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Etiology of dental erosion – extrinsic factors

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The extrinsic causes of dental erosion can be grouped under the headings of environmental, diet, medications and lifestyle. Environmental factors mainly involve exposure to acid fumes by workers in factories without proper safeguards. Swimming pools with low pH due to inadequate maintenance have also been implicated. Dietary factors have received the most attention and are likely to affect the broadest segment of the population. Most acidic foods and drinks have the potential to cause dental erosion in the human mouth. The total acid level (titratable acid) of dietary substances is considered more important than their pH, because it will determine the actual H^+ available to interact with the tooth surface. Other constituents of foods and beverages will also have a modifying effect, including the calcium, phosphate and fluoride concentration, the acid type, and physical and chemical properties that influence the clearance rate from the mouth. It is not appropriate to assign relative degrees of risk to the different dietary substances except in general categories, because of the many human biological and behavioral factors that influence the clinical expression of dental erosion. The types of foods and beverages consumed, and the frequency and time of consumption are lifestyle factors that are considered most important regarding the clinical development of dental erosion. Low pH medications and oral hygiene products have also been suggested as potential causes of erosion. The combination of frequent consumption of acidic substances and overzealous oral hygiene practices may be another high risk lifestyle factor.

Key words: dental erosion; diet; etiology; medications

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Introduction

The extrinsic factors involved in dental erosion will be reviewed under four headings: environmental, diet, medications, and lifestyle (see Table 1). Like many oral diseases, such as dental caries and periodontal disease, dental erosion must be characterized as a disorder with a multifactorial etiology. Most of the clinical literature in this area is based on case histories that attempt to link clinical findings with a particular factor. While one factor may play a predominant role in the erosion process in a given individual, it is likely that there are many factors that can contribute to this complex process. This review will concentrate on the available evidence concerning the extrinsic causes of dental erosion; however, to provide a complete review of this topic, the other interrelated aspects of tooth wear will also be discussed, namely, abrasion and attrition.

Environmental Factors

Severe cases of erosion involving primarily the incisal edges of anterior teeth have been associated with exposure to inorganic acids. MILLER (1) noted that dynamite factory workers were reported to have dental erosion due to atmospheric exposure to sulfuric and nitric acids. Industrial environmental factors have been shown to be the primary etiological factor in several clinical surveys (2–4). TEN BRUGGEN CATE (2) studied the prevalence and progression of dental erosion in a large group of factory workers in Great Britain, whose jobs involved exposure to acid fumes or aerosols. The study population included battery factory workers exposed to sulfuric acid, galvanizing factory workers exposed to hydrochloric acid, workers involved in other types of etching and cleaning processes involving mainly sulfuric and hydrochloric acids. The control population worked in acid-free departments of the companies participating in the survey. Battery factory workers were found to have the highest prevalence and incidence of dental erosion. Preventive measures intended to reduce acid exposure were found effective in reducing dental erosion.

More recent surveys of factory workers in Finland (3) and Germany (5) have reported that occupational dental erosion continues to be a problem in some countries. Of interest, the German study (5) also reported a high prevalence of attrition of the posterior teeth, which they attributed to increased fragility due to acid exposure. Tooth surface loss of posterior teeth has also been reported in Tanzanian fertilizer factory workers exposed continuously to sulfuric acid (3). This was attributed to mastication of highly fibrous food and foods containing abrasive particles, which in combination with acid erosion resulted in accelerated attrition of the posterior teeth.

An unusual case report (6) of a 27-yr-old man with rapidly progressing tooth surface loss of his labial anterior teeth was attributed to occupational exposure to airborne proteolytic enzymes. The individual admitted to habitual mouth breathing. The authors speculated that enzymatic digestion of the organic enamel matrix and possibly the acquired pellicle contributed to the exaggerated erosion/abrasion of the tooth surfaces. This isolated case must be viewed with some degree of skepticism until additional supportive evidence becomes available.

There have been several case reports of competitive swimmers suffering dental erosion from swimming at gas-chlorinated pools (7, 8). Large swimming pools generally use gas chlorination, which results in the formation of hydrochloric acid that requires neutralization and buffering to maintain the recommended pH range of 7.2–8.0. Inadequate monitoring of the pool water pH was considered the problem in both reports (7, 8).

In summary, any occupation or advocation, which involves daily exposure to acids, presents some degree of increased risk of dental erosion. Other occupations that may increase the risk of dental erosion include munitions manufacturing (2), printers (9), laboratory workers who mouth pipette acids (10), and professional wine tasters (11). Often this risk can be eliminated or greatly reduced with the use of proper safeguards that are generally in place in most developed countries. However, environmental causes of dental erosion may still be of concern in developing countries.

