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THE PROTECTIVE EFFECT OF FLUORIDE AGAINST
THE EROSION OF DENTAL HARD TISSUE.

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Supervisors: Dr. N. West and Dr. R. Williams

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DECLARATION

This dissertation is the product of my own investigation except where I have indicated my indebtedness to other sources.

The material contained herein has never been submitted for another diploma and is not being submitted concurrently for any other diploma.

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The erosive effect of acidic soft drinks on tooth tissue has been frequently reported in the literature (Eccles and Jenkins 1974). The phenomena is believed to be increasing due to the “health diet” and longevity of the natural dentition (Hand et al 1986).

Fluoride is known to have an effect in reducing enamel solubility hence, the aim of these investigations was to determine whether fluoride preparations affect erosion attributed to citric acid and citric acid based preparations.

Fluoride was applied by various modes. Firstly, fluoride was added to the acidic soft drinks prior to acid exposure. Secondly, topical fluoride application to the enamel surface in the form of toothpastes, mouthwashes and gel was investigated prior to acid exposure. Results indicated both methods reduced enamel erosion considerably after 30 minutes with exposure to citric acid and citric acid based products. The study was entirely laboratory-based. The majority of results demonstrated the addition of 1ppm (0.001mg/ml) fluoride to the acid solution reduced erosion to a greater degree than pre-treating the enamel surface with a fluoride product of much higher free fluoride concentration.

In conclusion fluoride pre-treatment either in the form of enamel surface treatment or addition to the acidic component reduced erosion of tooth tissue significantly.
INTRODUCTION
Erosion of tooth tissue has been frequently documented in the literature and is likely to become more important than ever in the near future.

The 1993 Child Dental Health Survey reported that over half of five and six year old children had eroded surfaces on one or more primary incisors. Among children aged eleven or older, a quarter or more were found to have some erosion of the palatal surfaces of the upper permanent incisors. Erosion has increased in children particularly from the higher socio-economic groups. The lower echelons have more plaque and caries, but limited erosion of tooth tissue (Steinberg et al 1972).

Apart from reducing acidic intakes either in volume or frequency (Grobler 1987) other methods of tooth tissue protection need to be evaluated. Various salts have been examined and the fluoride ones seem an eminently sensible choice for investigation.

The aims of these investigations were to evaluate the protective nature of fluoride on the enamel surface when subjected to erosive attack, further to attempt to determine the most efficient form of fluoride application. Addition of fluoride to the acidic source was determined, for both acids and acidic soft beverages such as Orange Drink, Orange Juice, Ribena RTD and Baby Ribena. Surface pre-treatment of fluoride was also investigated prior to acid exposure both in the form of citric acids and acidic soft beverages based on citric acid.
REVIEW OF LITERATURE
1.1 EROSION

Dental erosion can be defined as an irreversible loss of dental hard tissue due to a chemical process without involvement of micro-organisms (Eccles 1979).

Tooth wear has traditionally been subdivided into three categories: abrasion, erosion and attrition. It is helpful to make these subdivisions for diagnostic purposes. More recently it has been recognised that it is more common for tooth wear to represent a combination of causes. Erosion typically presents as bilateral concave defects without the chalkiness or roughness normally associated with decalcification. The surface of the enamel is characteristically shiny, with a highly polished appearance. The edges of the lesion are smooth, and there is little colour change to emphasise the enamel loss.

The erosive action of fruit juices has been recognised for a long time, references dating back as early as 1882 (Darby). Tooth decalcification due to excessive fruit consumption has been reported and Pickerill (1912) noted wasting of enamel surfaces in Sicilian lemon suckers. Since then, a number of other reports have been made from clinical material.

The causative agents of erosion are usually acidic substances, the attack rate differing in respect to specific properties of certain acids. Dental erosion may be caused either by extrinsic or by intrinsic factors. Extrinsic factors include demineralising acidic food, beverages, snacks, or exposure to acidic contaminants in the working environment.
(Ten Bruggen Cate 1968; Levine 1974; Eccles and Jenkins 1974; Asher and Read 1987). In modern Western societies the extrinsic “dietary” factor is becoming more important as, in order to avoid gaining weight, some people frequently consume large volumes of fruit, salad dressing and acidic beverages. Due to the availability of sport drinks, these beverages are popular refreshments. However, the mode of consumption is often continuous, in the form of sips over a long time, hence there is particular concern about their erosive potential (Meurman et al 1987; Sorvari et al 1988; Rytomaa et al 1988; Jarvinen et al 1991). Dietary habits are not the only reasons for dental erosion. Anorexia nervosa, Bulimia and gastrointestinal disturbances with frequent regurgitation cause erosion by propulsion of gastric content into the mouth, due to intrinsic factors (Howden 1971; Hellstrom 1977; Clark 1985; Jarvinen et al 1988). In addition, prolonged use of hydrochloric acid for achlorhydria and some iron preparations may cause erosion. A greater proportion of the public are exposed to the potential risk of erosion from beverages and foods containing acid or chelating agents. This form of erosion has been reported by Darby (1892), and Miller (1907) and in Sicilian lemon suckers by Pickerill (1912), More recently cases have been reported by Stafne and Lovestedt (1947), Hicks (1950), James and Parfitt (1953), Finch, (1957) and Allen (1967). The importance of citrus fruit-based beverages and foods and natural fruit juice in dental erosion is due to their popularity and the relative efficiency of citric as a decalcifying agent by virtue of its hydrogen ion concentration and chelating ability (Elsbury 1952). Many so-called ‘iced lollies’ sold in large quantities in this country are frozen synthetic fruit cordials. Children suck them for long periods of time and in this way acid is held in contact with the teeth. This may well expose them to dangerously low pH levels and result in harmful erosion. Sucking fruit-flavoured sweets will also
increase the oral acidity. In this connection McCay and Will (1949) state that the buffer
capacity of human saliva varies, and even after half a minute’s exposure to phosphoric
acid solutions some mouths cannot buffer these above pH 3.5. A low unstimulated
salivary flow rate with insufficient buffering and rinsing of acids is believed to be an
additional factor in developing dental erosion (Woltgens et al 1985; Jarvinen et al
1991). Dental erosion is fairly common, as was shown in a recent epidemiological
study in Switzerland where 391 randomly selected persons were investigated (Lussi et
al 1991). It was found that 7.7% of the younger age-group (26-30 years) and 13.2% of
the older age-group (46-50 years) showed at least 1 tooth affected with labial erosion
with involvement of dentine. Overall, 16% of the participants had at least 1 tooth with
signs of facial erosions. Occlusally, at least one severe erosion was observed in 29.9%
of the younger and 42.6% of the older subjects, whereas only 2% of the older subjects
showed severe lingual erosions. The above-mentioned study also revealed that citrus
and other fruits, fruit juice as well as vomiting were risk factors with the most
significant impact on this dental hard tissue defect (Lussi et al 1991). A case-control
study of 106 cases of erosion showed the same pattern with citrus fruits, soft or sport
drinks, apple vinegar and vomiting associated with dental erosion (Jarvinen et al 1991).

During the Second World War, the consumption of canned fruit juices and acid
beverages, especially of the cola type, increased in America and the question of its
effect upon the teeth assumed a new importance in dental research. In 1943, McClure
described the erosion of enamel of rat molar teeth produced as a result of their drinking
acid beverages in place of water.
Initial demineralisation is characterised by surface softening with dissolution of prism peripheries and no subsurface lesion formation taking place. In this case surface microhardness (SMH) is sensitive to exhibit shallow lesions, provided that the lesions are less than 50μm deep at any time during the study (Featherstone 1992).

