twice daily in caries prone patients. Zachrisson (1976) and Zachrisson (1978a) believe that the use of dilute solutions daily are more effective than stronger solutions at longer intervals. Much of the benefit from daily rinsing he believes is because daily rinses are easier to remember and hence patients are more likely to carry out the procedure.

A clinical trial to test the efficacy of use of a gel containing 0.4% stannous fluoride was carried out by Stratemann and Shannon (1974). The gel was used daily by orthodontic patients over a period ranging from eighteen to twenty four months. They found that the incidence of new decalcification occurring around bands was reduced in these patients when compared to a control orthodontic group which did not use fluoride gel. The reduction in decalcification was particularly marked in those patients who were found to use the gel as directed, on a daily basis. Those who used the gel less regularly experienced higher levels of decalcification.

Craig (1975) has suggested alternate regimes of fluoride therapy to be used during orthodontic treatment. Daily rinsing with 0.05% sodium fluoride solution is recommended.

Alternatively, he suggests the weekly use of an acidulated phosphate fluoride gel or weekly rinsing with a 0.2% sodium fluoride solution. Any of these procedures, he suggests, should be accompanied by the daily use of either a sodium monofluorophosphate or sodium fluoride dentifrice. This approach to fluoride therapy during orthodontic treatment is supported by Harvey (1980).

Trask (1975) advocated the use of a 1.23% APF gel applied either daily or weekly in orthodontic patients by the use of thermoplastic vinyl trays, or in positioners after the completion of treatment. Because of the added cost of making trays for application of the gel, Trask advises that this form of fluoride treatment be restricted to those patients who have a vehicle for application. This includes those patients who have a mouthguard for sport or have a positioner after treatment. He also recommends this form of fluoride application in patients with very high caries risk. Cooke and Wreakes (1978) also suggest the use of APF gels in positioners for recalcifying areas after orthodontic therapy.

Laboratory and clinical investigations by Shannon, St. Clair, Pratt and West (1977) evaluated solutions and gels containing equal amounts of fluoride in the form of stannous and sodium fluoride. The clinical tests involved only small numbers of orthodontic patients - forty three subjects were divided into the four test groups. Both in the form of solution (0.1%), used as daily mouthrinses, and gel (0.4%), applied by brushing at night, stannous fluoride groups showed no increase in areas of decalcification around the orthodontic bands. The groups using the same concentration of sodium fluoride solution and gel both showed an increase of 30% of patients and 3% of banded teeth, with increased or new areas of decalcification occurring around the bands. Again in this study, as with that of Stratemann and Shannon (1974), only decalcification occurring around the bands was evaluated. No attempt was made to include decalcification occurring under the bands as the scoring of decalcification was made in the study after one year and consequently fixed appliances were still in place. Also, it must be noted that the experimental protocol was not fully explained in this report. If the tests were not carried out as a double blind study, there may be some question of the reliability of the results obtained. The laboratory testing on pre-etched and intact enamel showed both the stannous fluoride solution and gel reduced the enamel solubility more than the coresponding concentrations of sodium fluoride.

Wisth and Nord (1977) found a tendency, although not statistically significant overall, to reduction in DMFS count in an orthodontic group using a 0.05% sodium fluoride mouth-rinse daily and given proper oral hygiene instruction throughout treatment, over a control group of non-orthodontic, non-fluoride using controls of the same age. The final examinations were performed eighteen months to two years after the bands were removed. It must be noted, however, that no initial records were taken prior to placement of bands and hence the orthodontic group may have had significantly less caries prior to banding. The tendency for patients undergoing orthodontic treatment to have lower DF readings prior to treatment was noted by Hollander and Ronnerman (1978).

Hirschfield (1978) attempted to examine the effects of APF daily mouthrinses on the amount of decalcification occurring in an orthodontically treated group, over the entire twenty to twenty eight months of treatment. A group of thirty patients rinsing for thirty seconds nightly with "Phos-Flur" showed significantly less decalcification on the right lateral incisor and the mandibular left first permanent molars, which were the teeth examined for the purposes of this study. This study does take into consideration the enamel under the bands in the teeth selected for evalution. Also, it appears that the results presented by the author in the table of results do not correspond with the results reported in the text.

Very recently Shannon and Tarin (1980) examined the effects of daily rinsing with sodium and stannous fluorides, over one and two week periods, on the fluoride content of the enamel, enamel solubility reduction and the thickness of enamel removed after exposure to acid. They found that both sodium and stannous fluoride increased the level of fluoride by comparable amounts but stannous fluoride rinses were more effective in reducing enamel solubility, and less enamel was removed on exposure to acids. The authors contend that these findings support the notion that stannous fluoride is a more effective agent to use as a mouthrinse. As noted previously it has not been proven that enamel solubility reduction and/or increased fluoride uptake by enamel necessarily produced protection against caries.

Unquestionably then, the use of low concentration fluoride mouthrinses and gels can be a highly effective caries preventive procedure. It is apparent from the literature that frequency of application is a more important factor than the actual fluoride concentration. Daily applications are necessary to obtain the highest possible level of performance.

2.3.2 Professionally administered solutions and gels containing fluoride.

Basically this involves the use of the same materials discussed in the section prior to banding. Although Zachrisson (1975) refers to the use of sodium fluoride or APF applications to enamel prior to recementing any bands, few other authors mention this good opportunity to gain added protection for the enamel when bands are loosened or otherwise need recementing. As noted previously, although no studies have been performed on the use of fluoride varnishes under orthodontic bands, this may offer added benefits in terms of uptake of fluoride by the enamel.

Mollenhauer (1978) suggests that a chlorhexidine solution containing up to 2% sodium fluoride which is administered in the office by toothbrushing at each visit (once per month) is both an effective way of reducing caries experience during orthodontic therapy as well as improving gingival condition.

In the study by Shannon and McFarland (1974) discussed earlier, APF (0.8%) and stannous fluoride (0.4%) solutions were used as office mouthrinses together with daily brushing of 0.4% stannous fluoride at home. Good reductions in enamel solubility were recorded after a twenty eight day period.

Magness, Shannon and West (1979) reported on a clinical investigation of the sequential use of APF and stannous fluoride mouthrinses by orthodontic patients in an office procedure.

The authors contend that this procedure is useful in protecting patients who will not comply with home preventive programmes. They found 18.2% of patients had new or increased areas of decalcification around their orthodontic bands in 1.3% of teeth banded after a fourteen month period. The authors compared these figures with the control group of the Stratemann and Shannon (1974) study where 58% of patients had increased areas of decalcification. It has been noted previously that direct comparison of different studies is difficult as the groups studied came from different populations and the studies are carried out under different experimental conditions. Unfortunately, Magness, Shannon and West had no control group of their own to compare the decalcification figures of their test group.

2.4 ADDITIVE EFFECT OF MULTIPLE FLUORIDE SUPPLIES

A number of clinical studies have been initiated to determine if applications of fluoride from various sources would give additive anticaries effects. In general, most studies have been encouraging but it is difficult to evaluate which combination of procedures give greatest protection.

Gish and Muhler (1965) found that the use of a stannous fluoride prophylactic paste followed by a topical stannous fluoride application (semiannually) and the use of a stannous fluoride - calcium pyrophosphate dentifrice at home had additive effects even in an optimally fluoridated community. Thus the group receiving all three forms of protection were found to have greatest reductions in caries increments, followed by those receiving two forms and then those receiving only one form. All groups receiving fluoride treatments had reduction in DMFS increments over a group receiving semi-annual prophylaxes with a placebo paste, topical application with water and using a placebo dentifrice. The reductions ranged from 41 to 67%.

A study by Bixler and Muhler (1966) found similar additive effects with the use of a stannous fluoride prophylaxis, topical application and home use of a dentifrice.

In contrast Horowitz and Lucye (1966) examined the cariostatic effect accompanying the use of annual stannous fluoride prophylactic paste or annual topicals with 8% stannous fluoride. After two years of the study they could find no protective benefits to be derived by the use of either agent singly or when used in combination.

Scola and Ostrom (1968) found a combination of annual stannous fluoride prophylaxis followed by topical application with 10% stannous fluoride and the use of a stannous fluoride - calcium pyrophosphate dentifrice daily gave significantly greater reductions in DMFS increments than using a combination of any two of these methods of application. The group studied were seventeen to twenty four years-old naval personel. They found reductions of 48 and 61% in DMF surfaces when using four minute and fifteen second topical applications in combination with prior prophylaxis and use of a home dentifrice.

Combinations of APF and sodium fluoride in the form of prophylactic pastes, rinses to remove the paste and topical applications were studied by Szwejda (1972b). He found that both APF and sodium fluoride required a topical application subsequent to the use of prophylactic paste and fluoride rinse to give significant protection over a group of controls.

Forsman (1974) found modest additional caries reductions from sodium fluoride and monofluorophosphate dentifrices used in clinical tests for two years in children who used fortnightly sodium fluoride mouthrinses.

A double-blind study by Downer, Holloway and Davies (1976) revealed that the combined use of supervised brushing with monofluorophosphate daily and semiannual prophylaxes with APF paste followed by a topical application of APF solution produced a reduction of 35% in DMFS increments. The caries increments were compared with controls who brushed daily with a placebo dentifrice and received semiannual applications of sodium chloride preceded by a prophylaxis with a placebo paste. The authors considered that the degree of reduction may have been greater if the control group had not received the intensive oral hygiene programme daily.

Beiswanger, Billings, Sturzenberger and Bollmer (1978) found significant reductions in DMF surfaces by the use of both APF solution applied annually in the office and also in a second group using a stannous fluoride-calcium pyrophosphate dentifrice daily at home. A third group receiving both the topical applications annually and using the test dentifrice at home had about 20% greater reductions in DMFS increments than either treatment administered separatelv. Thus the authors report that the use of both forms of caries prevention produced better results than either method used alone. Also the results indicated either system used alone gave about equivalent protection.

In contrast, Mainwaring and Naylor (1978) failed to show any added benefits from the combined professional application of APF gel in trays and the at-home of a sodium monofluorophosphate dentifrice. After three years, the use of the agents singly and in combination all produced reductions in decay experience compared to a control group. However, the findings failed to show any differences in particular treatment regimes.

2.5 THE USE OF FLUORIDES IN AREAS WITH OPTIMALLY FLUORIDATED WATER SUPPLIES

It is of great importance to know whether in addition to the full effect of optimally fluoridated drinking water, one can obtain additional protection by fluoride application procedures which are effective in fluoride-deficient areas. Unfortunately no studies have been reported on benefits in orthodontic patients raised in optimally fluoridated areas. However, some reports have been published which indicate some fluoride applications may give added benefits.

Downs and Pelton (1951) reported no benefits after one year for children who lived in a naturally fluoridated area and received topical applications of a 2% sodium fluoride solution. However, the study had only a small number of participants and was of short duration.

By comparison, Muhler (1960a) evaluated the use of 8% topical stannous fluoride applied semiannually in a group of children aged six to seventeen years. The water supply of the community had been optimally fluoridated for a period of six years. Results after thirty months of investigation showed that children in the test group experienced an overall reduction in incremental DMF surfaces of 49% compared with children in a control group not receiving topical applications. Obviously not all children in the study would have received lifetime protection from the water supply.

As noted in the previous section Gish and Muhler (1965) found reductions in DMFS increments by combined use of a stannous fluoride prophylaxis paste, topical application and dentifrice in a test group drinking optimally fluoridated water. Although the DMFS increment reductions were similar to those obtained in non-fluoridated communities in terms of percentages, it must be noted that since the increments of caries are smaller in fluoridated areas, so the increments of caries reduction are proportionately small.

Goaz, McElwaine, Biswell and White (1966) investigated the anticariogenic effectiveness of daily brushing at home with a 6% sodium monofluorophosphate solution in an optimally fluoridated community. After nine and fourteen months, children in the test group showed a significantly lower number of DFS than the children in a control group. After twenty one months about 50% reduction was shown in DFS. A large number of reported reversals in diagnosis make these results doubtful.