Diet

Based on the volume of published material on the subject, the role of diet in the etiology of dental erosion has received the most attention. Early observations in the dental literature on the role of acidic foods in dental erosion date back to Darby (12) and Miller (1). Miller (1) concluded that all acids were capable of causing erosion, including acids found in wine. The actual clinical scientific evidence, directly linking a particular acidic food or beverage as the primarily etiological agent causing erosion, is limited. However, the combination of all available evidence strongly supports the role of many commonly consumed acidic foods and beverages in dental erosion. Acidic foods and drinks have been implicated based on clinical studies, animal studies, and *in vitro* investigations.

Clinical Studies

The clinical studies will be reviewed under four headings: clinical trials, epidemiological studies, case reports, and experimental clinical studies.

Clinical trials – Thomas (13) conducted one of the few clinical trials that attempted to investigate the effects of acidic beverages on human teeth. While this study suffers from many inadequacies, this type of study is not likely to be repeated because of ethical reasons, and thus will be reviewed in detail. The study evaluated the effect of daily ingestion of different amounts of acidic beverages on macroscopic and microscopic changes in the labial surface of maxillary anterior teeth of a group of dental students and dental hygiene students. The microscopic changes were reproduced using a collodion replica technique. The students were divided into groups of 20, drinking either orange juice, grapefruit juice, or carbonated cola, and subdivided into groups of five that drank either 6, 12, 18 or 24 ounces of the juice or carbonated beverage per day. A group of 10 students served as controls and refrained from ingesting all forms of citrus fruits and carbonated beverages.

Thomas (13) noted that the first appearance of any microscopic alteration of the enamel surface occurred between the fourth and sixth week of the study. The macroscopic changes ranged from a dulling of the labial surface to the appearance of chalky white areas. These marked changes were observed only in two of the students, one who consumed 24 ounces of grapefruit juice and the other who consumed 24 ounces of the carbonated cola beverage. All experimental groups were found to have some alteration of surface enamel; however, even within the high consumption groups, some students did not experience any detectable erosion. Orange juice was found to cause less erosion than grapefruit juice or carbonated cola beverage. The author suggested that several factors may explain the variation in the response of the subjects. These included: the manner in which the fluid is taken into the mouth, the tooth surfaces that come in contact with the fluid, and the duration of contact with the teeth. This in turn is influenced by swallowing habits, motions of the lips and cheeks, and access to saliva. Other host factors were also considered to modify the erosion process, such as the buffering capacity of saliva, the chemical and physical properties of enamel, and the shape and contour of the teeth. These biological factors will be discussed in greater detail later in the paper.

STABHOLZ *et al.* (14) compared the ultrastructure of exfoliated primary teeth of children, who drank 100 ml of orange beverage on school days for 12 to 18 months, with teeth from children who did not receive any beverage at school. They observed slight demineralization of the teeth of children who received the orange beverage. Interestingly, the investigators noted that the children exposed to the orange beverage were found to have less caries in their permanent teeth than the control group.

Epidemiological studies – Case-control studies and epidemiological studies have also provided important information on the relationship of diet and dental erosion. LINKOSALO & MARKKANEN (15) compared dental erosion in a group of lactovegetarians with their gender- and age-matched controls. None of the controls were found to have erosion, while over 75% of the lactovegetarians had erosion. They found the most important dietary factors to be the frequency of consuming vinegar and vinegar conserves, citrus fruits and acidic berries. Based on a case-control study of Finnish adults, JÄRVINEN *et al.* (16) found a strong association between patients diagnosed with dental erosion and consumption of citric fruits more that twice per day, soft drinks daily, and apple vinegar or sports drinks once a week or more.

In a survey of Swiss adults, LUSSI *et al.* (17) reported that citrus fruits, other fruits (apples, pears and plums) and fruit juices were significantly associated with erosion. MILLWARD *et al.* (18) evaluated the role of diet in dental erosion in a group of 101 English children, 4–16 yr of age, seeking dental care at a University Dental Service. Of this group, 20 children were referred by general dentists specifically because of a concern about tooth tissue loss. A very high prevalence of erosion (80%) was reported for this study population. However, most of the erosion observed was in the mild category, which can be difficult to accurately score. Furthermore, given the design of this study, it is not possible to make inferences to the general population. The authors reported that an increase in the mean frequency of consumption of fruit drinks, carbonated beverages and fruit juices were each associated with an increase in the severity of erosion. Of note was the finding that bedtime consumption of fruit juices was strongly associated with the most severe cases of erosion.