1.1.1 DIFFERENTIAL DIAGNOSIS OF DENTAL EROSION

The lesions of erosion are most commonly confused with those of toothbrush abrasion, occlusal attrition, or arrested caries. However, in most cases it is possible to distinguish between them on the basis of the shape and contour of the defects, the colour of the exposed dentine and the site distribution.

Erosion produces defects of enamel and frequently dentine which vary in size and shape but are usually shallow in relation to the surface area, of normal colour and have a smooth hard concave floor with a rounded or lipid margin. This is in contrast to the cervical grooves and gingival recession associated with toothbrush abrasion. Some erosion defects however, may be aggravated by abrasion. Dentine stimulation may be a feature and the patient’s principal complaint may be of pain. The defects of occlusal attrition as seen in bruxism or resulting from a diet containing coarse particles or as an age change may vary from small occlusal or incisal facets to gross flattening of the crown. Amalgam and gold restorations may show similar changes, in standing proud of the occlusal surface. Arrested carious lesions of dentine often have a smooth hard
surface but are usually dark-brown or black in colour and may have sharp enamel margins showing chalky opacity-features not associated with erosion.

The lesions of erosion may differ in site from those of caries, attrition and abrasion. In the case of erosion due to beverages or vomiting, the principal sites are the palatal surfaces of the upper anterior teeth and premolars and the occlusal surfaces of the lower premolar and molar teeth. In addition, erosive beverages may produce lesions on the labial surfaces of the upper anterior teeth. The principal sites of erosion caused by the presence of acid fumes in the atmosphere are the labial and incisal surfaces of the anterior teeth. An asymmetrical or local distribution of lesions may be due to a fruit or sweet-sucking habit or the frequent and careless pipetting of erosive solutions in the laboratory, while the characteristic form of erosion seen in infants due to the use of a fruit-juice filled comforter has been described in the literature. Although lesions of arrested caries, attrition and abrasion may be seen on the occlusal or buccal surfaces of teeth, they are unlikely to be seen on the palatal surfaces of the premolar upper teeth.
1.1.2 SUSCEPTIBILITY TO EROSION

Individual susceptibility is dependent upon the severity and frequency of the insult and the ability of the saliva to dilute and buffer acid as well as the intrinsic resistance of the enamel to attack.

Apart from people exposed to an occupational hazard or who are prone to vomiting, those who suffer from conditions which make an increased fluid intake necessary or desirable may consume more acid beverages and may be at risk. Such conditions include diabetes insipidus (Finch 1957) and renal calculi. In addition, a high fruit juice intake may be encouraged as part of weight-reducing diets.

Although it has been suggested that saliva having a low pH or high citrate content may cause erosion, the role of saliva is now regarded as a protective one as it is in preventing dental caries. Consequently, conditions which can cause a reduced secretion may predispose the individual to both erosion and caries. Such conditions include congenital glandular defects, Sjogren’s syndrome and related collagen diseases such as lupus erythematosus, postmenopausal changes, chronic anxiety states, therapeutic radiation atrophy and the use of atropine or atropine-like drugs.

There is evidence that the resistance of teeth to erosion may be increased by topical application of fluoride solutions, while Holloway and others (1958) obtained a 30 per cent reduction in the incidence and severity of erosion in rats by fluoridating their drinking water at the 2 ppm level. It is possible therefore that people living in a
fluoridated area or using fluoride toothpaste may be relatively less susceptible to erosion.

In 1958 Holloway suggested that in respect of erosion the amounts of acid beverages normally drunk by adults were probably too small to be of great significance, although in children their influence was deleterious (Holloway 1958 and others).

Although fruit juice may form a minor proportion of the total acid beverage consumption of the population, the change in fruit juice consumption may reflect an increase in the consumption of all fruit juice beverages. If this is so and if this trend continues, erosion, possibly in combination with caries and abrasion, may become clinically significant. It is hoped that practitioners will be aware of this potential danger and that methods of prevention will be investigated.

1.2 FLUORIDE AND THE REDUCTION OF EROSION

Fluorides are used in dentistry to improve demineralisation resistance of human enamel against acid attack (Brown et al., 1977; Feagin et al., 1980; Ostrom et al., 1984; ten Cate and Duijsters, 1983; Arends et al., 1984), as well as to stimulate enamel remineralisation (Silverstone, 1977; Ingram and Nash, 1980). Several details of the mechanisms involved, however, are still not fully understood. There is, for example, only limited information on the relationship between fluoride uptake and remineralization in vivo.
The *in vivo* remineralizing actions of individual topical agents have been widely investigated, but the actions of combinations of agents have not been widely studied. The effects of fluoride containing dentifrices are well-documented (Arends and Gelhars, 1983; Corpron *et al.*, 1986) and fluoride mouthrinses have also demonstrated significant remineralizing capacity of enamel lesions *in vivo* (Featherstone *et al.*, 1992; Corpron *et al.*, 1986). The early SnF$_2$ agents (i.e., 8% SnF$_2$ solutions) were effective in reducing enamel solubility and inhibiting bacterial growth, but such agents experienced disuse because of an unpleasant taste and frequent gastric distress following application. The current self-applied 0.4% SnF$_2$ gels (1000 ppm F) represent a significant reduction in the F$^-$ content (20-fold reduction compared with the 8% solution), offer an acceptable taste and have demonstrated a limited capacity to remineralise enamel lesions (Clark *et al.*, 1985).

The effects of F$^-$ upon remineralization have traditionally been evaluated by microhardness testing, F$^-$ uptake and microradiography. In a study by Clark *et al.*, 1985) microhardness testing revealed that although both treatment groups demonstrated significantly greater rehardening and resistance to acid attack than controls, no differences appeared between treatment groups. It has been reported that the linear relation between surface hardness and lesion mineral content is restricted to early lesions of shallow depths (<50µm), whereas the lesions used in the above study approached 60±10µm in depth, and the microhardness testing revealed only gross differences.
Several studies have observed that low concentrations of fluoride in solution reduced the rate of enamel demineralisation. Manly and Harrington (1959) found that as little as 0.1 ppm fluoride slowed the rate of enamel dissolution, whereas ten Cate and Duijsters (1983a, 1983b) observed complete inhibition of bovine enamel demineralisation using a concentration of 2 ppm fluoride in a partially saturated acetate buffer. Further, Arends et al., (1983) used bovine enamel to observe that lesion depth progression was linearly dependent upon the concentration of added fluoride in a demineralizing medium (0.1 mol/L lactic acid, pH 4.5) containing no pre-dissolved mineral ion constituents and decreased with increasing fluoride. Upon extrapolation, it was concluded that a concentration of 30 ppm fluoride would stop enamel demineralisation. Under the dynamic conditions present within the oral cavity, fluoride will reduce the rate of enamel demineralisation, as described, as well as increase the resistance of the surface enamel to subsequent acid attack through the incorporation of fluoride.

Typically, samples of tooth enamel or synthetic hydroxyapatite are exposed to acidic (Arends et al., 1983), neutral (Amjad et al., 1981) or to fluctuating pH (ten Cate and Duijsters, 1982) treatments under constant or dynamic composition conditions (Amjad et al., 1981; ten Cate and Duijsters, 1982). These studies have clearly shown that fluoride can both reduce the rate of demineralisation and increase the rate of remineralization.