In two reports by Horowitz and Heifetz (1967) and Horowitz and Heifetz (1969) examined the use of four minute applications of 8% and thirty seconds applications of 10% stannous fluoride solutions applied annually. All children in the study had lived all their lives in a fluoridated community. They found after three years that a reduction of 21% in DMFS was obtained by the use of the four minute applications. This was found to be a statistically significant reduction. The group receiving the thirty seconds applications did not derive any decay-preventive benefits. The authors thus emphasised the need for maximum isolation time during topical applications.

The study by Englander, Sherrill, Miller, Carlos, Mellberg and Senning (1971) on children raised in a fluoride community, found modest reductions in DMFS increments in a group using APF gels applied in mouthpieces three times per week. After thirty months, the difference between the test and control groups in terms of DMFS increases was 0.63 . This figure was found to be statistically significant, although as the authors themselves note, not clinically impressive.

Szwejda (1972a) found that children living in communities with fluoridated drinking water received little benefit from the use of either APF or stannous fluoride prophylaxis paste annually but topical applications of APF and stannous fluoride solutions did produce modest reductions of 28 and

25% in DMFS over a four year period. The author considered that these reductions were not of sufficient magnitude to recommend the techniques in public programmes.

Mellberg, Nicholson, Miller and Englander (1970) studied the fluoride concentration in enamel recorded in exfoliated deciduous teeth and permanent teeth extracted for orthodontic reasons. All children in the study resided in an area of optimally fluoridated water. They found that topical applications of APF gel applied by "mouthpieces" three times weekly for thirty months at school increased the fluoride found in their outer layers of enamel significantly. They considered that the fluoride was permanently bound and became greater as the number of treatments completed was increased.

Marked reductions of 33% and 43% in DMF surfaces were found by two independent observers in a report by Radike, Gish, Peterson, King and Segreto (1973). The test group used a stannous fluoride mouthrinse (0.1%) daily at school over a two year period whilst the controls used a placebo rinse. All children in the study had lived all their lives in a community with a water supply which had been optimally fluoridated for seventeen years. This study stands out as the best documented report of the results of mouthrinses used in optimally fluoridated areas.

Gish, Mercer, Stookey and Dahl (1975) found statistically significant reductions in DMF surfaces in a group of children six to fourteen years of age who brushed semiannually for three years with a 9% stannous fluoride prophylactic paste. Again these children had been life-time residents in an optimally fluoridated community. The magnitude of the reduction was 30.1% over a control gourp using a placebo paste for brushing.

It is evident from these reports that fluoride containing substances can increase the protection of enamel afforded by the process of water fluoridation. APF gels, used as a topical, have not been shown to prevent the caries process in communities with low caries levels, such as occur in high fluoride areas.

As pointed out by Englander, Sherrill, Miller, Carlos, Mellberg and Senning (1971) on a cost/benefit ratio such procedures are not warranted in a fluoridated community (in public programmes), when considered for use on individuals in high caries risk situations (such as orthodontic patients) these techniques may be found very beneficial. Since water fluoridation is considerably less than 100% effective, it is important to recognise the possible need in orthodontic patients of added protection.

CHAPTER 3.

OTHER MEANS OF PREVENTION

The use of fluoride containing materials is only one means by which decalcification can be reduced during orthodontic therapy. The aim must be to eliminate these disfiguring lesions. Other procedures which should be taken into consideration when attempting this goal include:-

1) Checking original lesions present before banding.
2) Use of well-fitting bands.
3) Use of correct cementing techniques.
4) Use of coating techniqes.
5) Improving oral hygiene techniques of the patient.

3.1 INSPECTION FOR DECALCIFICATION PRIOR TO BANDING TEETH.

Noyes (1937), Sved (1946), Bach (1953) and Zachrisson and Zachrisson (1971a) have observed the need to recognise any areas of decalcification on teeth prior to banding. The parents and patient should be made aware of these areas and note to this effect placed on the patient's treatment card. This helps prevent any embarrassing situations when bands are removed and these lesions are re-exposed. Equally important is the recognition of the need for any restorations prior to banding. Both Quinn (1956) and Hollander and Ronnerman (1978) consider proximal restorative treatment can be postponed, even in cases of fairly advanced lesions because the rate of progress of these lesions was found to be relatively slow beneath orthodontic bands when properly cemented. However, Gibbin (1937) and Zachrisson (1976) state that all cavities should be restored prior to band cementation. This seems to be a sensible approach as it may be difficult to explain to parents and patient that restorations needed after appliance therapy were not in fact caused by the bands being in place.

3.2 BAND FIT.

Berkson (195 considered that band construction was a far greater factor than cement in band retention. Yet regardless of how skilfully an orthodontic band might be shaped it will not maintain its retention on a tooth throughout functional use without the aid of cement.

Berkson also pointed out that structural faults were always present in adhesive materials and the thinner the film the fewer the faults likely to be present as it was quite impossible to produce a mixture that was homogeneous throughout.

Basically the cement is used to protect the tooth under the band from the ingress of plaque and soluble materials. By keeping the cement thickness to a minimum it is hoped that less area will be exposed to the oral environment and so cement solubility is kept to a minimum (as discussed by Phillips, 1973) and also less thermal changes would occur at the margins as suggested by Nelsen, Wolcott and Paffenbarger (1952).

Few studies have been conducted on the properties of cements in relation to its usefulness in orthodontic practice. Wisth (1972) found immediate penetration of cement sealing orthodontic bands by aqueous solutions of low molecular substances. After only five minutes exposure to methylene blue solution all gingival and occlusal margins were penetrated by the dye both in the use of zinc oxyphosphate and hydro phosphate cements to seal the bands. About 50% of the cement area was stained with the dye after five minutes and, after two hours the entire cement layer was stained. Although the author points out that this study does not show the exact timing of the inflow of methylene blue, as about two hours passed between removal from the dye and the final photography of the cement, nevertheless much faster inflow was noted than would be expected. An identical penetration result was obtained when radioactive phosphorous was employed as the measurement tool. Wisth felt that this result sustained the hypothesis that the cement layer may be penetrated by fluoride ions which possibly act as a fluoride deposit, thereby ensuring the resistance of the enamel to decalcification. However it would also represent a means of entry to hydrogen ions, from acids, allowing for the encouragment of decalcification of the enamel.

Schroeder, Sather, Jowsey and Taylor (1974) used a radioisotope (^{15}Ca) to study the permeability under orthodontic bands sealed with different cement types and using different cement removal methods. They suspended the test teeth for twenty four hours in the radioisotope. Although the amount of penetration found was significantly less than that found by Wisth (1972) it was found that penetration was evident to some degree in all specimens even over this short period of time.

It would appear then that the sealing of orthodontic bands by the use of cement materials does allow the penetration by some low molecular weight substances. Proper band fitting reduces the risk of further percolation occurring between the band and the enamel surface.

3.3 CEMENTATION TECHNIQUE.

As noted in the previous section the weak link in the securing of fixed appliances to the teeth appears to be the medium used to cement the bands. Fitzsimons (1969) has shown that although the cement does not etch the enamel surface, even in very thin consistances, the alteration of the liquid/powder ratio can have marked effects on particularly the solubility of the cement. By increasing the liquid/powder ratio, in order to increase working time and hence cement more bands with one mix, Fitzsimons found that the solubility of all cements tested increased rapidly. Thus the cement is more easily dissolved by acids produced by plaque. Thus it is necessary to mix all cements to the recommended liquid/powder ratio to gain optimal physical properties of the materials. Other methods such as the use of a cool slab for mixing and using wide spatulation may be used to increase working time, if needed, without causing detrimental effects in the set cement.

Probably the most important procedure at every visit is to check the integrity of all margins of all bands for adequate seal. Most authors, such as Sved (1946), Dolce (1950), Ingervall (1962), Shannon and Miller (1972) and Zachrisson (1974), writing about the prevention of decalcification under orthodontic banding stress the importance of this procedure.

3.4 COATING TECHNIQUES.

The idea of using coatings to protect the enamel under orthodontic banding is not new. Murless (1936) suggested the routine use of silver nitrate followed by eugenol as a means of "abating dental caries" in anchor teeth beneath orthodontic bands. However, the staining of any decalcified areas present left an unsightly result.

When Lefkowitz and Bodecker (1938) first made the observation in experiments on dog's teeth that contact with cement made the teeth permeable to potassium permanganate dye, they suggested that some reagent such as varnish should be placed prior to cementing orthodontic bands. Lefkowitz (1940) followed this up by placing a varnish under half of the buccal surface of four teeth which were to have bands placed. He found that:-

> "Preliminary observations indicate that the method is effective"

i.e. that varnish protects the enamel against the decalcifying effects of the cement.

Castello, Massler, Monteleone and Süher (1948) found that, in experiments on the decalcifying effects of different cement mixes, colloidion served as a protective film against the etching action of cement. Also the cement adhered to the colloidion-covered enamel surface as firmly as it did to the exposed enamel. They thus suggested the use of colloidion as a method of protecting the enamel surface under orthodontic banding.

Meyers (1952) used copalite varnish to coat teeth in a clinical test. He states that 27.4% of the 263 control teeth studied showed new areas of decalcification after six months of treatment. However, the correct percentage, when calculated from the figures presented is 23.9%. Only 5.9% of the 275 coated teeth showed new areas of decalcification after the same period of therapy. Adams (1955), however, reported that some orthodontists using varnish to protect enamel had noticed an increase in the number of loosened bands.

More recently attention has focused on the use of acid-etch materials, applied to teeth prior to banding, to protect enamel surfaces from decalcification during orthodontic therapy. Lee, Orlowski and Kobashigawa (1973) suggested the use of a resin (Protecto) either with or without the prior etching of enamel to protect enamel under and around orthodontic bands against decalcifications.

In vitro studies by Tillery, Hembree and Weber (1976) found that Protecto when used in an acid-etch system gave greater protection against decalcification than one application of either an APF gel or stannous fluoride solution over an eleven weeks period.

Neumann (1976) similarly found that both Protecto and Nuvaseal gave better protection against decalcification under orthodontic banding than a single application of either of two commercially available APF agents. He found that Protecto was somewhat more effective than Nuvaseal, although it was not stated whether these materials were applied as acid-etch procedures.

In contrast, Hughes, Hembree and Weber (1979) and Younis, Hughes and Weber (1979), using the same in vitro techniques as Tillery, Hembree and Weber (1976), found that, over twenty one weeks Nuvaseal protected the teeth better than copalite varnish, portrait veneer or even Protecto. Both Nuvaseal and Protecto were applied as acid-etch procedures.

Zachrisson (1976) and Zachrisson (1978b) believe that sealing with acid-etch materials in areas which are particularly caries-prone, such as the buccal of lower molars, is a good preventive idea. Brandt (1980) supports this contention.

I feel that the available evidence suggests that acid-etch type materials are certainly the most positive protection against decalcification under and around orthodontic banding. Its great advantages are that it is a single application technique and requires no patient co-operation to be effective. The major deterrants to routine use are that its placement requires more office time and the fact that interproximal protection is difficult. As noted by Zachrisson (1978b) the polymerisation process is inhibited, in thin sections, by contact with air and this makes sealing of the interproximal surfaces a problem.

3.5 ORAL HYGIENE.

Zachrisson and Zachrisson (1971b) drew attention to the vital importance of proper oral hygiene measures during orthodontic treatment, despite the use of proper fluoride protection. They found an almost linear relationship between the level of oral hygiene (evaluated by the use of a Plaque and Gingival Index score) and a Caries Index developed to evaluate decalcification as well as frank caries.

Obviously, oral hygiene is greatly complicated following the placement of fixed orthodontic appliances - for reviews see Shannon and Miller (1972) and Shannon (1972). However, orthodontists have an unexcelled opportunity to teach preventive dentistry and disease control to their patients. Mostly, the patients are at an age when sensitivity to learning and habit formation are at a peak. Orthodontists customarily explain to their patients the importance of oral hygiene before and during treatment. However, because the patient is seen regularly and over a prolonged period of time, the orthodontist has the opportunity, as well as, I believe, the obligation to play an even greater role in preventive dentistry and, specifically disease control both during and after orthodontic therapy. The aim should be to attain habits which not only will be effective in preventing disease of teeth and periodontal tissues but have far reaching implications throughout the patient's lifetime.