Case reports – Most of the clinical evidence, linking specific dietary factors to dental erosion, appears in the form of anecdotal case reports. STAFNE & LOVESTEDT (19) reported that some individuals drinking lemon juice daily for therapeutic reasons showed a marked degree of erosion after only three months of use, while other individuals experienced less erosion after more than a year of use. This was attributed to differences in the amount and buffering capacity of the individuals' saliva. Drinking lemon juice between meals was considered an important factor. A later report (20) described four cases of erosion involving either drinking lemon juice, eating or sucking lemons. A severe case of erosion was reported in a 27-yr-old woman diagnosed with diabetes insipidus, who ingested large quantities of fruit juices and diluted fruit squashes because of a need for increased fluid intake (21). ECCLES & JENKINS (22) described 26 cases of erosion, which they associated with consumption of excessive quantities of fruit, fruit juices and other acidic beverages. The manner in which a food or beverage is consumed was considered a modifying factor that affects the pattern of the erosion in the mouth.

A number of case reports have focused on unusual or abusive consumption of acidic beverages (23–28). HIGH (23) described an unusual pattern of dental erosion in a 23-yr-old male that was attributed to a past habit of holding a cola beverage in his mouth until all the carbonation had dissipated. Other reports of parafunctional habits that have been connected to dental erosion include swishing concentrated orange cordial (25) and carbonated cola beverage (28) between the teeth before swallowing. MUENINGHOFF & JOHNSON (24) reported on a case of a 34-yr-old male who drank 64 oz of a diet carbonated cola beverage per day over a 2-yr period. The authors attributed the erosion process to the large amounts of lemon concentrate that he added to the beverage. Dental erosion due to excessive consumption of fruit flavored drink has also been observed in 9–16 yr-old-children (26). The authors noted that the acidic beverage was in many cases consumed in a more concentrated form than recommended by the manufacturer.

Several authors have recommended the drinking of acidic beverages through a straw introduced into the mouth past the teeth (22, 29). However, there are case reports that indicate that unusual methods of drinking a fruit-flavored cordial or a fruit drink with a straw caused marked erosion of the anterior teeth (25). Both cases involved children placing the straw against the labial surface of the maxillary anterior teeth. A similar case involved a 5-yr-old girl who drank orange juice throughout the day using an infant drinking cup with its spout placed labially to the incisor teeth. The prolonged use of baby fruit juice at night time in a feeding bottle used as a comforter has been reported to have caused extensive dental erosion in a 2-yr-old girl (27).

Experimental clinical studies – Other clinical studies have evaluated the erosion potential of beverages by less direct methods. IMFELD (30) evaluated five categories of acidic beverages by telemetrically measuring the pH in oral fluids and in interdental plaque after drinking 100 ml or rinsing with 15 ml of the beverages. Ciders, citric fruit juices, fruit juice drinks, flavored drinks, diet drinks, and mineral waters were tested. In all cases, rinsing with 15 ml of the test beverage resulted in a lower oral fluid pH value and a more prolonged pH depression than drinking 100 ml of the beverage. This was attributed to a more extensive distribution of the beverage in the mouth following rinsing. Grapefruit juice, which had the highest level of titratable acid, was the only beverage tested in which the pH of oral fluids remained close to pH 4 for an extended period. All of the other acidic beverages produced an initial low pH in oral fluids that reflected their intrinsic pH value, followed by a rapid pH recovery. Mineral water was considered to have little or no potential to cause erosion. Prolonged pH depression at the interproximal plaque site was associated with the fermentable carbohydrate content of the beverages. It was suggested, based on the above findings, that sugar-containing acidic beverages may promote both dental erosion and dental caries.

Using a different approach. MEURMAN *et al.* (31) observed that the pH on the surface of the tongue of five healthy subjects rapidly returned to baseline values after ingestion of acidic beverages. They concluded that the retention of ingested acidic substances on the tongue was not a contributing factor to dental erosion of the lingual surface of the teeth.