The pH cycling has also been highly utilised for the study of fluoride containing materials (e.g., ten Cate et al., 1988). The pH to which the enamel is exposed is varied
with time. In most experiments enamel can be cycled between demineralising, remineralizing, and test solutions to give pH changes similar to the oral situation.

1.2.1 FLUORIDE AS AN ESSENTIAL NUTRIENT.

The National Research Council (1974) once listed fluoride as an essential nutrient but subsequently took the more cautious position that fluoride is a "...beneficial element for humans" because of its positive impact on dental health (National Research Council, 1989). The Council amended its stance because an essential role for fluoride in human growth studies had not been confirmed, and because a physiological mechanism by which fluoride would influence growth had not been demonstrated. Available evidence does not justify classifying fluoride as an essential element by accepted standards (National Research Council, 1989).

Guidelines on the “optimum” intake of fluoride in children have an interesting history. In the same 1943 report in which it was estimated that the “average daily diet” contained 1.0-1.5 mg of fluoride, McClure (1943) suggested that this same diet provided some 0.05 mg fluoride/kg body weight/kg body weight/day for children aged 1-12 years.
1.2.2 FLUORIDE SOURCES AND METABOLISM.

There are numerous sources of fluoride that contribute to human fluoride consumption. Food and drinking water are major sources, the latter being particularly important where the water is fluoridated. Foods and carbonated beverages processed with fluoridated water are sources of dietary fluoride, regardless of where they are consumed.

The fluoride absorption rate from fluoride-containing drinking water, beverages and supplements is typically around 95%. Fluoride intake from foods may vary, but approximately 80% absorption may be expected on average. Once absorbed across the gastro-intestinal tract, fluoride is distributed by the blood supply to all parts of the body. The bulk of the retained fluoride is deposited in the hard tissues, and a significant portion is excreted, while a very small amount of the fluoride is present in the soft tissues. The actual patterns of this distribution will vary with the subject’s age and previous fluoride exposure.

1.2.3 FLUORIDATED WATER

Dean (1942) stated that some 10% of children in optimally-fluoridated areas were affected by fluorosis. This is an average figure which covered a wide range in different communities.
A particular problem in this regard is the practice of the prescribing of fluoride supplements in communities where the water is optimally fluoridated. In such communities, fluoride supplements were designed as an alternative to the fluoride that would have been provided from the consumption of the water. The prescription of systemic fluorides where water is fluoridated will usually lead to excessive fluoride ingestion by infants and young children.

There is a need for studies to clarify various issues involving enamel fluorosis. First, further work is required to develop and define measurement systems for fluorosis. Second, factors that affect the expression of fluorosis should be explored, such as acid/base balance, living at high altitudes and similar considerations. Third, further research should be carried out to identify and estimate the effects of nutritional and metabolic factors that may influence the development of enamel fluorosis. Forth, in fluoridated communities, studies are needed to estimate more precisely the putative role played by baby cereals as well as powdered and concentrated infant formulas in influencing the prevalence of enamel fluorosis. Fifth, more information is needed about changes in fluorosed enamel surfaces over time from remineralization, the action of acidic foods, and abrasion. Sixth, public attitudes should be evaluated to determine the levels at which enamel opacities are perceived to be a problem.

1.2.4 ALTERNATIVES TO WATER FLUORIDATION.

While water fluoridation is by far the best community-based, caries-preventive measure, various circumstances may require alternative approaches for making fluoride
available to larger populations. One method that has been tested extensively and implemented successfully is salt fluoridation. This is the method chosen by Switzerland to address fluoridation needs. The method has also been introduced in France, Spain, Costa Rica, and other Latin American and Caribbean countries.

The increased use of bottled drinking water, and its variable fluoride content, requires further examination. Recent studies have indicated that many bottled waters are low in fluoride concentration, some are close to the 1.0ppm F⁻ level, and a few contain surprisingly high concentrations of fluoride. Indeed it has been shown that some processed beverages contain sizeable fluoride concentrations. To guide consumers and health care providers, it is recommended that the labels on all bottled drinking water and processed beverages show the fluoride concentration of the contents.

1.2.5 AIR-BORNE FLUORIDES.

Air intake of fluoride is usually negligible, around 0.04 mg fluoride/day in most North American environments. Exceptions can occur around some industrial plants which work with fluoride-rich material, such as aluminium smelters, without safeguards to prevent the escape of fluoride-containing compounds. Such local environmental hazards should be controlled to the greater possible extent, and nowadays they are uncommon in North America. There is no evidence that intake of fluoride from airborne sources in North America has increased over recent years.
1.2.6 MODE OF ACTION

Fluoride has various modes of action. Firstly, enamel containing fluoride is less soluble than enamel “without” fluoride. Therefore, in the presence of enamel-bound fluoride, demineralisation starts at a lower “critical” pH after sugar consumption. Secondly, fluoride enhances the rate of crystal growth. This could result in larger crystallites and in more resistant enamel, and favours remineralization in the dynamic tooth decay-repair process. Thirdly, fluoride exerts an inhibitory effect on acid production by bacteria.

Fluoride is present in the mouth at all times. After eruption of the teeth, the outer enamel is constantly de- and remineralised, which results in a high fluoride content (Weatherell et al., 1977). After any type of fluoride administration, such as $F^-$ application, rinsing of brushing, the oral fluid concentration decreases exponentially with a half-life of about 1 hour. It thus seems reasonable to assume that the free fluoride concentration in plaque is in the 1ppm range for extended periods during the day. From intraoral pH determinations, it is shown that “subcritical” pH values of 4.7-5.3 occur during 2-7 hours daily (Jenkins, 1978).
1.3 EFFECT OF INCORPORATED FLUORIDE ON ENAMEL SOLUBILITY.

Crystallographic studies suggest that the replacement of hydroxyl groups with the smaller fluoride ion should result in a more stable apathetic structure, i.e., in a mineral phase which is less soluble than hydroxyapatite. If fluoride is present, therefore, during the formation of enamel (or bone), fluoride ions will become constituents of the crystalline lattice.

Low concentrations of ionic fluoride (F\(^-\)) in the oral cavity are now considered to play an important role in the effectiveness of topical F\(^-\) agents (Arends et al 1984). The level of F\(^-\) in oral fluids following topical F\(^-\) application is the result of a complex interaction of factors which influence the clearance of F\(^-\) from the mouth and factors which aid in the retention of F\(^-\) in the mouth (Zero et al., 1988). Tooth structure, dental plaque, spaces between teeth and soft tissues, and surface coatings of hard and soft oral tissues are all possible sites of retention in the mouth.

It is well known that the fluoride content of the "intact" surface layer of the white spot in particular, is higher than that in the adjacent non-caries enamel, (Dowse and Jenkins, 1957; Little and Steadman, 1966; Hallsworth and Weatherell, 1969). It has been suggested (Weatherell et al., 1977) that part of this observed increase of fluoride in white-spot enamel may result from a greater uptake of fluoride by porous enamel than by sound enamel and by a preferential loss of low-fluoride-containing mineral. In addition, it has been demonstrated (Weatherell et al., 1977) that more fluoride is taken up by sound enamel treated with an acidified fluoride solution, as compared with sound
or acid-etched enamel treated with fluoride solutions at pH7. It has also been shown (Ostrom et al., 1984), using intra-oral devices containing bovine enamel slabs, that individuals who experimentally displayed a greater tendency to demineralize the bovine enamel were also those who exhibited the “highest benefit” from fluoride rinses along with a greater uptake of fluoride, as compared with a group with lower experimental “cariogenicity”.