Undoubtedly, effective plaque control is the prime consideration for good oral hygiene. Lindhe and Axelsson (1973) and Suomi, Greene, Vermillion, Doyle, Chang and Leatherwood (1971) demonstrated that even on a short-term basis (one to three years), people receiving frequent prophylaxis and personal oral hygiene instruction have cleaner teeth, less caries involvement, less gingival inflammation, a slower rate of apical migration of the epithelial attachment, and less bone loss radiographically than persons not receiving such attention.

Given that the orthodontic patient represents an increased caries risk, Alexander, Jacobs and Turpin (1977) and Zachrisson (1978a) both believe that, relative to the magnitude of this problem, efforts extended to improve oral hygiene in average orthodontic practices are minimal and frequently inadequate. Therefore, they believe, preventive approaches designed specifically for the orthodontic patients are long overdue.

Schwaninger and Schwaninger (1975) point out that the beginning of this oral hygiene programme must be with the orthodontist himself. They believe he must be convinced didactically of the physiological manifestations of inadequate daily plaque removal and, moreover, perform regular habits of good oral hygiene himself. Only in this manner, they state, can he transmit the adequate enthusiasm and trust necessary to motivate others. It is essential that the oral hygiene problem in orthodontics not be dismissed as a matter of patient, parent or family dentist responsibility after a cursory sentence of instruction and warning.

The next necessity is to gain the trust and confidence of the patient. Assuming that the orthodontist and his staff are sufficiently motivated, the individuality of each patient must be allowed to emerge. Once the correct patient/doctor relationship has been attained then all factors involved with the influence of plaque on caries and periodontal disease need to be explained. Alexander, Jacobs and Turpin (1977) stress the need for the patient and parent to understand fully any discourse and suggest that technical terminology or dental jargon may be a definite barrier to learning. They also suggest that non-authoritative and non-threatening verbal testing help reinforce information and impress the fact that patients be encouraged for good aspects of their oral hygiene efforts rather than continually chastised for deficiencies.

Toothbrushing, undoubtedly, is the most popularly accepted means for food debridement and plaque removal. No reports have been made concerning the clinical effectiveness of the various recommended methods of toothbrushing in orthodontic patients. Sagnes, Zachrisson and Gjermo (1972) and Sagnes (1974) report that, in the hands of children, who may lack the dexterity to master more involved procedures such as the roll method, the best cleaning effects were obtained with horizontal techniques. Zachrisson and Zachrisson (1971a), Zachrisson (1974), Schwaninger and Schwaninger (1975), Wisth and Nord (1977) and Zachrisson (1978a), recommend either horizontal scrub or Bass techniques to ensure good cleaning along gingival margins which is of paramount importance in orthodontic patients. Although Womach and Guay (1968) found electric toothbrushing to be superior to manual toothbrushing when used by orthodontic patients, Kobayashi and Ash (1964) found each method to be equally effective in their study. Schwaninger and Schwaninger (1975) believe that the main criteria for either manual or electric toothbrushing is that the brush be adaptable enough to reach the surface of the teeth made less accessible by the orthodontic appliances. Zachrisson (1974) and Zachrisson (1978a) recommend a small, soft or medium hard, nylon bristled and multibristled brush.

Zachrisson (1974) and Schwaninger and Schwaninger (1975) suggest the use of watersprays and the additional use of urea peroxidase or chlorhexidene mouthrinses to aid plaque removal but it appears that toothbrushing is more than adequate, as long as the quality is stressed rather than the quantity.

CHAPTER 4.

MECHANISMS OF DECALCIFICATION AND MODE OF ACTION OF FLUORIDE

4.1 THE PHYSIOCHEMICAL DYNAMICS OF DECALCIFICAITON.

Enamel demineralisation under oral conditions is generally accepted to result from acid produced by the metabolism of cariogenic micro-organisms in dental plaque - for review see Kleinberg (1979). The formation of dental caries is more complex than the simple dissolution process of hard tissue. The histology of incipient carious lesions has been reported in detail by various investigators including Darling(1956a and b) Darling (1958), Soni and Brudevold (1959), Silverstone (1967) and Silverstone (1968). The most striking histolgic feature of the incipient lesion is the presence of a relatively sound surface layer of enamel overlying the demineralised zone i.e. the bulk of the mineral loss in the early stages of demineralisation occurs at some distance from the enamel surface.

Early workers, studying the demineralisation process, suggested that the formation of this relatively unaffected surface layer, over the small lesion of enamel caries, was closely associated with the special properties of the surface enamel. Chemical studies by a number of workers have shown that if the original enamel surface was removed, then the remaining enamel was more susceptible to acid demineralisation. This greater resistance of the surface enamel to caries dissolution has been explained as being due, in part at least, to its higher degree of mineralisation compared with subsurface enamel - Brudevold (1948), Hals, Morch and Sand (1955). This together with higher fluoride content (Isaac, Brudevold, Smith and Gardner, 1958), and perhaps a greater amount of insoluble protein in the surface enamel (Darling, 1958), may account for it being less soluble than subsurface tissue as shown by acid-etching studies (Sullivan, 1954).

More recently several workers have removed part of the natural enamel surface prior to in vitro experiments with artificial caries systems in order to see if a surface zone would form superficial to the lesion on the new enamel surface. Sperber and Buonocore (1963) and Gray and Francis (1963) both showed that a relatively well mineralised layer would be produced superficial to a demineralised region on abraded enamel during in vitro testing with acid buffers. Von der Fehr (1967) showed that a well-mineralised surface layer could be created on abraded enamel, overlying a heavily demineralised region, in vivo as well as in vitro. Using an acidified gel technique, Silverstone (1968), produced lesions on artificially abraded enamel surfaces which had up to 500μm of surface enamel cut away prior to the experiment. The lesions created on these surfaces still showed well-mineralised surface layers.

These results suggest that the "special"physical and chemical properties of surface enamel, relative to subsurface enamel, are not entirely responsible for the presence of a well-mineralised surface zone above the small carious lesion.

Comprehensive models explaining the controlling factors in the development of those features of the incipient lesion are relatively few. The most widely accepted early explanation of the mechanisms involved in the initiation of subsurface decalcification was found in a physical model proposed by Holly and Gray (1968) - see Fig. 7.

The model is based on a double membrane. The outer membrane consists of a relatively sound outer layer which remains of constant thickness. This intact layer is brought about by the incorporation of hydroxyethyl cellulose (HEC) into the experimental solution. The authors propose that this HEC "sorbs" to the enamel surface and protects it from

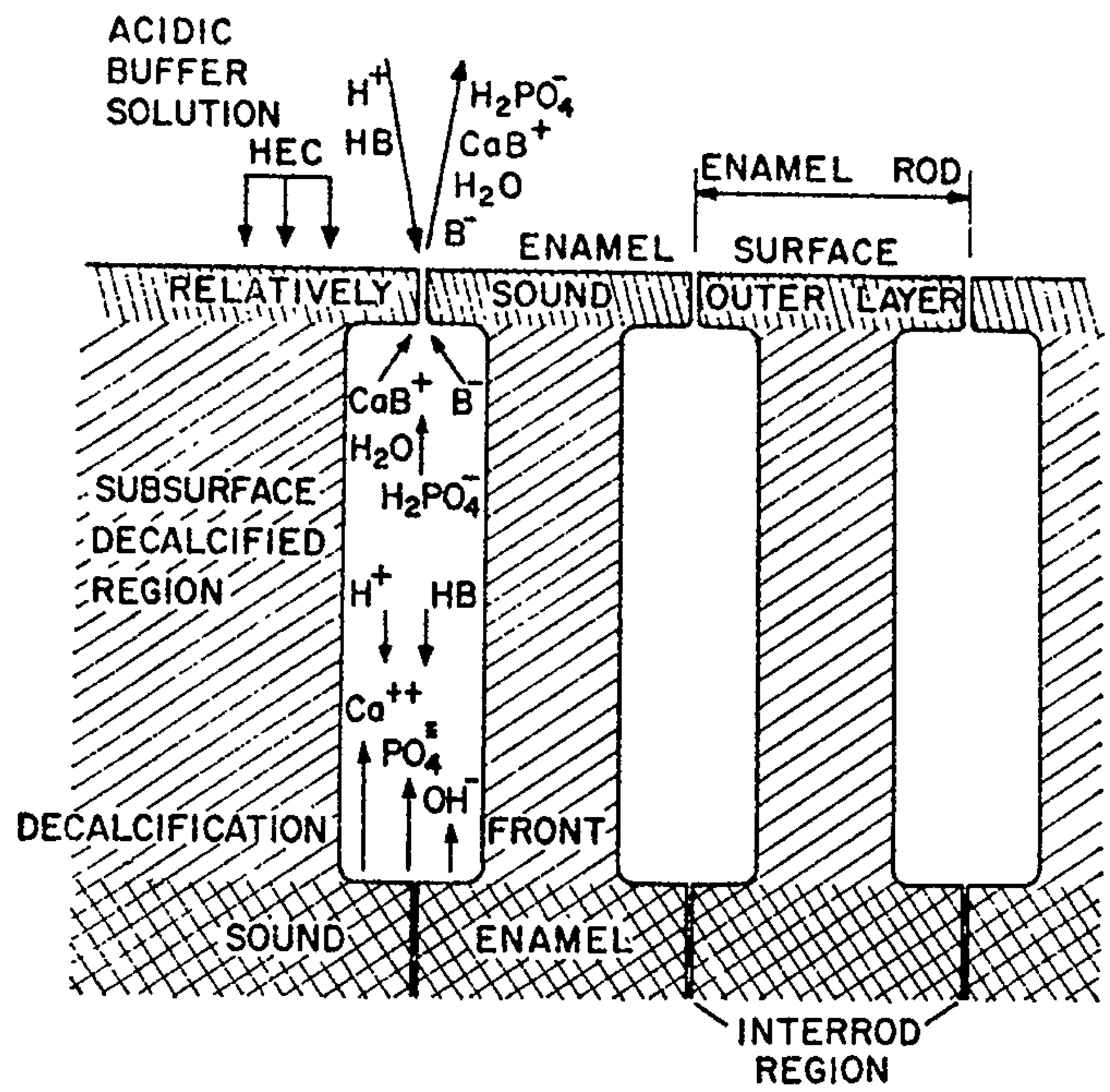

Fig. 7 Model of progress of an incipient caries-like lesion (Holly and Gray, 1968. p.325)

attack by the hydrogen ions and undissociated acid. This protection mechanism was considered to be carried out by the enamel pellicle in the in vivo situation.

The subsurface decalcified region represents the outer membrane which increases in thickness with time. The hydrogen ions and undissociated acid enter through the interrod spaces of the sound outer layer into the subsurface region to undergo reaction at the decalcification front. The reaction products then diffuse from the reaction sites, out of the enamel and into the bulk solution.

From this model the authors developed mathematical equations which described the time-dependence of the acid concentration and the depth of decalcification during the formation of an incipient carious lesion.

More recent attempts to explain the subsurface phenomenon focus on thermodynamic and kinetic considerations. Moreno and Zahradnik (1974) proposed a model which appears to explain many of the features of the incipient lesion - see Fig. 8.