An *in situ* model has also been used to study the erosive effect of an acidic carbonated beverage and the reparative effect of saliva and dairy products in the human mouth (32, 33). The *in situ* model consisted of tooth sections held in the mouth of subjects on palatal appliances. It was found that after 1 h of exposure to an acidic beverage, the enamel surface of the tooth sections was considerably softened as measured by surface microhardness changes (32, 33). A 1-h exposure to cows' milk (32) and a 5 min chewing period with cheddar cheese (33) both resulted in statistically significant increases in surface hardness of the acid-softened enamel. A 1-h exposure in the mouth to saliva also significantly rehardened the acid-softened enamel (32), while exposure to stimulated saliva for 5 min did not significantly reharden the enamel (33).

Interpretation of clinical studies

The clinical studies described above provide evidence from a wide range of sources implicating various foods and beverages in the etiology of dental erosion. Although limited in number and scope, the clinical trials provide the most direct evidence that acidic fruit juices and beverages can result in dental erosion. The finding by THOMAS (13), of marked variation in the response of different subjects receiving the same erosive challenge, suggests that biological factors may modify the erosion process (discussed below).

Epidemiological studies have provided supportive evidence that consumption of various acidic fruits and juices, carbonated and uncarbonated beverages, sports drinks, and vinegar conserves, are associated with dental erosion. Many case reports have implicated specific dietary substances, including, lemon juice, orange juice, carbonated cola beverage, orange cordial, and fruit flavored drink. In all cases, the problem was associated with unusual or excessive consumption behavior. These anecdotal reports are limited in their ability to establish causality, given the well-known problems of the inaccuracy of patient recall and multifactorial nature of tooth wear; however, in composite they support the role of specific dietary substances in dental erosion. Experimental clinical studies involving measurement of intra-oral pH after ingestion of a food or beverage provide some information on their erosive potential; however, this approach measures pH at specific locations in the mouth that is not generalizable to other areas of the mouth. Furthermore, pH is only one of many factors that determine the erosion potential of a food or beverage (discussed below).

Animal Studies

Animal models have been widely used to evaluate the erosive effect of different acidic beverages (34–43). MCCLURE (34) first described the extreme sensitivity of molar teeth of rats to acid destruction by inorganic acids and acidic beverages. Ingestion of dilute solutions of hydrochloric and lactic acids was found to be very destructive to enamel and dentin, primarily of the mandibular teeth. A comparison of different acidic beverages showed that cranberry juice caused the greatest degree of erosion, while grapefruit juice and two carbonated beverages, ginger ale and a cola soft drink, caused a similar degree of erosion. A subsequent study showed that limited amounts of acidic beverages could induce dental erosion in dogs and monkeys in addition to rats (35). However, the experimental design used for this study does not allow comparison among these animal models.

In experiments using what must be considered a very high challenge model, WYNN & HALDI (36) observed substantial differences in the amount of erosion of rat mandibular molar teeth caused by fruit juices. Grapefruit juice caused the most erosion followed in a descending order by grape, apple, pineapple, orange, prune and tomato juice. The investigators noted that there was a general trend toward an increased erosion with increased acidity of the fruit juices; however, other factors including the type of organic acid anion appeared to be modifying the process. It was pointed out that the findings from the rat model cannot be directly applied as a guide for dietary recommendations because of differences in rat and man. It is likely that the lapping method of fluid intake used by the rat results in prolonged contact with the mandibular teeth. MCCAY & WILL (37) observed that extensive erosion could be detected in rats fed 10 ml of 0.055% phosphoric acid per day over a 6 wk period, while orange juice produced a limited degree of erosion and no detectable erosion was found with tomato juice.

An extensive study of the erosive properties of a wide range of fruits, fruit juices, soft drinks and other beverages using the rat model was conducted by MILLER (38). Fruit juices were found to cause three to seventeen times greater enamel erosion than an equivalent amount of the fruit from which the juice was prepared. Differences in the eating and drinking patterns between rat and man may diminish the clinical relevance of this finding. A marked erosion effect was observed with grape juice and less of an effect with orange and pineapple juices. Carbonated beverages caused a moderate degree of erosion, which in general was less than the marked erosion found for non-carbonated fruit flavored drinks. There was considerable variation in the amount of enamel erosion between different brands of the same type of carbonated beverage. Other commonly ingested beverages, milk, cocoa, coffee and tea, had no erosive effects on rat enamel. As with the earlier rat studies discussed above, a clear relationship could not be established between the pH and titratable acidity of the beverages and their enamel erosive properties. Of interest was the observation that when an erosive fruit juice was combined with a non-acid fruit (papaya) or non-acid beverage (milk), the erosive property was lost. This finding supports the contention that consumption of acidic beverages in combination with other foods during meals may be less destructive to teeth than when consumed between meals.