Although it is possible to increase the fluoride levels in enamel for a short period of time following a topical fluoride treatment, minimal quantities of fluoride are retained in sound enamel.
MATERIALS AND METHODS
2.1.0 PREPARATION OF SAMPLES AND TEST SOLUTIONS.

All investigations involved exposing enamel samples, embedded in epoxy resin, to citric acid or citric acid based beverages. Surface profiles were determined with surfometry prior and proceeding acidic exposure and results recorded.

2.1.1 Preparation of the enamel surface.

Caries free, unerupted human wisdom teeth were collected from the Oral Surgery Department at the Bristol Dental Hospital. As the water around Bristol is nearly all fluoride free, it was assumed the teeth all had minimal levels of fluoride. This can be assumed as it is believed that fluoride supplements would not be taken at the time of maturation of wisdom teeth and no topical fluoride could be applied because the teeth were unerupted. This only leaves population migration from the Bristol area which we believe was minimal. The teeth were stored in 10% sodium hypochlorite solution until they were to be used. The sodium hypochlorite solution was changed every week and the teeth were washed in distilled water prior to being used.

Crowns of the human wisdom teeth were sectioned from their roots and embedded in epoxy resin\(^1\), with the buccal surface uppermost. They were ground to produce a flat surface 4mm in width removing minimal amounts of enamel.

\[^1\) Stycast part A and B. Hitek electronics. Scunthorpe. South Humberside.\]
2.1.2 Preparation of the epoxy resin.

Plastic moulds were greased using Vaseline\(^2\), to stop the resin from sticking to the sides. The resin was weighed out on a ratio of 25 parts of A to 7 parts of B. The mixture was stirred for five minutes and then left on the bench to stand for a further five minutes in order to allow the air bubbles to escape.

A small amount of the mixture was poured into the moulds (just enough to cover the samples) and the sections of enamel were then put into the resin. The resin was left overnight to set.

2.1.3 Baseline Surfometry.

When the samples had been removed from the moulds, baseline profiles were recorded on the surfometer\(^3\) (machine accuracy 0.01\(\mu\)m). The equipment used was a SF200 surfometer, Planer Products Ltd, Windmill Road, Sunbury-on-Thames, Middlesex TW16 7HD. This instrument was operated in a vibration free environment with the head shielded from draughts and severe temperature changes. The head comprised of a measuring head with traverse mechanism for a displacement transducer fitted with a diamond stylus to follow the surface of item under test. The signal from the measuring

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\(^2\) Yellow soft paraffin BP. Depuy Healthcare, Leeds LS25 2JY.

\(^3\) Surfometer. Planer equipment. Sudbury-on-Thames.
head was processed on the electronic control unit and signals were displayed on the monitor screen, a separate printer providing a hard copy of the screen data.

The head unit traversed the specimen at a constant velocity from left to right at a speed of 10mm/minute. The measuring head was fitted with a stylus of 20μm tip radius, the force of the stylus on the surface varying linearly with deflection at the rate of 8mg force per micron deflection, the maximum force at 100μm being 1.0g. The traverse of the head was selected, 5mm (5,000 microns) being chosen for enamel. The accuracy of resolution of the surfometer was 0.01μm.

Each sample had its baseline profile measured by surfometry, which involved measuring the area to be treated. The distance to be measured was marked on the specimen with indelible ink. Two readings were taken for each specimen and the mean recorded. The baseline reading had to be between 0.00 and 0.40μm deflection to be accepted. The specimen was then treated and marked on the surrounding material to identify the area of investigation. A second pair of readings were then recorded and the mean taken. The difference between the baseline and final reading identified the amount of material lost.

The samples were taped up with PVC⁴ to expose 3mm of tissue to be treated. Five samples were used in each experiment.

⁴PVC Instrument marking tape.
2.1.4 Preparation of 0.3% Citric Acid.

Citric acid was prepared by weighing out 3 grammes of citric acid and adding 1 litre of distilled water producing a 0.3% concentration. The solution was mixed using a magnetic stirrer for half an hour before use. Fresh 200mls of the stock solution was used for each acid exposure.

2.1.5 Preparation of the Beverages

The beverages used in the experiment were; Orange Drink, Orange Juice, Ribena RTD and Baby Ribena (see appendix 1). A fresh 200mls of each beverage was used for each acid exposure The beverages were all warmed in the water bath to 35°C. Titratable acidity and pH were measured.

2.2.0 THE EFFECT OF 0.3% CITRIC ACID ON ENAMEL.

Five enamel blocks were submerged in a 0.3% solution of citric acid for 10 minutes at 35°C in a water bath, being agitated from time to time, then lightly rinsed with cold tap water. Measurements were then made across the enamel to measure the depth of tissue loss in micrometers, as compared to the baseline reading. This was repeated twice more with the same samples.

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Footnotes:

5 Magnetic stirrer. Fisons Medical equipment.
6 Water bath. Grant
The same investigation was performed with distilled water instead of citric acid, to act as a positive control.

2.3.0 THE TIME DEPENDENT EFFECTS OF ACIDIC CONSUMER PRODUCTS ON ENAMEL.

In the previous experiment, enamel sections were exposed to 0.3% citric acid, this next experiment dealt with erosion due to citric acid based products. These consumer products were used to gain a more realistic view of dietary erosion of enamel. The consumer products chosen were four popular citric acid based drinks. The drinks were Orange Drink, Orange Juice, Ribena and Baby Ribena.

Enamel samples were prepared (2.1.1) and placed into a solution of Orange Juice in the water bath at 35°C for 10 minutes, being agitated from time to time. After 10 minutes the samples were removed from the water bath and gently washed with tap water. The tape was then removed and the samples were measured on the surfometer. This process was repeated a further two times. This procedure was then repeated on fresh enamel samples using Orange Drink, Ribena RTD and Baby Ribena.
2.4.0 THE ADDITION OF 1PPM FLUORIDE TO CITRIC ACID BEFORE EXPOSURE TO ENAMEL.

In order to determine the protective effect of sodium fluoride on the enamel surface, 1ppm (0.001mg/ml) sodium fluoride was added to the 0.3% citric acid solution and loss due to erosion determined. The results could then be directly compared to the loss of enamel due to just a citric acid solution (2.2.0).

Fluoride 1ppm concentration was added to 0.3% citric acid and then this solution was adjusted to pH 3.2 using sodium hydroxide. Five enamel samples were then subjected to acid attack at 35°C for 10 minutes. This procedure was repeated for the same samples on two further occasions. This enabled a time dependent result to be determined.

2.5.0 THE ADDITION OF 1PPM FLUORIDE TO CONSUMER PRODUCTS BEFORE EXPOSURE ON ENAMEL.

Fluoride (1ppm/0.001mg/ml) was added to the acidic consumer products prior to being tested on the five enamel samples.

Samples were agitated in Orange Juice with the addition of 1ppm fluoride for 10 minutes at 35°C in the waterbath. After 10 minutes the samples were removed, washed
with distilled water and measured on the surfometer for tissue loss. This method was repeated a further two additional times to determine tissue loss in micrometers.