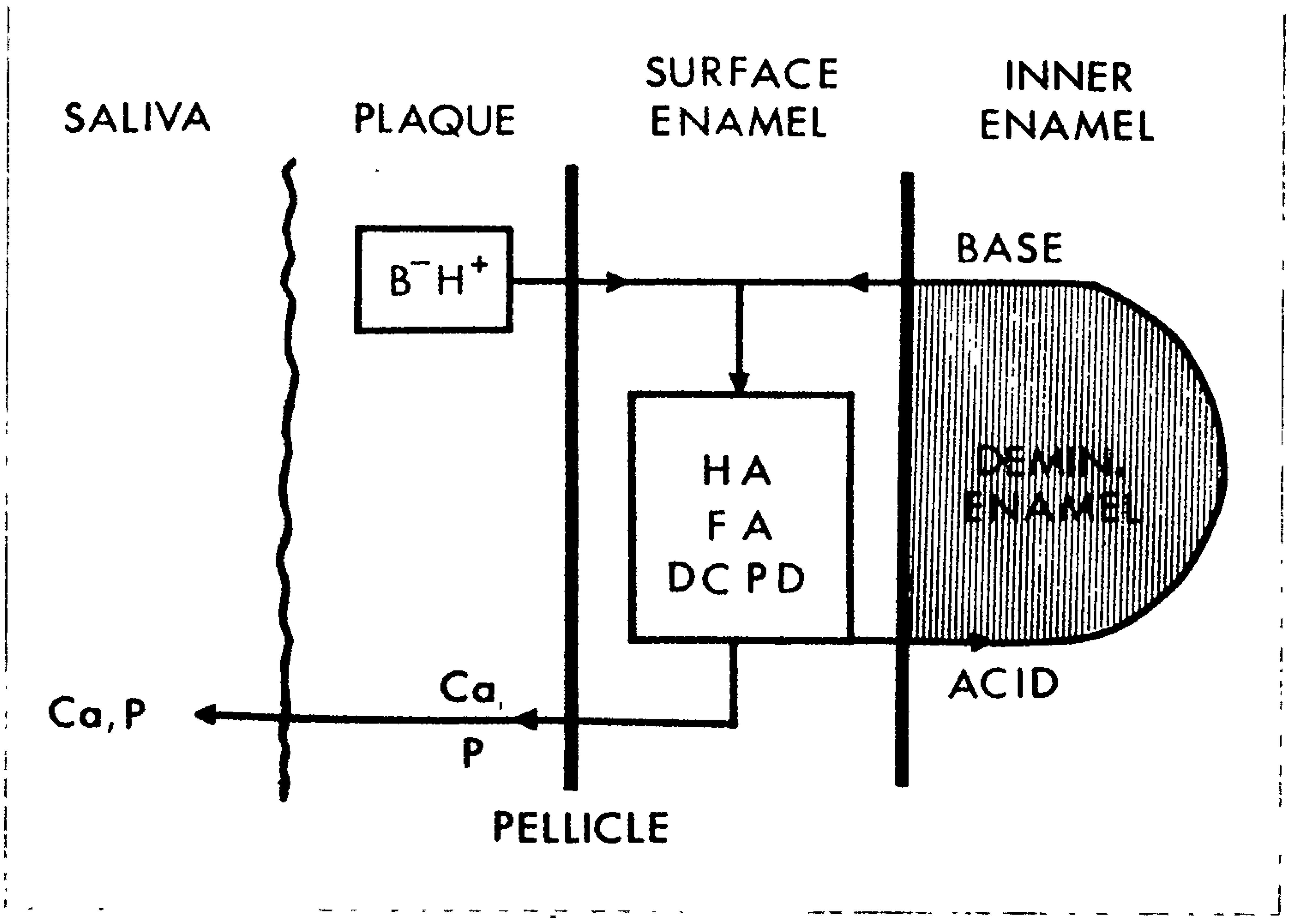

Fig. 8 Schematic representation of model for subsurface demineralisation, (Moreno and Zahradnik, 1974. p.227)

According to this model, organic acids (H^+B^-) produced by the metabolic activity of the microorganisms in plaque, diffuse into enamel. Under certain conditions of acid concentration and initial pH, slight dissolution of the surface occurs followed by precipitation of other solid compounds containing calcium and phosphate ions e.g. $Ca\,H\,PO_4 \cdot 2H_2O$ (DCPD) and $Ca_5F(PO_4)_3$ (FA). The fluoride for the precipitation of fluorapatite comes from the naturally occurring fluoride in dental enamel. The composition of the surface layer is a function of the thermodynamic properties of the three solid phases (DCPD, FA and the bulk of the enamel), the acid concentration and the initial pH of the acid. Diffusion of acid constitutents occurs from the surface zone into the inner enamel. As they diffuse deeper into the enamel, they are neutralised by the dissolution of the inner enamel mineral.

Conversely, calcium hydroxide in this neutralised inner zone is higher than the surface zone, hence basic constituents will diffuse towards the surface zone. At the same time, diffusion gradients will bring about transportation of soluble constituents from the surface enamel into the saliva.

The model thus acts as a pumping mechanism, with matter being pumped from the inner enamel to the surface zone and then into the saliva. The surface remains unaltered simply because it is continually being regenerated. The pumping rates are in reality diffusion fluxes. The fluxes must be such that the rate of precipitation in the surface zone at least matches the rate at which matter is transported from this zone into the saliva, otherwise a cavitation would appear. As the lesion progresses, the rate of precipitation decreases because the rate of dissolution of the inner enamel is reduced (smaller surface area) and the diffusion path increases. Eventually the rate of transfer from the surface enamel to the saliva becomes greater than the rate of precipitation in this former zone. This marks the initiation of the collapse of the structure, and a cavity is the resultant.

Later experiments by Zahradnik, Propas and Moreno (1978) found that seven days old enamel pellicle protects the tooth from demineralisation induced by cariogenic micro-organisms. They found that this protection was not afforded by a decrease in the adherence of microbial deposits. The authors believe that the pellicle may act as a permselective membrane which controls the transport of matter from the surface of the enamel into the saliva.

Brown (1974) has attempted to develop a "physicochemical mechanism" for the formation of dental caries. By this he implies:-

> "a model of the system which takes into account thermodynamic, kinetic, structural and temporal considerations."

In developing this model Brown has extensively investigated the equilibrium solubility of compounds which can exist in the Ca O - H_3PO_4 - H_2O system. Hydroxyapatite is only one such compound. Others include, but are not limited to $Ca\ HPO_4$, $Ca\ HPO_4 . 2H_2O$, $C_8\ H_2\ (PO_4)_6 . 5\ H_2O$ and $\beta\ Ca_3\ (PO_4)_2$. Basically, Brown uses the solubility equilibra for the hydroxyapatite dissolution and determines the effect that changes in the composition of certain species of the system e.g. $Ca(OH)_2$ or H_3PO_4 would have. The system is enormously complex but it appears that certainly the factors controlling the events in the body of the lesion and in the reaction zone are thermodynamic in nature.

4.2 MODES OF ACTION OF FLUORIDE.

Since the carious process begins at the plaque-enamel interface it is convenient to consider the possible mechanism of fluoride action in two groups: those mechanisms operating on the chemistry of the enamel and those acting by way of the plaque. The mechanisms by which fluorides act on the chemistry of the enamel can be further divided into those leading to an increase in enamel resistance to dissolution, and those leading to enamel remineralisation.

4.2.1 Reactions of topical fluorides with enamel leading to increase in enamel resistance to dissolution.

Chemical analysis of extracted teeth show that immediately after in vivo application, fluoride penetrates 30-40μm into the enamel (Rinderer, Schait and Muhlemann,1965; Brudevold, McCann, Nilsson, Richardson and Coklica, 1967). Baud and Bang (1970) used an electron microprobe to show about a 50μm penetration after a four minute application of APF solution (1.23% fluoride). Wei and Frobes (1974) used the same technique to show an average 20μm penetration following the application of a 10% stannous fluoride solution. In vivo experiments have demonstrated that a large quantity of the fluoride present in the enamel immediately after treatment is lost after fourteen days (Rinderer, Schait and Muhlemann, 1965; and Mellberg, Laakso and Nicholson, 1966). Bruun,(1973) found that the residual fluoride content was similar in the surface enamel one and eight weeks after topical treatment with sodium fluoride. He thus contends that such fluoride is firmly fixed for at least this two month period. Thus it appears that fluoride readily diffuses 30-50μm into enamel following topical application. However it fails to react readily with the enamel to form compounds that are stable in the oral environment.

Hydroxyapatite is considered to be the basic mineral present in dental enamel. Prolonged exposure to low concentrations of fluoride can cause exchange of the hydroxyl ion whilst still maintaining the apatite structure. The resultant is the formation of fluorapatite:-

$$Ca_5(PO_4)_3OH \ +F^- \rightarrow Ca_5(PO_4)_3F \ +OH^-$$

Because the two apatites are isostructural, the conversion of hydroxyapatite to fluorapatite requires the diffusion of fluoride and hydroxyl ions through the solid. Solid state diffisuion is known to be extremely slow under normal temperatures and pressures. Therefore, this phenomenon probably only occurs on the surface of the enamal during topical applications (Chow, 1977). In fact Berndt and Stearns (1978) believe that most substitutions of fluoride for hydroxyl ions are incomplete and a pseudo-binding, solid solution termed fluorhydroxyapatite is formed.

Another way of forming fluorapatite is by dissolution of the hydroxyapatite and subsequent precipitation of fluorapatite. Gron (1977) reports that the process again is favoured by prolonged exposure to low concentration of fluoride:-

$$Ca_5(PO_4)_3 \ OH \rightleftarrows Ca^{2+} /3(PO_4)^{2-} \ +OH^-$$

$$5Ca^{2+} + 3 \ (PO_4)^{3-} + F^- \rightleftarrows Ca_3 \ PO_4 \ F$$

Early workers believed that the process of fluorapatite formation was the main mechanism behind the enamel solubility reduction noted after exposure of fluoride containing substances and indeed to the caries reducing effects of these products - for review see Levine (1976). More recently it has been found that under most circumstances fluorapatite is only slightly more insoluble than hydroxyapatite, and the differences in amount that are likely to dissolve is not sufficient to be a factor in cariostasis (for review see Brown, Gregory and Chow, 1977). These same authors, however, show that a very thin layer of fluorapatite on the surface of predominantly hydroxyapatite can make the whole material behave much as though as it all contained fluorapatite. They thus suggest that an ideal situation for reducing enamel solubility is to keep sufficient fluoride ion in the vicinity of the enamel surface to keep a layer of fluorapatite present. This requires a continual supply of fluoride ion.

Brown, Gregory and Chow (1977) further believe that the apparent decrease in solubility accompanying the incorporation of fluoride ion in enamel may in part be due to the fact that, in the presence of fluoride ion, the pH is lowered. This also results in the lowering of the $Ca(OH)_2$ activity. The ultimate effect of these conditions, when applied to the situation within a carious lesion, is to alter the rates of diffusion in a way that diminishes the rate of caries formation or increases the rate of remineralisation when fluoride ion is present.

McCann (1953) and McCann and Bullock (1955) studied the reactions between fluoride ions and synthetic hydroxyapatite or enamel over a wide range of fluoride concentrations and found that relatively high fluoride concentration (greater than 2,000 p.p.m.) and low solution-to-solid rates favoured fluoride formation:

$$Ca^{2+} + 2F^- \rightleftarrows CaF_2$$

Topical application depends to a large extent upon the use of relatively high concentrations of fluoride, often with rather long periods of time between reapplications. These conditions favour the formation of calcium fluoride. APF was developed in an attempt to increase the fluoride uptake by the tooth, to increase the formation of fluorapatite, and to discourage calcium fluoride formation (Brudevold, Savory, Gardner, Spinelli and Speirs, 1963; and Wellock and Brudevold, 1963). Subsequent X-ray crystallographic examination of APF solution interaction with powdered enamel by Frazier and Engen (1966), Wei and Forbes (1968) and Baud and Bang (1970) has shown that calcium fluoride is the major reaction product when the enamel was finely powdered. Baud and Bang (1970) were able to show that fluorapatite also formed when coarse powdered enamel was exposed to APF solutions for three days. In topical treatment by Wei and Forbes (1968), intact enamel failed to show formation of any significant amounts of calcium fluoride by X-ray crystallographic means. Caslavska, Moreno and Brudevold (1975) conversely showed that a five minutes treatment on polished subsurface enamel samples, with APF solution resulted in up to 19,550 p.p.m. of fluoride uptake in the layers. Of this uptake, less than 400 p.p.m. of fluoride was compounded in the enamel as fluorapatite, the remainder was present as calcium fluoride.