HOLLOWAY *et al.* (39) also compared a large number of soft drinks, including fruit squashes and cordials, and carbonated beverages sold in the United Kingdom at the time of the study. All the fruit squashes and cordials were found to be comparable to a 0.5 % citric acid sucrose solution (positive control) in their ability to cause *in vivo* erosion of rat molars. The carbonated beverages were less erosive than the fruit-flavored drinks. It was pointed out that the degree of erosion is not dependent on the pH of acidic drink ingested, but the effective pH that is maintained at the tooth surface. Thus, the titratable acidity of the beverage and saliva buffering capacity are important factors in dental erosion.

STEPHAN (40) compared the erosive effects of a wide spectrum of foods using the rat model. Of the 53 foods tested, only seven of the foods produced dental erosion. These were the low pH beverages (cola – pH 2.5; orange drink – pH 2.9) and foods (apples – pH 4.3; orange slices – pH 3.4; lemon slices – pH 2.5; grapes – pH 3.4; dried apricots – pH 3.5). The remainder of the test foods were all above pH 4.5. Also noteworthy was the finding that the beverages produced erosion mainly of the lingual surfaces of the rat molar teeth where the tongue came in contact, while for the more solid foods erosion was more common on the occlusal surfaces.

A more recent rat study by SORVARI (42) reported that sport drinks also caused marked erosion or rat molars. The addition of fluoride was shown to have a protective effect. MISTRY & GRENBY (43) compared several acidic beverages with the rat model and used a new digital image analysis system for assessing erosion of rat molars. Carbonated orange drink was found to be the most erosive, followed by uncarbonated orange drink and then apple juice. Of note was that these findings did not correspond with earlier rat studies (38, 39) and results from *in vitro* studies (44, 45).

Interpretation of animal studies

Direct comparison of the findings of the above mentioned rat studies is highly problematic. None of the earlier studies provided statistical analysis of the data to establish whether their observations have statistical validity. Several of these studies (34, 39) noted marked variation in the degree and pattern of dental erosion among rats receiving the same treatment, which was attributed to differences in drinking habits and possible differences in susceptibility to erosion. These studies also varied in their experimental design. In some studies, the test food or drink was given *ad libitum* (34, 36), while in other studies the amount and frequency of intake were controlled (37–39). Even in studies that attempted to control the amount of intake, the preference of rats for a particular food or drink may have altered the experimental findings. The length of the experimental period also varied widely among the different studies as well as the age of the rats at the start of the study. The method of evaluating erosion also varied among the different rat studies. The earlier studies involved quantifying the amount of erosion by measuring the loss of weight of the rat molar teeth (34, 36), while most of the other studies used different types of scoring systems (35, 37–42).

Given the above considerations only general conclusions regarding the role of diet in dental erosion can be derived from these rat studies. Interpretation of rat studies is also complicated by the well-established differences between rats and humans. Besides differences in physiologic mechanisms of drinking between the species mentioned earlier, differences in properties and composition of saliva and enamel may greatly affect the erosion process. The pH, buffering capacity and phosphate concentration of rat saliva are known to be different from human saliva. The solubility properties and morphology of rat teeth and human teeth are also known to differ. The impact of these differences on the qualitative and quantitative expression of dental erosion is not known.

In vitro investigations

In vitro studies of dental erosive properties of acidic foods and drinks have a long history and have become more popular in recent times (1, 37, 38, 44–55) MILLER (1) observed that an extracted tooth placed in grape juice for 4 wk after being slit in half had a stronger erosion of the enamel than the dentin. WEST & JUDY (46) demonstrated the enamel erosive potential of different acidified candies when dissolved in water. They estimated that placing acidified candies in the mouth immediately next to tooth enamel will result in a concentrated solution of the candy with a pH of 3–4, and suggested that if this practice was repeated on a daily basis, this would result in serious demineralization of the teeth. MCCAY & WILL (37) observed that teeth placed in 50 ml of a carbonated cola beverage or phosphoric acid sucrose solution with a similar concentration as the beverage, demineralized during exposure times ranging from 3 to 336 h.

BIBBY & MUNDORFF (47) compared a considerable number of snack foods using an *in vitro* salivary fermentation demineralization system. Of interest was that acidic fruit-flavored candies inhibited new acid formation by bacterial fermentation, yet produced more enamel demineralization than any of the other snack foods tested. Although fresh fruits have also been shown to cause *in vitro* demineralization due to their inherent acidity, they are generally considered of low risk of causing erosion because they stimulate salivary flow and are rapidly cleared from the mouth (48).