This procedure was then repeated on enamel samples with Orange Drink, Ribena RTD and Baby Ribena to determine tissue loss.

2.6.0 THE AMOUNT OF FREE FLUORIDE IN THE TOOTHPASTES AND MOUTHWASHES.

The next investigations were performed in order to determine the effect of fluoride products on the enamel surface prior to acid exposure.

However, the majority of fluoride products do not state the amount of free fluoride present in them, so the first experiment was performed to determine the amount of free fluoride present. This was thought to be important to interpret the results from the effect of fluoride products.

The amount of free fluoride in the toothpastes and the mouthwashes was determined by preparing concentrations of known fluoride solutions and determining a standard fluoride graph using a F\(^{-}\) probe. Samples of the toothpastes and mouthwashes were then measured on the F\(^{-}\) probe and the value was compared to the standard fluoride graph. Concentrations of fluoride in the toothpastes and mouthwashes could then be determined.
The pH was also determined with a pH metre\(^7\).

**2.7.0 FLUORIDE PRE-TREATMENT OF THE ENAMEL SURFACE BEFORE EXPOSURE TO CITRIC ACID.**

Five enamel samples were pre-treated with one of seven randomly chosen fluoride applications, Colgate Total toothpaste, Aquafresh toothpaste, Macleans Sensitive toothpaste, Endekay mouthwash, Plax mouthwash, FluoriGard mouthwash and an acidulated gel, prior to exposure to 0.3% citric acid for 10 minutes at 35°C. Profiles of specimens were recorded by surfometry prior and after treatment and the average reading taken. This process was repeated 3 times.

**2.7.1 Pre-Treatment With Fluoride Toothpaste.**

Each toothpaste slurry was prepared using 5g of toothpaste and 20ml of distilled water. It was then put on a Rotamix\(^8\) for five minutes in order to produce the slurry. Specimens were agitated in the slurry for one minute and then exposed to the acid environment. Samples were pre-treated with fluoride in this manner before subsequent exposures, (All toothpastes are documented in appendix 2).

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\(^7\) pH meter. Jenway 3030

\(^8\) Rotamix.
2.7.2 Pre-Treatment With Fluoride Mouthwash.

Samples were soaked in one of the mouthwashes for one minute, 10ml of the mouthwash was used for each tooth. After being removed from the mouthwash the samples were washed in distilled water. This was performed before each of 3 exposures to 0.3% citric acid for 10 minutes at 35°C (All mouthwashes documented in appendix 2).

2.7.3 Pre-Treatment With Fluoride Gel.

Samples were treated on only one occasion with the gel. The gel was painted onto the enamel and left for four minutes, the gel was then washed off using distilled water before 5 enamel samples were exposed to the citric acid (Appendix 2).
2.8.0 FLUORIDE PRE-TREATMENT OF THE ENAMEL SURFACE BEFORE EXPOSURE TO CONSUMER PRODUCTS.

Samples were pre-treated with one of 3 types of fluoride application, a toothpaste, gel or mouthwash prior to exposure to the consumer products for 10 minutes at 35°C. The fluoride products were picked at random, one of each of the fluoride treatments, this was in order to reduce the volume of work. Profiles of specimens were recorded by surfometry and the average reading taken. This process was repeated 3 times.

2.8.1 Pre-Treatment With Fluoride Toothpaste.

A fluoride toothpaste (Colgate Total) was prepared as a slurry, 5g of toothpaste and 20ml of distilled water. It was then put onto a whirlmixer for five minutes in order to produce a slurry. The enamel samples were agitated in the toothpaste slurry for one minute. The samples were washed in distilled water and exposed to Orange Juice at 35°C for 10 minutes being agitated regularly.

The samples were measured after 10 minutes on the surfometer in order to determine the tissue loss. This method was repeated a further two times.
This procedure was then repeated for Orange Drink, Ribena RTD and Baby Ribena. (All consumer products are documented in appendix 1).

2.8.2 Pre-Treatment With Fluoride Mouthwash.

Five enamel samples were soaked in Endekay mouthwash for one minute, 10 ml of the mouthwash was used for each tooth. After being removed from the mouthwash the samples were washed in distilled water and placed into Orange Juice for 10 minutes at 35°C, being agitated from time to time. They were then removed, washed and measured on the surfometer in order to determine the tissue loss. This method was then repeated a further two times for Orange Juice.

The same procedure was performed for orange drink, Ribena RTD and Baby Ribena substituting these acidic soft beverages for Orange Juice.

2.8.3 Pre-Treatment With Fluoride Gel.

Enamel samples were pre-treated with a fluoride gel prior to being exposed to Orange Juice, Orange Drink, Ribena RTD and Baby Ribena.
Five enamel samples were treated with an acidulated fluoride gel. The gel was painted onto the enamel surface and left for four minutes. The gel was then washed off the samples using distilled water and the samples placed into the Orange Juice for 10 minutes at 35°C being agitated from time to time. After being removed from the orange juice the samples were washed in distilled water and measured on the surfometer in order to determine the tissue loss.

Samples were treated on only one occasion with the gel, but the exposure to the Orange Juice was repeated a further two times.

This procedure was then repeated substituting the Orange Juice with Orange Drink, Ribena RTD and Baby Ribena.

2.9.0 STATISTICAL METHODS.

All data were collected and appropriate statistical analyses performed. Graphic representation accompanies each investigation. For the majority of the investigations one way analysis of variance was performed on the results, accompanied with Sheffé analysis where P<0.05. Thus, confidence intervals demonstrated where the differences occurred. All standard deviations and standard errors were calculated but as they all fell within a 0.40± range they were not included in the figures.
RESULTS
3.1.0 THE EFFECT OF 0.3% CITRIC ACID ON ENAMEL.

Five enamel sample were exposed to citric acid of concentration 0.3%, for 30 minutes.

The results are shown in Figure 1.

As expected, there was a significant difference in the loss of enamel (P<0.05) between the 0.3% citric acid and the distilled water at 35°C.

From these results it can be seen that after 30 minutes exposure of 0.3% citric acid to enamel there was a 3.37μm loss of tissue. Further there appeared to be a time, at about 20 minutes, where the loss of enamel increased more rapidly due to citric acid exposure. A plateau did not occur after three 10 minute exposures to the citric acid.

Results from enamel exposed to distilled water indicated water had no effect on the loss of enamel surface.
THE EFFECT OF 0.3% CITRIC ACID ON THE EROSION OF ENAMEL.

FIGURE 1
3.2.0 THE TIME DEPENDENT EFFECTS OF ACIDIC CONSUMER PRODUCTS ON ENAMEL.

Enamel samples were exposed to a variety of acidic soft beverages. Results indicated that Orange Drink was the most erosive to enamel after 30 minutes and Baby Ribena the least. This is demonstrated in Figure 2.

From Figure 2, it can be seen that the products produced loss of enamel in the order, greatest first; Orange Drink, Ribena RTD, Orange Juice and Baby Ribena. Orange Drink was shown to be extremely erosive to enamel compared with the other consumer products. Orange Juice was not as erosive as Orange Drink only removing 1.26µm after 30 minutes. Baby Ribena caused the least erosion to the enamel surface removing 0.68µm after 30 minutes. Erosion of the enamel surface increased with time on exposure to each acidic product.

The titratable acidity of each beverage was calculated by titration and pH was measured using a pH metre results are shown in Table 1.