The stability of calcium fluoride has long been a matter of debate. McCann (1968) pointed out that 12-15 mg. of calcium fluoride will dissolve in one litre of saliva before saturation occurs. Consequently a surface layer of calcium fluoride would not be stable in the oral environment and would tend to wash away. This led certain authors to conclude that the generation of calcium fluoride was not desirable (for review see Gron, 1977). However, as pointed out by Chow (1977) calcium fluoride may play a role in increasing solubility of the enamel as a whole by acting as a store of fluoride ion, which may, upon dissolution, be taken up by the apatite to form fluorapatite at a later stage. Since calcium fluoride is unstable in the noraml oral environment, and since the caries process is such a slow and gradual process, there is a need to replace the protection regularly (Brown, Gregory and Chow, 1977; and Chow, 1977). This concept seems to fit the clinical observations of Ericsson (1977) of the importance of the frequency of application in making topical fluoride treatment effective.

The reactions of stannous fluoride with enamel involves both the stannous ion and the fluoride ion. Wei and Forbes (1968) reacted hydroxyapatite with stannous fluoride and identified a new crystalline material that appeared rapidly. It was suggested that the material was a tin phosphate but that it differed in stoichiometry and/or structure from those previously identified. Jordon, Wei, Bomberger and King (1971) later identified this compound as $Sn_3 F_3 PO_4$ and found it to be the major product in reacting sound or carious dentine, enamel and synthetic hydroxyapatite with stannous fluoride. Krutchkoff, Jordon, Wei and Nordquist (1977) used infra-red internal reflection spectroscopic studies of flattened enamel surfaces to show the formation of $Sn_3 F_3 PO_4$ in enamel blocks exposed to 10% stannous fluoride for two hours. They failed to show its presence after four minutes exposure.

Wei and Forbes (1974) and Wei (1974) used electron microprobe and scanning electron microscopic studies respectively to examine surface changes in enamel exposed to 10% stannous fluoride for periods ranging from thirty seconds to one week. No morphological changes were evident after thirty second exposures. Probe analysis, however, showed somewhat irregular distribution of tin to a depth averaging 20μm and fluoride was found only in the tin bearing areas. After four minutes the surface appeared roughened, as though an uneven layer of surface precipitate had been formed. The distribution of tin showed an increased concentration in the deeper enamel although the depth of penetration was irregular. Prolonged exposure resulted in increasing precipitation of a new surface layer. The morphology of this surface layer was consistent with the presence of $Sn_3 F_3 PO_4$, calcium fluoride and residual apatite being the main species found in surface enamel after exposure to stannous fluoride solution.

In summary it would appear that fluoride diffuses into the enamel when applied to the surface. It fails, however, to rapidly form compounds which are stable in the oral environment and much of the topically applied fluoride is lost within twenty four hours. Little is known about the reaction products formed during three to four minute applications in vivo. Prolonged in vitro exposures of enamel to fluoride solutions cause dissolution - precipitation processes where calcium fluoride and (in the case of topical stannous fluoride) $Sn_3 F_3 PO_4$ are the major products. Formation of fluorapatite in addition has been demonstrated in samples of coarsely powdered enamel after exposure of acid fluoride solutions. It is uncertain how this combination of fluorapatite and calcium fluoride may act to decrease the enamel solubility.

4.2.2 The Antibacterial Action of Fluoride.

Over the years much effort has been expended in the search for agents that will effectively inhibit plaque formation. Recent evidence suggests that stannous fluoride may derive some of its caries inhibiting effects in this way.

An early study by Konig (1959) reported that stannous fluoride inhibited plaque formation in rats. Glantz (1967) reported a reduction in the weight of dental plaque capable of adhering to enamel after treatment with stannous fluoride (containing 1200 p.p.m. fluoride ion). This reduction was not noted after rinsing with the same concentration of fluoride ion in a sodium fluoride solution.

Tinanoff, Brady and Gross (1976) used enamel blocks embedded into acrylic to form an appliance which was worn in the mouth to test the effects of rinses with sodium fluoride and stannous fluoride on colonisation of enamel by oral bacteria. Electron microscopic techniques were used to assess the bacterial colonisation.

They found that accumulation of bacteria on the enamel surfaces was little affected by once daily rinses of sodium fluoride (100 p.p.m. fluoride), but that twice daily rinses appeared to interfere with the attachment of bacteria as they were found in clumps and were poorly attached to the enamel. Stannous fluoride (100 p.p.m. fluoride) was found to have greater effects on the bacteria. Once daily mouth-rinses with the solution reduced bacterial colonisation greatly, whilst twice daily produced enamel surfaces essentially devoid of bacteria. These studies ranged from two to seven days. The authors suggest possible mechanisms of this reduction in colonisation as being either altered adhesive properties of the bacteria to the enamel or between bacteria and bacteria.

A further study by Gross and Tinanoff (1977) confirmed the reduction in absolute numbers of micro-organisms colonising the enamel blocks after exposure to two days of stannous fluoride rinsing. They further showed that particularly streptococcal counts were reduced by 97.9%.

Hoffman, Tow and Cole (1977) evaluated the effectiveness of 10% stannous fluoride used as a topical agent in affecting colonisation of enamel in an in vitro experiment. The parameters compared were postincubation pH, bacterial concentrations on the surface and enamel surface alterations. They found that stannous fluoride-treated samples consistently yielded higher pH readings, reduced micro-organisms adhering to the surface and reduced smooth surface alterations. These authors contend that many fluorides act in several ways to inhibit cariogenesis, and antibacterial action seems to be one.

Svantun, Gjermo, Eriksen and Rolla (1977) added further evidence to support the contention of an antibacterial action for stannous fluoride. They showed that two concentrations of stannous fluoride mouthrinses (0.2% and 0.3%) reduced plaque index values significantly in a group of subjects who did not use any oral hygiene measures over a three week period. Twelve test patients were used and plaque was stimulated by the use of sucrose mouthrinses. A control group using distilled water as a mouthrinse acted as a baseline for the plaque scoring. Chlorhexidene was found to inhibit plaque accumulation also. A strong metallic taste (particularly with the 0.3% solution) and some yellowish-brown discolouration of the tongue and teeth was reported.

Loesche (1977) reviewed the literature on the anti-bacterial effects of topical fluorides. He came to the conclusion that the effects of caries reduction noted with the use of higher fluoride concentrations in topical applications may be due mainly to the elimination of

Streptococcus mutans from the tooth surface. Since he considers S. mutans to be the major bacterial form in the caries process, and since S. mutans colonises only the tooth surface and is not found on the oral soft tissues, he suggests this process may result in the caries reductions noted after topical applications of fluoride.

Svatun (1978) reported that the antibacterial affects found in fluoride solutions used as mouthrinses were also present when used in a dentifrice. To eliminate the individual variations often associated with toothbrushing, which the author considers is inclined to mask possible differences between experimental toothpastes, the dentifrices were applied to the teeth in cap splints. He found that significant reductions in plaque index were found in the group administered with stannous fluoride-containing dentifrice compared to a group receiving a placebo dentifrice. As with previous reports by this author, no oral hygiene procedures were performed by the participants during the two day trial. Sucrose mouthrinses were also used by the twelve subjects who made up the four test groups in the study. The author considers that the stannous ion is associated in the plaque inhibition exerted by the stannous fluoride. He considers that the stannous ion may change the surface potential of the bacteria and prevent binding to the tooth.

This necessity of the stannous ion in any antibacterial action was corroborated by Skjorland, Gjermo and Rolla (1978). Using the same testing protocol as Svatun, Gjermo, Eriksen and Rolla (1977) and Svatun (1978), they found that solutions containing 20 m.mol/litre stannous fluoride and stannous chloride exhibited a marked plaque-inhibiting action when used twice daily as mouthrinses. The same concentration of sodium fluoride or sodium chloride failed to produce a reduction in plaque formation. Aluminium, zinc and magnesium salts of chloride also reduced plaque formation, although not to the same extent as stannous containing solutions. They considered that polyvalent cations may prevent plaque formation by interaction with negatively charged plaque components essential in the absorption mechanism, or by inhibiting some enzyme activity essential in plaque formation. Metallic taste and moderate staining were again reported.

Although not directly concerned with plaque formation, a study by Svatun and Attramadal (1978) showed that acid production in four day-old dental plaque was markedly inhibited by a single mouthrinse with 0.2% stannous fluoride for at least seven hours. A commercial toothpaste containing stannous fluoride and stannous pyrophosphate had an effect similar to the 0.2% mouthrinse. It was also observed that tin accumulated in the dental plaque. About 40% of the amount present in the plaque immediately after the mouthrinse was still retained seven hours later. The authors suggest that the reduction in acid formation after stannous fluoride exposure may be the result of a disturbance in the membrane transport mechanism of the bacteria or through inhibition of enzyme systems essential in the fermentation of sugars.

Zahradnik, Propas and Moreno (1978) used lactate buffer systems and a bacteriologic system containing S. mutans in an attempt to determine the major means of protection, against decalcification, attained by the use of fluoride substances. Teeth, for the experiments were sectioned buccolingually. Half was retained as the control whilst the remaining half was given an application of the fluoride solution. The solutions tested were a 2% sodium fluoride and an APF containing 1.2% fluoride. The results showed that decalcification in the buffer system, after 72 hours, was not reduced by a single application of either fluoride solution. A statistically significant decrease in the thickness of the altered enamel layer was observed after single exposures of both sodium fluoride and APF solutions followed by five days incubation with S. mutans. Further they showed that the APF treatment consistently showed a greater level of protection against bacterial challenge. A further test involved the application of potassium hydroxide to the enamel after treatment with the fluoride solution. This was done to selectively remove the calcium fluoride formed in the enamel after exposure to sodium fluoride and APF (see Caslavska, Moreno and Brudevold, 1975). It was found that the sodium fluoride-treated teeth no longer displayed protection against the bacteriologic challenge. The teeth exposed to APF prior to the potassium hydroxide treatment, moreover, exhibited greater demineralisation than the control when placed in the culture.

Zahradnik, Propas and Moreno concluded that the protection against demineralisation afforded by sodium fluoride and APF does not appear to be related to the enhancement of the stability of the enamel toward acid attack. Protection was, however, noted against demineralisation induced by cariogenic micro-organisms in vitro. The results do not provide information about the exact mechanism of this protection. However, all observations lead to the conclusion that this protection is related to the presence of calcium fluoride, which, as we have seen, is the major reaction product when dental enamel is treated with any topical fluoride. The presence of this salt Moreno and Zahradnik (1979) believe is likely to affect both the rate of cellular attachment and the glycolytic metabolism.

In a clinical study by White and Taylor (1979) two groups of subjects from a Boys' Home were used. The test group used brushing and rinsing with stannous fluoride compounds and the control group used placebo compounds. All participants brushed with either test or control dentifrices and rinsed with corresponding test or control solutions twice daily, under supervision, for the first six days. No difference in plaque scores was noted between the two groups during this phase. This result may be expected in a very closely supervised programme where most of the plaque would be physically removed by toothbrushing. The next five days involved twice daily rinsing with the solutions only, with no other oral hygiene practices. Plaque scores during this period showed a highly significant reduction in the group using stannous fluoride. Hence once again the antibacterial effects of stannous fluoride appear to have been demonstrated.

Kilian, Larsen, Ferjerskov and Thylstrup (1979) designed a study to test whether the initial colonisation (within the first five days) of enamel was affected by fluoride. They could find no reduction in numbers or change in types of bacteria recovered from test enamel surfaces treated with hourly rinses of sodium fluoride, over those recorded on control enamel. Nor could they find any changes in bacterial numbers when fluoride was incorporated into the test surfaces in the form of calcium fluoride or fluorapatite. Conversely, significantly fewer bacteria, and mainly actinomycetes, were recovered from surfaces exposed hourly to a 0.373% stannous fluoride solution. The authors thus hypothesised that the antibacterial effect of stannous fluoride may be ascribed to a combined adhesion-interference activity of the tin ion and a bacteriocidal effect of the solution. The results indicate that the fluoride ion per se has no appreciable effect on the initial colonisation of smooth surface enamel.

An experiment using rats as the test subjects was set up by Shern and Couet (1979) to assess the affects of stannous fluoride on six day-old plaque. The test rats were given a high concentration (2%) mouthrinse twice daily. After seven days they found very significant reductions in the plaque levels, as measure by fluorescent microscopy, in the test rats over the controls, who were given distilled water as rinses. Also it was found that the stannous fluoride rinses were effective in restricting the ability of plaque to lower the pH afer exposure to sugar solutions.