RYTOMAA *et al.* (49) used surface profile measurements to evaluate the depth of enamel erosion after exposure to acidic drinks and milk products for 4 h under constant agitation. With this model system, a cola beverage, orange drink and sports drink were the most erosive. Diet cola beverage and orange juice were less erosive. Beer, coffee, strawberry yoghurt, buttermilk and carbonated mineral water produced little or no erosion under the experimental conditions. In this *in vitro* model system, the products with a pH above 4 did not cause erosion, while the products with a pH below 4 all caused distinct erosion. A second experiment was conducted to evaluate the protective and/or reparative effect of saliva or saliva supplemented with 2 ppm fluoride. A 15 min exposure to an erosive product apparently resulted in an irreversible lesion, which was not protected by 2 h cycles of treatment with either saliva or fluoridated saliva interspersed with exposure to the erosive challenge.

GROBLER *et al.* (50) evaluated different fruits by determining the amount of calcium released from enamel after repeated exposure to 120 μl of the erosive treatment over a 40 min period. The supernatant of centrifuged minced fruit was used as the test treatment. The highest initial erosion rate (during the first 10 min) was found for apricot, which had the highest amount of total acid. Grape and guava were intermediate, while apple and orange had the lowest erosion rate. After this initial phase, the erosion rate decreased for all fruits, but less so for grape. A companion study (52) evaluated fruit juices and carbonated beverages using a similar methodology. Orange juice and cola beverage caused the most demineralization during the early time periods, followed by apple juice. The diet cola beverage caused the least erosion of the products tested. This was attributed to the calcium concentration of the diet cola, which was more than double the other drinks.

GRENBY *et al.* (45) compared the potential erosive effects of various drinks marketed for consumption by infants with a number of drinks marketed for general (adult) consumption (44). They incubated the drinks with hydroxylapatite (HA) for 30 min and measured calcium and phosphate dissolution. The infant drinks were generally found to be less acidic and caused less demineralization. The investigators could not establish a clear relationship between the acidity (pH, titratable acid) and dissolution of HA, but noted that drinks that dissolved the least HA had the highest content of calcium and phosphate. The authors concluded that it is very difficult to establish guidelines as to which drinks are safest for teeth.

Sports drinks have also been evaluated in other studies (51, 53). MEURMAN *et al.* (51) evaluated the dissolution of HA by thirteen sports drinks that contained either citric or malic acids. Two experimental sports drinks with a higher pH than the commercially available products were also tested, one containing citric acid and the other malic acid. The experimental sports drinks produced less calcium dissolution than any of the commercially available products. An additional comparison of the two experimental drinks was made, using bovine enamel as the test substrate. The degree of enamel erosion was assessed by surface profilometric analysis and surface microhardness (SMH) measurements. The malic acid-containing drink appeared to result in slightly less erosion than the citric acid drink under some of the test conditions; however, the conclusion that malic acid is less erosive than citric acid was not supported by statistical analysis of the data presented in this article. In a subsequent study, MEURMAN & FRANK (53) observed, based on enamel surface ultrastructural changes, that malic acid-containing sports drink (pH 3.4) was less erosive than either citric acid-containing sports drink (pH 2.8) or phosphoric acid-containing cola beverage (pH 2.6) after 15–30 min treatment periods. However, it must be pointed out that the pH differences among the drinks may be largely responsible for the experimental effect.

LUSSI *et al.* (54) evaluated the erosion potential after a 20 min exposure to 5 ml of different beverages and foods. A diet carbonated lemon flavored beverage was found to have the most enamel erosive capacity as determined by changes in surface microhardness (SMH). It was followed by grapefruit juice, apple juice and salad dressing. Orange juice, carbonated cola beverage, a low phosphate-containing sports drink and white wine also resulted in statistically significant changes in SMH. A high phosphate-containing sports drink, drinking whey and yoghurt did not significantly change enamel SMH. The erosive capacity of the different test substances was found to be significantly associated with their titratable acidity, pH, phosphate content and fluoride content, based on multiple regression analyses.

Recently, even honey has been added to the list of acid foods and beverages evaluated with *in vitro* erosion models. Fortunately, for individuals with a predilection for natural foods, honey was shown to be of low erosion potential in spite of its low pH (55). The calcium, phosphate and fluoride content of honey were found to only partially explain its non-erosive properties. It was suggested that other factors may also play a role, such as the presence of colloidal particles and its high sugar content.