Table 1 Titratable Acidity and pH of the acidic soft drinks.

<table>
<thead>
<tr>
<th>Consumer product</th>
<th>Titratable Acidity</th>
<th>pH</th>
</tr>
</thead>
<tbody>
<tr>
<td>Orange Drink</td>
<td>0.800%</td>
<td>2.91</td>
</tr>
<tr>
<td>Orange Juice</td>
<td>0.600%</td>
<td>3.40</td>
</tr>
<tr>
<td>Ribena RTD</td>
<td>0.310%</td>
<td>2.70</td>
</tr>
<tr>
<td>Baby Ribena</td>
<td>0.125%</td>
<td>3.53</td>
</tr>
<tr>
<td>Citric acid</td>
<td>0.3%</td>
<td>2.15</td>
</tr>
</tbody>
</table>
THE TIME DEPENDENT EFFECTS OF ACIDIC CONSUMER PRODUCTS ON ENAMEL.
3.3.0 THE ADDITION OF 1PPM FLUORIDE TO CITRIC ACID BEFORE EXPOSURE TO ENAMEL.

1ppm fluoride was added to 0.3% citric acid before exposure to the enamel samples in the water bath at 35°C for 30 minutes.

As shown in Figure 3 the addition of 1ppm sodium fluoride to the citric acid before exposure to enamel significantly (P<0.05) reduced the amount erosion. After 30 minutes in contact with the enamel, the citric acid with the addition of 1ppm sodium fluoride, had reduced the amount of erosion to only 2.73\(\mu\)m loss compared with 3.37\(\mu\)m loss with only citric acid (see 3.1.0).
THE ADDITION OF 1PPM FLUORIDE TO CITRIC ACID BEFORE EXPOSURE TO ENAMEL.
3.4.0 THE ADDITION OF 1PPM FLUORIDE TO CONSUMER PRODUCTS BEFORE EXPOSURE ON ENAMEL.

1ppm fluoride was added to the acidic consumer products before they were exposed to the enamel samples. Results indicated that the addition of 1ppm of sodium fluoride did significantly (P<0.05) reduce the amount of erosion caused from the acidic products. As shown in Figure 4 the Orange Juice with the addition of 1ppm sodium fluoride caused 1.08μm tissue loss after 30 minutes compared to 1.26μm with "plain" Orange Juice (3.2.1). The erosion caused by the Orange Drink with the addition of 1ppm sodium fluoride was only half the amount than with plain Orange Drink 2.52μm loss compared to 4.49μm loss respectively.

For Ribena RTD the addition of 1ppm sodium fluoride also protected the enamel from erosion after 30 minutes exposure. There was a 2.08μm loss with the addition of sodium fluoride to citric acid compared to 3.93μm loss with just Ribena RTD.

Baby Ribena with the addition of 1ppm sodium fluoride was still within the baseline reading after 30 minutes exposure (0.29μm loss). Without the addition of sodium fluoride to citric acid the result was only slightly higher at 0.68μm loss.
THE ADDITION OF 1PPM FLUORIDE TO CONSUMER PRODUCTS BEFORE EXPOSURE ON ENAMEL.

CONSUMER PRODUCTS
- ORANGE JUICE
- ORANGE DRINK
- RIBENA RTD
- BABY RIBENA

FIGURE 4
3.5.0 AMOUNTS OF FREE FLUORIDE IN THE TOOTHPASTES AND MOUTHWASHES.

The amounts of free fluoride in the toothpastes and mouthwashes was measured using a F⁻ probe. The results are in Table 2 and Figure 5.

Table 2

<table>
<thead>
<tr>
<th>Product</th>
<th>free fluoride mg/ml</th>
<th>Total fluoride mg/ml</th>
<th>pH</th>
</tr>
</thead>
<tbody>
<tr>
<td>Citric acid</td>
<td>0</td>
<td>0</td>
<td>2.15</td>
</tr>
<tr>
<td>Aquafresh</td>
<td>0.0027</td>
<td>0.09</td>
<td>9.38</td>
</tr>
<tr>
<td>Plax</td>
<td>0.0027</td>
<td>0.104</td>
<td>7.01</td>
</tr>
<tr>
<td>Macleans Sensitive</td>
<td>0.0087</td>
<td>0.104</td>
<td>7.16</td>
</tr>
<tr>
<td>Endekay</td>
<td>0.012</td>
<td>0.104</td>
<td>6.55</td>
</tr>
<tr>
<td>Colgate Total</td>
<td>0.014</td>
<td>0.14</td>
<td>7.24</td>
</tr>
<tr>
<td>Acidulated gel</td>
<td>0.0206</td>
<td>0.920</td>
<td>5.15</td>
</tr>
<tr>
<td>FluoriGuard</td>
<td>0.0509</td>
<td>0.920</td>
<td>5.91</td>
</tr>
</tbody>
</table>

From the results it can be seen that the products vary greatly. The product with the most amount of free fluoride was FluoriGard with 0.0509 mg/ml. Aquafresh toothpaste and Plax mouthwash both had the least amount of free fluoride available in the product (0.0027mg/ml).
THE AMOUNT OF FREE FLUORIDE IN THE TOOTHPASTES AND MOUTHWASHES.

**FIGURE 5**
3.6.0 FLUORIDE PRE-TREATMENT OF THE ENAMEL SURFACE BEFORE EXPOSURE TO CITRIC ACID.

Various toothpastes and mouthwashes were applied to the enamel surface prior to exposure to citric acid. Results indicated that the acidulated gel gave the greatest protection to the tooth from erosion and Aquafresh toothpaste the least, see Figure 6.

In these experiments the pre-treatment of the enamel surface with the fluoride products reduced the loss of enamel after exposure to the citric acid to some degree, this was only significant (P<0.05) with acidulated gel, FluoriGard and Colgate Total toothpaste compared to no fluoride pre-treatment, with acid exposure.

From Figure 6 it can be seen that acidulated gel had the greatest effect on reducing the amount of erosion after 30 minutes. The acidulated gel protected the enamel surface after only one four minute exposure against the citric acid giving a reading of 2.25μm loss after 30 minutes compared to 3.37μm with no fluoride pre-treatment.

FluoriGard also protected the enamel surface giving a reading of 2.38μm tissue loss after 30 minutes compared with 3.37μm loss without any fluoride pre-treatment.

Colgate Total, Aquafresh, Macleans Sensitive and Endekay had a protective effect on the enamel surface and all gave very similar results. However, Colgate Total was slightly better at protecting the enamel surface than the others. Plax was little better than no pre-treatment.
FLUORIDE PRODUCT PRE-TREATMENT OF THE ENAMEL SURFACE BEFORE EXPOSURE TO CITRIC ACID.

FIGURE 6
3.7.0 FLUORIDE PRE-TREATMENT OF THE ENAMEL SURFACE BEFORE EXPOSURE TO CONSUMER PRODUCTS.

3.7.1 Pre-Treatment With A Fluoride Toothpaste.

The enamel surfaces were pre-treated with a fluoride toothpaste, Colgate Total prior to exposure to a variety of soft citric acid based beverages. Results indicated that Orange Drink was the most erosive after 30 minutes and Baby Ribena the least. This is demonstrated in Figure 7.