In a study on orthodontic patients, Ogaard, Gjermo and Rolla (1980) showed a plaque-inhibiting effect from a stannous pyrophosphate dentifrice. When applied directly to the teeth of patients with fixed orthodontic appliances, the dentifrice was found to reduce the amount of plaque present on the tooth, (assessed by a visual method) significantly more than a control paste containing monofluorophosphate. The plaque score was performed twenty four hours after the application of the paste. Each patient acted as his/her own control by receiving an application of one dentifrice, and one week later an application of the other. The plaque scores were then correlated. A second experiment compared the plaque scores on teeth after three weeks of brushing with each dentifrice. Again the procedure was carried out as a double-blind, crossover study with each patient using both dentifrices with at least one week lapse between the use of the second dentifrice. Again plaque scores were significantly lower after using the stannous fluoride dentifrice. The authors suggest that the use of a stannous fluoride containing dentifrice should be advised to all orthodontic patients as it may have both plaque inhibiting as well as solubility reducing effects.

From the review it would appear that at least stannous fluoride has significant anti-bacterial properties. The exact mechanism by which stannous fluoride inhibits plaque formation and function is still unclear. Some of the ways that stannous fluoride may act, include:-

i) Interfering with the initial adhesion of bacteria to the enamel pellicle.

ii) Interfering with the subsequent multiplication and aggregation of plaque bacteria.

iii) Inducing a shift in plaque flora towards relatively fluoride-resistant micro-organisms.

iv) Inhibition of microbial glycolytic activity.

4.2.3 The role of fluoride in remineralisation processes.

As we have seen it is now considered that the formation of the carious lesion is due to a dynamic series of events rather than one of simple demineralisation. It would appear, therefore, that the surface zone itself is a manifestation, in part at least, of a remineralisation process.

Following a very early report by Head (1912) on the possibility of a remineralisation phenomenon occurring in caries, work of a more scientific nature has been carried out over the past twenty years. There is ample evidence to show that acid softened enamel surfaces, artificial caries-like lesions and small carious lesions can all be remineralised in vitro (for review see Silverstone, 1977). This process of remineralisation may be the phenomenon responsible for the so-called "reversals" of diagnosis in clinical caries, whereby early lesions, detected clinically and by intraoral radiography, apparently have "disappeared" when examined at a later date using identical criteria as noted by Anderson (1938), Muhler (1961), Hinrichsen (1964) and Backer-Dirks (1966). However, as noted by the authors such "healing" or remineralisation can only take place as long as cavitation has not occurred.

Basically the two agents most generally studied in relation to the remineralisation process are saliva and synthetic calcifying fluids. It is apparent that both agents will produce some degree of remineralisation in vitro. When comparing their remineralising action, saliva is found to be far more limited than the synthetic calcifying fluids. Saliva's action is confined to the surface layers, and this may be related to its viscosity, which may restrict penetration into the lesion (Silverstone, 1977). Also human saliva varies for different individuals in its ability to reharden enamel (Koulourdies, Feagin and Pigman, 1965).

In 1961 Koulourides, Ceuto and Pigman described conditions which they had developed for rehardening tooth surfaces previously softened by exposure to an acid buffer solution. Solutions containing 1 p.p.m. of fluoride ion showed a faster rate of rehardening than those without fluoride, indicating that it accelerated the hardening process. In a later study by Koulourides (1968) showed that fluoride exerted a significant effect on the rehardening rate of buffered-softened enamel surfaces. Even at a concentration of 0.05 mM, fluoride accelerated the rehardening rate by a factor of four or five. In this report the author points out that this effect of fluoride should be distinguished from the antisolubibilty effect. The remineralisation effect, he considers requires the presence of fluoride in the fluid environment of the tooth surface, whereas the antisolubility effect increases the chemical stability of the tooth surface towards acid attack. Fluoride can be provided at the sites of tooth dissolution either from the oral fluid environment or from dissolving enamel crystals. In both cases it will favour reformation of mineral apatite. Thus the degree of enrichment of enamel with fluoride, would protect the tooth surface even if part of the fluoride is not incorporated in the hydroxyapatite lattice. Again this suggests the need for continuous use of fluoride substances to achieve this remineralising effect.

Silverstone (1972) showed that synthetic calcifying solutions could increase the negative birefringence of sound enamel. This, the author believes, can only be explained in terms of the deposition of mineral from the calcifying fluid since the synthetic solutions used contained no organic material. Further, in these studies, it was found that the presence of fluoride ions, added to the calcifying fluids, led to an increase in both the value of the negative birefringence recorded i.e. increased deposition of mineral crystals and also the rate at which the fluid caused the increase in negative birefringence. Only very low concentrations (0.05 mM) of fluoride were necessary in the calcifying solutions to produce this increased effect. Also, the increase was not significantly greater at 0.5mM fluoride than with 0.05mM. Thus, a low concentration of fluoride ion appeared to be sufficient to facilitate the precipitation of mineral into the enamel surface. In a later article, Silverstone (1977) notes that it may be advantageous to use high levels of fluoride so that as well as acting as a remineralising agent, it may also play a role as a topical fluoride.

A clinical study by Von der Fehr, Loe and Theilade (1970) support the conclusion that fluoride may help in remineralisation of small lesions. These investigators induced experimental caries by using sucrose mouthrinses over a period of twenty three days during which time the subjects were instructed to refrain from any oral hygiene procedures. Subsequently oral hygiene procedures were commenced and the subjects used daily mouthrinses with 0.2% sodium fluoride solutions for one month. Caries scores showed regression or "healing" of the experimental lesions during the fluoride mouthrinsing period.

The use of fluoride to effect remineralisation in patients who have experienced areas of decalcification during orthodontic procedures has been proposed by a number of authors. Hodgson (1971) suggests a technique which involves the stoning of the surface of the demineralised area followed by the application of a 1% sodium fluoride solution for fifteen to twenty seconds. Subsequent to this a desensitizing toothpaste is applied to the area using an ionising brush and allowed to remain for four to five minutes. The desensitizing paste is also supplied for use at home. The author stresses that the demineralised surface should be kept free from saliva subsequent to band removal and prior to the application of the fluoride solution.

Cooke and Weakes (1978) use selected tips on an ultrasonic instrument to remove the surface layers in decalcified areas occurring during orthodontic treatment. They then suggest the use of a positioner to apply APF gel to the affected areas to encourage remineralisation of the enamel.

In contrast to these reports Harvey (1980) suggests that where the enamel surface is intact i.e. only subsurface decalcification is present, it is important no instrumentation which would abrade the surface should be used. Rather the area should be kept free from saliva and a 2% sodium fluoride solution applied and maintained for four minutes. A calcium sucrose phosphate gel should then be applied and also left in contact with the affected enamel for four minutes. The patient is instructed to rinse daily with a 0.05% sodium fluoride solution and to use a calcium sucrose phosphate dentifrice daily. This approach appears to be more closely linked to the work carried out by researchers, in vitro, as it ensures that a continual supply of fluoride is present around the tooth surface which would help encourage remineralisation.

The importance of fluoride as a remineralising agent, is not limited to use subsequent to band removal, when clinically detected areas of decalcification are present. If daily use of mouthrinses and dentifrices are incorporated in home care procedures, then, this constant supply of fluoride is present to help provide remineralisation phenomena in the enamel even before the surface becomes affected sufficiently to present as areas of frank decalcification.

CHAPTER 5.

PRESENT STUDY.

5.1 INTRODUCTION.

As noted in chapter 1.2 many authors have attempted to evaluate the incidence of decalcification occurring during the time a patient is undergoing orthodontic treatment. All the studies are reported in areas where the communal water supply has less than optimal levels of fluoride. No reports were found, reporting the incidence of decalcification occurring on teeth during orthodontic therapy in fluoridated communities, such as occurs in Sydney, Australia. Study 1 of the present work was set up with the intent of gaining some idea of the incidence of decalcification occurring on the buccal surface of lower molar teeth and the lingual surface of upper molar teeth which were banded during fixed orthodontic therapy. This incidence was compared to a similar group of patients who did not receive orthodontic treatment. All patients were lifetime inhabitants in a community which has had an optimally fluoridated water supply since 1968.

From the literature review presented, it is apparent that many fluoride compounds have been shown to be effective in reducing the caries process. Also children undergoing orthodontic thereapy have been shown to represent a group with an increased caries risk. Many fluoride-containing products could be used to reduce this risk during the time that the patient is undergoing treatment.

In vitro testing by Tillery, Hembree and Weber (1976) found that although single applications of APF and stannous fluoride did reduce decalcification somewhat, the protection afforded was significantly less than that offered by adhesive coatings applied under orthodontic bands. The authors suggested that other fluorides and frequent reapplication should be tested.

The in vitro technique used by Tillery, Hembree and Weber (1976) to produce the caries-like lesions was basically a gelatin medium containing lactic acid. This medium is unsatisfactory for testing frequent reapplication of solutions where orthodontic bands are present, as the removal of the gelatin from under and around the bands, prior to application of the test solution would be difficult, if not impossible. As a result, a solution which could produce lesions resembling the features of the initial stages of the caries process was sought. Study 2 of the present work examines the use of such a medium to produce in vitro decalcification. Further, it tests the effect on the decalcification produced, of frequent re-exposure of the enamel to a dilute solution of sodium fluoride.

5.2 STUDY 1.

5.2.1 Materials and Method.

Materials

a) Experimental Groups.

The patients involved in this study were selected on the basis of being lifetime residents in the Sydney Metropolitan area which has a water supply which has been optimally fluoridated (1 p.p.m.) since 1968.

The control group numbering thirty, were selected from the patients attending the Orthodontic Department of the University of Sydney. The criteria for selection was that previous photographs were available of the buccal surfaces of the lower first permanent molars and the lingual surfaces of the upper first permanent molars. A second photograph was taken of these surfaces at a period not less than twelve months and not more than thirty months after the initial photographs. No fixed bands were cemented to the teeth studied on the control group in the period prior to the second set of photographs.

The test group consisted of fifteen patients. The patients were selected on the basis of having been treated with fixed orthodontic appliances (Begg technique) in upper and lower arches. They represent presentation case of M.D.Sc. Graduate Students at the University of Sydney annual examinations in 1980. Further criteria included the availability of adequate photographs of the buccal surfaces of the lower molars (either first or second permanent) that were used as an anchor molar, and the lingual surface of the corresponding upper molars (either first permanent or second permanent).

Table 1 summarises the composition and incidence of decalcification at the time of the first photograph in both the control and test groups.

Group	Number of Individuals		Mean Age at "Before" photograph	Decalcification present at "Before" photograph		Period between "Before" and "After" photograph
	Male	Female		Patients	Surfaces	
Control	13	17	12 yrs 7 mths $\pm$ 19 mths	7	9	20.4 $\pm$ 5.4 mths
Test	8	7	14 yrs 10mths $\pm$ 16 mths	3	5	19.2 $\pm$ 3.0 mths

Table 1.

Comparison of control and test populations.

b) Photography.

The photographs were all supplied as 35mm clolour transparencies. No attempt was made to standardise the photography as regards magnification, exposure or angulation, since the initial transparencies were taken prior to the commencement of the present study. However, only patients who were deemed to have transparencies adequate to observe the surfaces under scrutiny were accepted into the study.

Method.

a) Evaluation of Decalcification.

The evaluation of decalcification for both the control and the test groups was carried out as a double-blind study. The transparencies of all patients were randomly projected on a screen in a darkened room. They were viewed by four Second Year Graduate Students enrolled in the M.D.Sc. Degree at the University of Sydney. They each evaluated the buccal surface of the lower molar teeth and lingual surface of the upper permanent molar teeth shown in the transparencies, for the presence or absence of decalcification. The Zachrisson (1971a) classification was used to evaluate the surfaces. Scores of 1, 2 or 3 were marked as the presence of decalcification and 0 as absent.

b) Correlation of Scores.

The scores of the four observers, who considered decalcification was present in the surface examined, were added together for each transparency presented.