Other studies have implicated various fruit juices, fruit drinks, herbal teas and carbonated beverages based solely on their chemical properties, such as pH, titratable acidity and calcium, phosphate and fluoride content (56–61). LARSEN (62) concluded that dental erosion was the result of exposure to liquids undersaturated with respect to both hydroxyapatite (HA) and fluorapatite (FA). Thus, the erosion potential of fruit juices and soft drinks could be calculated based on their degree of saturation with respect to hydroxyapatite and fluorapatite. LARSEN (56) analyzed the pH, calcium, phosphate, and fluoride content of various acidic fruit juices and carbonated beverages, and determined that they were capable of erosion, since they were all undersaturated with respect to HA and FA. Sadly, champagne was also found to fall in this category.

Interpretation of in vitro *studies*

As with animal studies only general conclusions can be reached from these *in vitro* studies. Direct comparison of the *in vitro* studies cannot be made because of major differences in the experimental design among the studies. The hard tissue substrate used in these studies was from a wide range of sources – human teeth, bovine teeth, rat teeth or powdered hydroxyapatite, which vary greatly in their dissolution properties. A number of investigators have also studied the erosion properties of human dentin (63–65). There are also differences in the method of preparation of the substrate, i.e., polished vs. unpolished tooth surface. It is well established that grinding and polishing the tooth surface will increase the dissolution rate of enamel (66, 67). The methods of evaluating dental erosion included calcium and/or phosphate loss, profilometric surface measurements, surface microhardness testing, and evaluation of ultrastructural changes. The test conditions under which the different treatments were employed varied in regard to the volume of the test solution, the length of the treatment period, the temperature, and the use of agitation. Each of these parameters will affect the dissolution rate of enamel (68). There is also the likelihood of interactions among these parameters, which complicates the situation further. This may explain why many of the *in vitro* study reports differ in how they rank the erosion capacities of the same test products. It is also possible that different brands of the same dietary product type as well as different lots of the same brand may not have the same erosion capacity.

The translation of the findings of the *in vitro* studies described above to the human mouth is also problematic. The erosive effect of transient exposure to acidic foods and beverages in the human mouth is influenced by factors that are not accounted for in *in vitro* erosion models (69). These can be broadly grouped under behavioral factors and biological factors. The behavioral factors will be discussed later under the heading of lifestyle, and the biological factors will be discussed here.

Biological factors modifying the erosion process

The biological modifying factors include saliva, tooth composition and structure, dental anatomy and occlusion, the anatomy of oral soft tissues in relationship to the teeth and physiological soft tissue movements such as swallowing pattern. Of these, saliva is considered the most important factor and will be discussed in detail.

Saliva – Saliva is known to have many properties (70) that can serve a protective function against dental erosion: (1) dilution and clearance of a potentially erosive agent from the mouth; (2) the neutralization and buffering of dietary acids; (3) maintaining a supersaturated state next to the tooth surface due to the presence of calcium and phosphate in saliva; (4) formation of the acquired pellicle by the adsorption of salivary proteins and glycoproteins, which has the ability to protect the enamel surface from demineralization by dietary acids; and (5) providing calcium, phosphate and possibly fluoride necessary for remineralization.

There are a number of fairly dated studies that have attempted to relate various properties of saliva to dental erosion, such as salivary pH, buffering capacity, calcium and phosphate content of saliva, citrate content of saliva, pyrophosphate content of saliva, mucin content of saliva, and unstimulated and stimulated salivary flow rate (71). Of these salivary parameters, only the unstimulated salivary flow rate and buffering capacity have been directly associated with dental erosion (16, 72–74). There is a clear relationship between reduced salivary flow rate and the ability to clear dietary acids from the mouth. In addition, the bicarbonate level in saliva is positively correlated with salivary flow rate; therefore, saliva produced at a low flow rate has a lower pH and a lower buffering capacity. McCay & Will (37) reported that the ability to buffer an acidic carbonated beverage after rinsing for 30 s differed widely among individuals but was consistent for the same individual.

Another important role of saliva is related to the formation of the acquired pellicle. There is an extensive body of literature establishing the ability of the acquired pellicle to protect the enamel surface against acid demineralization (75). Mannerberg (76) observed that the presence of a pellicle provides protection against exposure to lemon juice. A recent study has shown that the acquired pellicle can protect enamel from erosion by a carbonated beverage (77). An important consideration regarding the pellicle is that dental erosion is frequently associated with individuals with a high level of oral hygiene (78). Commonly used dental products, such as toothpastes, contain abrasives that can remove or reduce the thickness of the pellicle, thus reducing its protective effects (79). The association of dental erosion with areas of teeth that tend to be free of plaque, supports this hypothesis.