3.7.2 Pre-Treatment With A Fluoride Mouthwash.

The enamel surfaces were pre-treated with a fluoride mouthwash, Endekay, prior to exposure to a variety of soft acidic beverages. Results indicated that Orange Drink was the most erosive after 30 minutes and Baby Ribena the least. This is demonstrated in Figure 8.

3.7.3 Pre-Treatment With A Fluoride Gel.

The enamel surfaces were pre-treated with a fluoride gel, an acidulated gel, and there was a significant reduction (P<0.05) in the amount of erosion of the enamel surface (appendix 2) prior to exposure to a variety of soft acidic beverages. Results indicated...
that Orange Drink was the most erosive after 30 minutes and Baby Ribena the least.
This is demonstrated in Figure 9.

In the following experiments the enamel samples which had been pre-treated with an acidulated gel had the least erosion from all the consumer products compared to toothpaste and mouthwashes. Colgate Total toothpaste and Endekay mouthwash both gave similar protection against the consumer products.
FLUORIDE PRE-TREATMENT OF THE ENAMEL SURFACE BEFORE EXPOSURE TO CONSUMER PRODUCTS.
PRE-TREATMENT WITH A FLUORIDE TOOTHPASTE (COLGATE TOTAL).

**FIGURE 7**

**TISSUE LOSS (MICRONS)**

**CONSUMER PRODUCT**
- ORANGE JUICE
- ORANGE DRINK
- RIBENA RTD
- BABY RIBENA
FLUORIDE PRE-TREATMENT OF THE ENAMEL SURFACE BEFORE EXPOSURE TO CONSUMER PRODUCTS. PRE-TREATMENT WITH MOUTHWASH (ENDEKAY)

FIGURE 8
FLUORIDE PRE-TREATMENT OF THE ENAMEL SURFACE BEFORE EXPOSURE TO CONSUMER PRODUCTS.
PRE-TREATMENT WITH ACIDULATED GEL.

FIGURE 9
DISCUSSION
Clinical erosion of tooth tissue is becoming an ever increasing problem in both adults and children. However, it was not until the publication of the Child Dental Health Survey that the extent of the problem was perceived.

The 1993 Child Dental Heath Survey reported that over half of five and six year old children had eroded surfaces on one or more primary incisors. Among almost a quarter of children of these ages, erosion had progressed into the pulp. Among children aged eleven or older, a quarter or more were found to have some erosion of the palatal surfaces of the upper permanent incisors. Tooth erosion is now recognised by the dental profession as an ever increasing problem, both in adults and children. Restoration of this type of wear is problematical and much research is being undertaken in the preventative field in order to reduce the effects of excessive acidic consumption.

If tooth wear continues at this rate there will be a number of adults with a dentition which is extremely difficult to treat.

Erosion of tooth tissue may be from a number of sources, acid from dietary habits being a known problem.

In particular organic hydroxy acids such as citric, malic, lactic and oxalic acids all erode tooth tissue as will phosphoric acid.
Citric acid is one of the main constituents of the soft drink industry along with phosphoric acid. Over the last ten years, consumption of acidic soft drinks has increased dramatically, with more carbonated drinks now sold than acidic soft drinks to dilute (squashes). The average person in Great Britain drinks over 131 litres of acidic soft drinks a year, or one litre a week. Some people consume more than this, which can lead to severe erosion of tooth tissue.

The aim of this research was to examine the effect of fluoride on tooth tissue with respect to reducing erosion from a dietary origin. The effect of fluoride in the reduction of caries is well documented however little is known concerning demineralisation and remineralisation of tooth tissue from acidic beverages.

These investigations were *in vitro* and can obviously not be extrapolated to a clinical situation. Nevertheless, the concepts are important and if anything with show the worst possible results which could occur in the oral environment with minimal or no saliva/pellicle and no tongue movements. Hence, meaningful trends can be determined and large numbers of investigations and number of specimens can be examined. After concluding this research, fluoride was shown to have a significant effect on the reduction of erosion of enamel *in vitro*, both with pre-treatment and with the addition of fluoride to consumer products.

Each investigation will be discussed in detail and relevance determined.
4.1.0 THE EFFECT OF 0.3% CITRIC ACID AND CITRIC ACID PRODUCTS ON ENAMEL.

Citric acid caused erosion of the enamel surface as expected from previous research (Asher and Read 1987). There was a significant difference in the loss of enamel between the 0.3% citric acid and the distilled water at 35°C. These citric acid results were of value as they could be used as controls for the remaining investigations.

Citric acid was examined first to establish a baseline before the citric acid based products were tested. The actual composition of each product is a secret formulation pH and titratable acidity can be determined, however the exact nature of the acid composition is problematical to determine and it was assumed that citric acid was the predominant acid.

The citric acid based consumer products also caused erosion of the enamel surface. The ranking of the degree of erosion was as expected with Orange Drink having the highest titratable acidity and lowest pH hence producing the most erosion and Baby Ribena having the lowest titratable acidity and highest pH producing the least. Ribena RTD was the product with the closest composition to 0.3% citric acid and produced similar erosive results. Each product differs considerably in composition, but this investigation in conjunction with previous work (Hughes and West BSDR 1994) suggests orange acidic drinks are more erosive than blackcurrent based ones.
4.2.0 THE ADDITION OF 1PPM SODIUM FLUORIDE TO CITRIC ACID BEFORE EXPOSURE TO ENAMEL AND CITRIC ACID PRODUCTS.

The next experiments involved adding fluoride to the citric acid component to determine the effect on tooth loss. These results could be compared to those in the previous investigations, and hence evaluate fluoride application in this form. 1ppm fluoride was chosen as this is the maximum fluoride allowed to be added to water. At this level it has been shown to be safe to tooth tissue, and if anything protective against caries by reducing the enamel solubility by the formation of fluoroapatite.

The most widely discussed hypothesis of the effect of fluoride in enamel is that it reduces its solubility. It was based on the discovery many years ago that if dental tissues are treated in vitro with fluoride, even in solutions as dilute as 1 ppm or less, the fluoride becomes incorporated in the tooth substance and they then dissolve more slowly in acid. When the fluoride concentration in enamel reaches about 3000 ppm (equivalent to the substitution of less than 10% of its OH groups) its effect in reducing caries is maximal. There have been two explanations offered for this. First, this concentration may be adequate to convert the outer part of the apatite crystals to fluorapatite which then exert a protective action on the unsubstituted hydroxyapatite within. Secondly, the entry of fluoride has been pictured as the filling of holes in the apatite crystal arising from the occasional absence of OH groups, an effect which would affect its stability and decrease its solubility (Dowse and Jenkins 1957).
The addition of 1ppm fluoride to the 0.3% citric acid reduced the amount of erosion of the enamel tissue after 30 minutes at 35°C, compared to no addition of fluoride.

These results were surprising due to the degree of reduction of erosion. Erosion of enamel was also decreased by the addition of fluoride to citric acid based products, particularly with respect to the products which caused the greatest erosion, namely Orange Drink and Ribena RTD. This method would appear eminently suitable for decreasing erosion in people with high soft beverage intake. The addition of 1ppm fluoride to the water would be a relatively safe procedure and would be easy to administer. Indeed many local water authorities are now considering fluoridation the water due to the dramatic effect shown to occur with reducing caries.

However, there is valid argument which is put forward regarding the possibility of fluorosis. If 1ppm fluoride was in the water, and large amounts of fluoride toothpaste and other products containing fluoride were consumed, this could lead to fluorosis problems negating the advantage proffered. However, on balance 1ppm fluoride in the water would benefit many individuals and would be inexpensive to administer.