In the control group, the initial photographs taken were designated "Before" transparencies and the ones taken twelve to thirty six months later were designated "After" transparencies. In the test group, the transparencies taken prior to treatment were designated "Before", and those taken subsequent to appliance removal were termed "After" photographs.

To assess the amount of decalcification that had occurred between the Before and After transparencies in both groups, the number of observers who considered decalcification was present in the Before was subtracted from the number who considered that decalcification was present in the After photograph. In order for a patient to be assessed as having acquired a new area of decalcification on the surface examined, a score of three or four was considered necessary. This would mean that at least three of the four observers considered that a new area of decalcification had occurred in the time between the two photographs.

5.2.2 Results.

The number of observers who considered that decalcification was present on surfaces examined in control and test group patients are summarised in Table 2.

The control and test groups were compared to each other with regard to the amount of decalcification present both at the Before and After transparency - see Table 3a and Table 3c. Further tests compared the amount of new decalcification occurring in the time between the two transparencies in both groups - see Table 3bi. Since those surfaces deemed to have decalcification present prior to the study period could not be found to increase in decalcification in the present study, Table 3bii was constructed to compare test and control surfaces in the incidence of decalcification occurring during the study but discounting previously decalcified surfaces.

	Control	Test
Number of Individuals	30	15
Individuals showing increased decalcification	1	7
Lingual surfaces of upper molars examined	60	30
Lingual surfaces of upper molars showing increased decalcification	0	5
Buccal surfaces of lower molars examined	60	30
Buccal surfaces of lower molars showing increased decalcification	1	7
Total surfaces examined	120	60
Total surfaces showing increased decalcification	1	12

Table 2.

Summary of decalcification occurring during test period.

a. Prior to the Study Period.

	Patients				Surfaces		
	No.	Percentage	± S.E.*		No.	Percentage	± S.E.
Control	7/30	20	± 8%		9/120	8	± 3%
Test	3/15	20	± 10%		5/60	8	± 4%
Difference		0.3% (t=0.03)				0.8% (t=0.02)	
Interpretation:		No significant difference between groups (p>0.20)				No significant difference between groups (p>0.20)	

b. During Study Period.

i) All patients and surfaces acquiring new decalcification.

	Patients				Surfaces		
	No.	Percentage	± S.E.		No.	Percentage	± S.E.
Control	1/30	3	± 3%		1/120	1	± 1%
Test	7/15	47	± 13%		12/60	20	± 5%
Difference		43% (t=3.26)				19% (t=3.7)	
Interpretation:		Highly significant difference between groups (p<0.01)				Highly significant difference between groups (p<0.01)	

ii) Surfaces with no prior decalcification acquiring new decalcification.

	Surfaces.	
	No.	Percentage ± S.E.
Control	1/111	1 ± S.E.
Test	12/55	22 ± 1%
Difference		21% (t=3.72)
Interpretation		Highly significant difference between groups (p<0.01)

* S.E. - Standard Error

Table 3.

Evaluation of patients and tooth surfaces exhibiting decalcification.

Table 3. (cont.)

c. After Study Period.

	Patients			Surfaces		
	No.	Percentage	± S.E.	No.	Percentage	± S.E.
Control	8/30	27	± 8%	10/120	8	± 2%
Test	10/15	67	± 12%	17/60	28	± 6%
Difference:		40% (t=2.74)			20% (t=3.15)	
Interpretation:	Highly sifnificant difference between groups ($p<0.01$)				Highly significant difference between groups ($p<0.01$)	

5.2.3 Discussion

The surfaces selected for study in this survey were the buccal surface of the lower molar and the lingual surface of the upper molar. These surfaces were chosen for two reasons. Firstly, only molar teeth were examined because, as noted previously, it would appear that orthodontic banding have distinct advantages over bonding in the posterior regions of the mouth. The smooth surfaces were selected because, from the review of the literature on the incidence of decalcification occurring during orthodontic therapy, it was apparent that the majority of workers agreed that smooth surfaces were more susceptible to attack whilst bands were in place - Dolce (1950), Meyers (1952), Bach (1953), Ingervall (1962), Muhler (1970), Zachrisson and Zachrisson (1971a). Secondly, adequate photographs were available of these surfaces from the standard intra oral survey conducted at the Orthodontic Department of the University of Sydney.

The control group was selected to match the test group as closely as possible for age and sex distribution. Unfortunately no record was obtained of the DMFS increments of both groups prior to treatment as the initial records were taken before this study was commenced.

The test group were treated by four graduate students enrolled in the M.D.Sc. degree at the University of Sydney. The inexperience of the operators in fitting bands for these patients would be outweighed by the stringent requirements of both the graduate student and demonstrator. Further these patients were presented to two examiners at the annual examinations.

Seven of the thirty control patients had nine of the one hundred and twenty surfaces examined, which were deemed to have decalcified areas. The test group had three of its fifteen patients with five of the sixty surfaces affected. A t-test revealed that there was no statistically significant difference between these two groups either as regards the number of patients or surfaces ($p \leq 0.02$) affected.

During the period between the two transparencies there was an increase in the number of surfaces which exhibited areas of decalcification in the orthodontically treated group. Seven patients (47%) showed increases in decalcification in twelve surfaces (20%) examined. The control group had only one individual (3%) who had one surface (0.8%) which became decalcified during the study period. The differences between the control and test groups proved to be statistically significant when compared with a t-test ($p < 0.01$).

It must be realised that no attempt was made to assess either the quantity or severity of decalcification present on any surface. As a result, any surface which was deemed to have decalcification prior to the test period could not score in the present study as having acquired new decalcification during the test period. As a result the number of surfaces exhibiting decalcification prior to the test period were excluded from the total surfaces and another t-test was performed to compare control and test groups. The control group, having new decalcification in one out of one hundred and eleven surfaces (1%) had significantly less increase than the test group which showed new areas in twelve out fifty five surfaces (22%) - $p < 0.01$. No such comparison was necessary on patient numbers as although a patient may have decalcification in a percentage of the four surfaces examined prior to the study period, no patient had all surfaces affected and hence the patient could still show increases in decalcification in the clear surfaces.

Overall, at the end of the study, the control group had eight patients (27%) with ten surfaces examined (8%) affected by decalcification. The treated group had ten patients (67%) with seventeen surfaces (28%) showing decalcified areas. The differences between the groups, both as regards patients and surfaces were found to be highly statistically significant ($p<0.01$).

Not all the patients in both groups had received lifetime benefits from optimally fluoridated water, as some of the individuals were born after 1968, when the Sydney water supply was first fluoridated. In this regard the test group was probably more affected since their mean age (14 yrs. 10 mths.) was slightly higher than the control group (12 yrs. 7 mths.). However, difference in the number of patients and surfaces examined, with respect to decalcification present at the initial transparency was found to be statistically not significant.

The increases in decalcification which occurred during the time of fixed appliance wear was found to be 20% of surfaces in 47% of patients. As noted previously, comparisons between studies is difficult because the criteria used to score decalcification and/or caries as well as the presence or absence of supplementary preventive measures used, e.g. fluoride therapy or oral hygiene regimes, vary greatly. In Meyers (1952) report, 38.4% and 45.4% of the upper and lower molars respectively in the control orthodontic group showed increased etched areas. Both lingual and buccal surfaces of all molars were examined in this study. Bach's (1953) group showed an increase of what I calculate to be 13.4% of teeth with new decalcification and/or caries occurring during orthodontic treatment. All teeth were included in this study, not just molars. Stratemann and Shannon's (1974) report had an orthodontic control group which showed 58% of patients had increased areas of decalcification. However, only areas adjacent to the bands were assessed as treatment was incomplete in some of the patients. As noted previously, Magness, Shannon and West (1979) quote an unpublished study which reports the incidence of decalcification occurring in an orthodontically treated group as 61.4% of thirty nine patients. However, no details of the protocol of the study are recorded.

As noted in chapter 3 the elimination of decalcification during orthodontic therapy requires a number of procedures to be incorporated in the treatment of patients. In treatment with the Begg technique the large diameter archwires used during Stage 111 are locked behind the anchor molars and firmly hold all bands and brackets. The result is that during the long period that the teeth are so held, cement may be dissolved or fractured and bands still remain quite firm. Careful observation of bands margins may pick this fault. However, particularly when band fit is good and cement margins are narrow, this may be difficult. One suggestion to overcome this problem may be that all molar bands should be removed prior to beginning Stage 111 and recemented as this generally represents approximately the midpoint of treatment. In this way a new cement is present to help reduce effects of dissolution and fracturing of the cement. Since anterior bonding is becoming more popular, only four or at most eight bands would be involved in such a procedure.

5.3 STUDY 2.

5.3.1 Materials and Method.

Materials.

a) Teeth.

Forty sound upper and lower first and second bicuspid teeth, extracted for orthodontic reasons were obtained from the Exodontia Department of the University of Sydney. The teeth were cleaned of adhering tissue and stored in isotonic saline. The teeth were selected on the basis of having their buccal surfaces free of decalcification or caries.

b) Chemicals.

All chemicals used were of the highest grade commercially available:- Lactic acid (B.D.H. Chemicals Pty. Ltd. - Port Fairy, Vic., Aust.); sodium hydroxide; sodium tripolyphosphate (Ajax Chemical Ltd., Sydney, N.S.W., Aust.); Fluorinse (Pacemaker Corp. - Portland, Oregon, U.S.A.)

The decalcifying solution was made up with distilled, deionised water.

c) Apparatus.

The apparatus used to suspend the teeth in the decalcifying solution consisted of two glass beakers (1 litre capacity) with lids. A nylon mesh (Nylex - Sydney, N.S.W., Aust.) with 10 m.m. square spaces was cut to size and suspended in the top of each beaker.

Method.

a) Preparation of the Teeth.

The buccal surfaces of each tooth was cleaned with pumice on a rotating bristle brush. On each buccal surface an adhesive dot (Fastonall - Denmark), measuring 4 m.m. in diameter, was placed and carefully burnished to seal its edges. A No. 1 fissure bur was used in a straight handpiece to cut a small-diameter opening transversely in the apical end of each tooth. Through this opening a 20cm. length of unwaxed dental floss (Johnson and Johnson Pty. Ltd., Sydney, N.S.W., Aust.) was tied.

The teeth were divided into two groups, with twenty teeth in each group. Each tooth in both groups was individually immersed in a coloured nail polish and suspended to dry. The two groups had a different colour nail polish. The control was coloured red, and the test group, orange. This allowed subsequent identification of the groups. After the nail polish had dried, the adhesive dots were removed, exposing a symmetrical area of uncoated enamel(see Fig. 9). This area was carefully cleared of any adhesive left by the dot, by wiping with an applicator stick.

b) Cementation of Orthodontic Bands.

Orthodontic bands (Rocky Mountain Orthodontics, Denver, Colarado, U.S.A.) were selected and loosely fitted to each of the forty teeth. The bands covered the exposed enamel on the buccal surface. The bands were cemented with a zinc phosphate cement (S.S. White Ltd., Harrow, Middlesex, U.K.). The cement was mixed using the manufacturer's recommended instructions (Powder/Liquid ratio= 1.3gms/o.50mls mixed over 1½ minutes). Five bands were cemented with one mix of cement. The excess cement was removed after setting. The cement union between the exposed enamel surface and the orthodontic band was broken by loosening each band with a posterior band removing plier (Rocky Mountain Orthodontics, No. 347, Denver, Colarado, U.S.A). This step was performed to simulate a loose orthodontic band in vivo.

c) Production of Decalcifying Solution.

The solution used to produce artificial decalcification of the enamel surface was that proposed by Mor and Rodda (1981). 1.0 M lactic acid was prepared three months prior to the

Fig. 9 Isolation of a 4 m.m. diameter area of enamel.

experimental period by storing in a refrigerator to ensure breakdown of the lactate polymers - Gray (1965). A 0.1 M solution was prepared from this specially aged lactic acid. This solution was brought to pH 4.5 (measured on a Labstaph Electrometer - N.L. Jones Instruments, Melb., Vic., Aust.) by the addition of sodium hydroxide and a 0.25mM solution of sodium tripolyphosphate (STPP).

d) Suspension of the Experimental Teeth in the Solution.