4.3.0 THE AMOUNT OF FREE FLUORIDE IN THE TOOTHPASTES AND MOUTHWASHES.

This investigation was thought an important experiment to undertake as fluoride products that can be bought of the shelf do not state how much of the total fluoride
present is in a free fluoride form. It was interesting to see the differences in the free fluoride content of the products investigated and surprising that Colgate Total toothpaste had a high free fluoride content compared to the other toothpastes. As expected the acidulated gel had the greatest amount of free fluoride present. This fluoride product is used every 6 months or so for children at risk from caries. However, it was surprising that FluoriGard mouthwash also had this amount of free fluoride. Knowing the total free fluoride contents of the toothpastes and mouthwashes made the interpretation of the following investigations more meaningful. It was not known whether the amount of free fluoride in the products would protect the enamel against the acid attacks and that the higher the amount of free fluoride the better protection it gave, until after all the results were analysed.

4.4.0 FLUORIDE PRE-TREATMENT OF THE ENAMEL SURFACE BEFORE EXPOSURE TO CITRIC ACID AND CITRIC ACID PRODUCTS.

Obviously as not all the water in Britain is fluoridated, few individuals benefit from its protective effect. However, there are many products on the market proclaiming high fluoride content. A selection of these fluoride products were investigated to see if their benefit compared to addition of 1ppm fluoride to the water, with regard to enamel erosion.
Firstly, loss of enamel was compared to the amount of free fluoride in the products, shown in Table 2. The acidulated gel and the FluoriGard had the highest amounts of free fluoride present and reduced erosion to the greatest degree. The acidulated gel was used for a one 4 minute concentrated exposure which was more effective than three 10 minute exposures of the FluoriGard. Colgate Total toothpaste had a high amount of free fluoride compared with the other toothpastes and mouthwashes, and these results reflected the reduction in erosion of enamel demonstrated by this product. Generally, the greater amount of free fluoride used in the pre-treatment of enamel, the less the erosion.

Turning to the results of fluoride pre-treatment prior to exposure to different soft acidic beverages, only one toothpaste, mouthwash and acidulated gel were investigated. Overall acidulated gel pre-treatment reduced enamel erosion from the consumer products to a greater degree than the mouthwash and toothpastes.

Acidulated gel pre-treatment was expected to reduce the amount of erosion of Ribena RTD to a similar degree as citric acid, however this was not the case. In explanation Ribena RTD contains other constituents which must have altered the chemical reactions. Tooth erosion appears an extremely complex reaction.

Interestingly, fluoride addition to the water supply generally gave better protection to the enamel surface than enamel pre-treatment with fluoride products. The reason for this phenomenon is unknown and needs further investigation.
CONCLUSION
Overall, the best method for reducing erosion from 0.3% citric acid and citric acid based consumer products was to add 1ppm sodium fluoride to the water. However, acidulated gel pre-treatment of the enamel surface was also extremely effective. The addition of fluoride (1ppm) to the consumer products is a possible method to reduce tooth erosion. It is not known how many times acidulated gel pre-treatment would be necessary for long lasting effects at reducing erosion, however this seems a possible cost effective method of treatment. Addition of fluoride to products is fraught with the problems of taste as fluoride would undoubtedly alter taste perception. Further, there may be opposition to fluoride addition to a product due to fear of overdose from other fluoride sources.

However, if the drink was manufactured in a water fluoridated area, it would automatically contain this ingredient. All these aspects need to be thoroughly examined, but the concept would work theoretically.

In conclusion the degree of erosion depends on the type of acid, its buffering capacity, acid titrability, pH and presence of any other components and frequency of exposure. All the consumer products tested caused some degree of erosion on the enamel samples. However, the addition of all types of fluoride to these products did reduce the amount of erosion to enamel.

In summary acidic soft drinks could be altered to contain fluoride, hence reduce erosion. Other measures including decreasing the acidic component and revised labelling of products could give better instruction on drinking e.g. no sipping, foaming
or mouthrinsing with the drink. Patients could be told to clean their teeth before they consume any acidic drink rather than after so as to protect the tooth from the acid attack.

5.1.0 FUTURE RESEARCH.

Future research could include the addition of calcium, for example calcium lactate, malate, citrate or phosphate to soft acidic beverages. Calcium lactate would seem a favourable ingredient having preferential bonding in the solution with respect to the tooth calcium thereby decreasing enamel solubility and chelation would not be as great a problem as calcium citrate. Hence, this may reduce erosion to tooth tissue. Although it may be possible to reduce the acidity of an acidic beverage, the drink would still have to pass the organoleptic test otherwise it would not be marketable to consumers and thus uneconomical to produce.


CORPRON R E, MORE F H, CLARK J W, KORYTNICKE D and KOWALSKI C J: 

DARBY E.T: Dental erosion and the gouty diathesis. Are they associated?. *Dent Cosm* 1892, 34: 629


LITTLE M F and STEADMAN L T: Chemical and physical properties of altered and sound enamel. 1966; Arch Oral Biol 11:273-278.


MILLER WD: Experiments and observations on the washing of tooth tissue variously designated as erosion, abrasion, chemical abrasion, denudation etc. Dent Cosmos 1907; 49:1-23, 109-24, 225-47.


STAFNE E C and LOVESTEDT S: A Dissolution of tooth substance by lemon juice, acid beverages and acid from other sources. J Amer Dent Ass 1947; 34:586.


WEATHERELL J A, DEUTSCH D, ROBINSOM C and HALLSWORTH A S:


Appendix 1

*Consumer products*

**Ribena RTD** - *SmithKline Beecham, Consumer Brands, Brentford, Middlesex.*
Blackcurrant juice, citric acid, water, sucrose, vitamin C, B6, B12, glucose syrup.

**Baby Ribena** - *SmithKline Beecham, Consumer Brands, Brentford, Middlesex.*
Blackcurrant juice, citric acid, potassium citrate, glucose syrup.

**Orange Juice** - *Tropicana UK Ltd, Bell Court, Leopale Lane, Guildford.*
100% juice direct from the orange.

**Orange Drink** - *Libby's Orange Drink, Nestle UK, St George's House, Croydon, Surrey.*
Orange juice, water, sugar, oranges, citric acid, vitamin C, flavouring, colour (beta carotene).
Appendix 2

Fluoride Toothpastes and Mouthwashes

Colgate Total Toothpaste - Colgate-Palmolive Ltd, Guildford.
Sodium Fluoride EP 0.32%

Aquafresh Toothpaste - SmithKline Beecham, Personal Care, Brentford, Middlesex.
Sodium Monofluorophosphate 0.75%, Sodium Fluoride 0.0165 W/W.

Macleans Sensitive Toothpaste - SmithKline Beecham, Personal Care, Brentford, Middlesex.
Sodium Fluoride B.P. 0.23% W/W.

Endekay Daily Fluoride Mouthrinse - Stafford-Miller Ltd, Welwyn Garden City.
Sodium Fluoride 0.05% W/W.

Plax Fluoride Mouthrinse - Colgate-Palmolive Ltd, Guildford.

FluorGard Weekly Mouthrinse - Colgate-Palmolive, Guildford, Surrey.
Sodium Fluoride 0.2% W/W.

Sodium Fluoride 2.53% W/W.