Each tooth in the two groups was individually tied to the nylon screen so as to disallow their touching. The two screens with their attached teeth were suspended in their respective beakers (see Fig. 10). The beakers each contained 800ml of decalcifying solution. The lids were placed in position and the beakers kept in a room at a constant temperature of 37°C.

e) Treatment of Teeth.

The control and test teeth were subjected to twice daily treatments, once in the morning and once in the afternoon. Both the test and control teeth were removed from the decalcifying solution, shaken to remove excess solution and placed in separate beakers, each containing 800ml. of distilled, deionised water for a period of one minute. The test teeth were then removed, shaken to remove excess water and placed in a beaker containing 100ml. of Fluorinse (containing 0.05% sodium fluoride) for a period of two minutes. Subsequently, the teeth were removed from this solution, shaken to remove excess, and replaced in the beaker containing distilled, deionised water for one minute. During these later two stages the control teeth remained in the distilled, deionised water. At the conclusion, both sets of teeth were removed from the water beakers, shaken and replaced in the decalcifying solution.

The teeth remained in the decalcifying solution for a period of twenty one days. Fresh Fluorinse and water was used each day for treatments.

f) Assessment of Decalcification.

At the conclusion of the twenty one days, both test and control teeth were removed from the decalcifying solution. The dental floss suspending the teeth was cut close to the apex of the tooth. The nail polish was removed from the crown of the tooth, but left on the root surface for later identification. The root was covered with adhesive tape to hide the colour-coded nail polish and a number placed to identify each of the forty teeth.

The assessment of decalcification was carried out as a double-blind study. The buccal surfaces of all teeth were examined by an independent observer - Dr. G.G. Craig M.D.S., Ph.D., from the Preventive Department of the University of Sydney. The teeth were scored on either the presence or absence of decalcification on the buccal surface of the teeth. A reproducibility trial was performed three days after the initial scoring.

Fig. 10 Control and test teeth suspended prior to addition of decalcifying solution.

5.3.2 Results.

The results of scoring the teeth for decalcification are presented in Table 4. The reproducibility test showed that scoring was identical on both occasions, hence only one table is presented.

	Number of surfaces tested	Number of surfaces showing decalcification after 21 days
Control	20	20
Test	20	0

Table 4.
Results of decalcification scoring.

5.3.3 Discussion.

All teeth in the control group demonstrated decalcification, thereby supporting the investigations of Mor and Rodda (1981). Macroscopically, this area of white-spot decalcification appeared with areas of decalcification found in vivo (see Fig. 11).

The results of the testing indicate that twice daily reapplication of a dilute, mouthwash concentration solution of sodium fluoride (0.05%), completely eliminated the formation of decalcification, during a twenty one day period. No statistical test was deemed necessary to test significant diffence between the groups.

The importance of the need for frequent reapplication appears to be supported by the great majority of researchers in the review of literature. Although frequent reapplication completely eliminated decalcification in the test enamel during the twenty one day period, further testing would need to be performed over extended periods of time to assess the effects long term. The present study does supply a vehicle whereby this long term testing of dilute solutions, supplied at frequent intervals may be tested, one against the other, and may also be used to test various frequencies against other types of preventive agents.

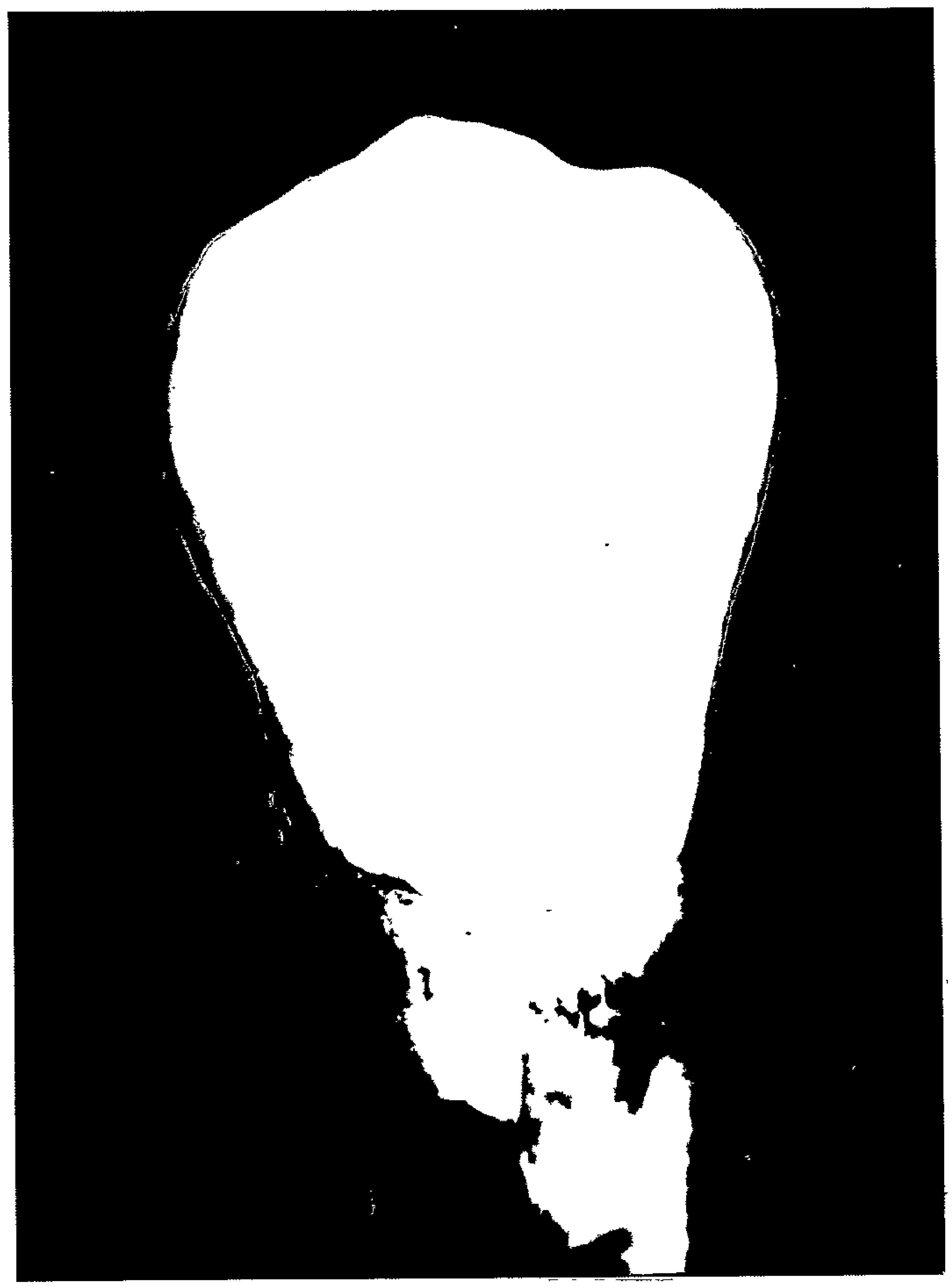

Fig. 11 White-spot decalcification produced in vitro in control tooth.

5.4 SUMMARY OF RESULTS.

Study 1.

1. From the review of the literature on the incidence of decalcification occurring during orthodontic therapy, no reports were found that attempted to assess the incidence in an area of optimally fluoridated water supplies. Study 1 of the present work was established to gain some idea of this incidence.

2. Two groups, one receiving fixed orthodontic treatment (Begg technique) in both arches (15 individuals) and the other receiving no orthodontic treatment (30 individuals) were examined to evaluate the incidence of decalcification occurring on the buccal surfaces of lower molars and the lingual surfaces of upper molars. All patients in the study had been exposed to a fluoridated water supply for thirteen years. The treated group were examined for a period representing the full time that the patient was undergoing fixed appliance therapy, and the untreated group for a similar period.

3. The incidence of decalcification was evaluated by four observers viewing 35mm colour transparencies of the surfaces examined. The surfaces were photographed prior to treatment and after removal of fixed appliances in the treated group. The untreated control group was photographed twice with an interval representing a similar period to the treated group.

4. Statistical evaluation revealed that the two groups were similar as regards decalcification at the initial examination time - $p<0.20$. Increases in decalcification during the period of the study were found to be statistically greater in the treated group (47% of patients and 20% of surfaces) than the untreated group (3% of patients and 1% of surfaces) - $p<0.01$. At the completion of the study the groups were found to be statistically different as regards decalcification in the surfaces examined - $p<0.01$.

Study 2.

1. The overall review of literature supported the contention that the frequency of application of fluoride was all important when considering its relative effectiveness in reducing the rate of the caries process. Study 2 attempted to find a vehicle whereby frequent reappliaction of fluoride-containing substances could be tested for effectiveness in reducing decalcification. The in vitro method developed was used to assess the protection afforded by a 0.05% solution of sodium fluoride applied twice daily on the decalcifying process over a twenty one day period.

2. Forty sound premolar teeth were divided equally into two groups. Both groups had a 4 mm diameter area of enamel isolated as the test surface on the buccal surface, by covering the rest of the tooth with nail varnish. Each tooth had a loosely fitted orthodontic band cemented to place. After cementation, the bond was broken to simulate a loose band in vivo.

3. The two groups were simultaneously immersed in a decalcifying solution. One group was removed from the decalcifying solution and immersed twice daily for two minutes in a solution containing 0.05% fluoride, whilst the other group was similarly removed and treated with deionised, distilled water. The trial continued for twenty one days.

4. At the conclusion of the test period all buccal surfaces were evaluated for the presence of decalcification by an independent observer. A reproducibility trial was performed three days later.

5. The evaluation revealed that all teeth treated twice daily with deionised, distilled water showed distinct decalcification of the exposed enamel whilst those treated with the 0.05% sodium fluoride twice daily had not test surface affected by decalcification.

5.5 CONCLUSIONS.

1. From the results of Study 1 it is apparent that a substantial percentage of patients (47%) and surfaces (20%) in the orthodontically treated group (Begg technique) acquired new areas of decalcification during the time that fixed appliances were in place. In a comparable period the non-orthodontic group did not show any marked increase in the percentage of decalcified surfaces. These results suggest that the increased caries risk in orthodontic patients, noted by many authors (see Shannon and Miller, 1972; for review) may manifest itself as increased areas of decalcification in some individuals, even when these individuals have been afforded the protection of fluoridated water for thirteen years, and in the majority of cases have received regular topical applications of fluorides.

2. It must be noted that Study 1 did not attempt to rate the severity of decalcification occurring. Certainly, some of the marks noted at the removal of bands were clinically significant and may have been reversed by the remineralisation action of saliva, noted in Chapter 4.2 c. Some of the decalcification, however, was more severe and one patient in the treated group was referred for restoration of one affected area. It is apparent that every attempt should be made to reduce all such iatrogenic changes to a minimum.

3. Study 2 may provide a vehicle for testing the relative effectiveness of both fluoride and non-fluoride products in reducing decalcification produced in vitro.

4. The results of Study 2 indicate that, over the twenty one day study period, the twice daily application of 0.05% sodium fluoride was extremely effective in eliminating the decalcification produced by the test solution. Thus this study supports the effectiveness of regular use of dilute solutions of sodium fluoride (0.05%) in preventing decalcification under and around orthodontic banding.

5. Both studies point to the need for further research. Study 1 could be repeated with the control and test groups being matched for DMFS increments at the initial examination. Also standardisation of the photography would be recommended. Further, the use of larger samples, with the orthodontically treated group coming from an experienced orthodontist's practice, may be advised. The participants may also be limited to individuals who have all had lifetime exposure to an optimally fluorided water supply.

6. Study 2 similarly provides the stimulation for further work. Certainly the effects of long term, regular fluoride administration on the decalcification produced by the present in vitro model, needs to be assessed. A well controlled clinical study to test the effects of frequent, low concentration fluoride exposure on the incidence of decalcification occurring during orthodontic therapy in an optimally fluoridated area is indicated. A well-matched orthodontic group which did not receive the fluoride supplement would be needed as a control group.

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