In summary, saliva plays an important role in modifying the potentially erosive effects of dietary foods and beverages, which cannot be easily modeled *in vitro*. Both the quantity and quality of saliva may account for observed differences in the extent of dental erosion in individuals who apparently subject their teeth to the same level of dietary challenge.

While it can be concluded that decreased salivary flow and buffering capacity can be a contributing factor in dental erosion, the relative importance of qualitative differences in composition in regard to calcium, phosphate and fluoride concentrations and differences in salivary components involved in pellicle formation need further study.

Tooth composition and structure – The hard tissue substrate used in *in vitro* models is also an important factor worthy of review. The composition of human teeth is known to be highly variable (80). Clinical studies have shown marked differences in the response of human teeth to acidic beverages (13, 76). *In vitro* model systems that use the natural surfaces of human teeth accounts for this biological variation. However, the use of human enamel specimens will also increase the experimental variation of the model (53, 81), and thus the model will require larger numbers of samples to achieve statistically significant differences between treatments (82). Most of the *in vitro* model systems use bovine enamel as the hard tissue substrate. Bovine enamel is considered a suitable substitute for human enamel for demineralization and remineralization studies (82, 83). Meurman & Frank (53) did not observe any difference in the progression of erosion or the surface ultrastructure of erosive lesions between bovine enamel and human prismatic enamel. The use of powdered hydroxyapatite has the least relevance to the clinical situation and is greatly different in its composition and solubility properties from human enamel (68, 80).

Dental anatomy and occlusion – The shape and contour of teeth and their prominence in the mouth in relation to drinking and swallowing patterns have been identified as factors that may modify the erosion process (13). Acid-eroded enamel is considered more susceptible to attrition, and thus, dental occlusion is likely to play an important role in manifestation of erosion-induced tooth wear patterns (2, 84). Conversely, tooth wear, primarily caused by parafunctional habits such as bruxism, will be greatly accelerated in the presence of an erosive challenge to the teeth (84). Dental occlusion may also be a factor in the etiology of noncarious cervical lesions based on the tooth flexure theory, whereby stress caused by eccentric occlusal forces causes cracks in the tooth structure in the cervical area that are more susceptible to acid erosion (85).

Anatomy of the soft tissues and physiological soft tissue movements – The anatomy of oral soft tissues in relationship to the teeth and physiological soft tissue movements will influence the tooth sites that acidic substances will contact (13) and will also influence the clearance pattern of acidic substances from the mouth. The soft tissues may also play a more direct role in the tooth wear process. JARVINEN *et al.* (86) observed that the most severe erosion was found on the palatal surfaces of teeth touched by the tongue. This finding, as well as observations made in rats (discussed above), supports earlier suggestions that tooth surfaces in contact with the tongue are prone to mechanical abrasion (31).

Medicaments

There have been a number of reports associating medications and over-the-counter dental products with dental erosion (19, 87–93). JAMES & PARFITT (87) reported that different iron tonic products had a wide pH range, pH 1.5 to 8.6. Based on their *in vitro* study, they concluded that potential for damage to teeth was dependent on the acidity of the preparation. It was also suggested that the frequency, length, and method of administration, as well as the susceptibility of the individual, will have a modifying effect. The authors did not provide any clinical evidence of erosion to support their contention.

Individuals suffering from achlorhydria may be treated with liquid hydrochloric acid by mouth. There have been several case reports of severe erosion due to this treatment (19, 88). It is not clear why this practice continues with the availability of encapsulated hydrochloric acid.

The increased use of vitamin C (L-ascorbic acid) preparations have also received some attention (89, 90). GIUNTA (89) attributed severe dental erosion in a 30-yr-old female to the chewing of three vitamin C tablets per day. MEURMAN & MURTOMAA (90) evaluated the pH and *in vitro* enamel demineralizing potential of different vitamin C preparations. All of the preparations were found to have pH values below 5.5, and cause dental erosion after a 100-h exposure period. Based on a short-term clinical study, the investigators concluded that in individuals with normal salivary flow the consumption of vitamin C preparations should not have untoward dental effects unless the preparations are left in direct contact with the teeth.

Acetylsalicylic acid (aspirin) is one of the most widely used medications throughout the world. SULLIVAN & KRAMER (91) examined the dentition of 42 children diagnosed with juvenile rheumatoid arthritis, who received massive doses of aspirin on a daily basis for extended periods. They reported that the children who received aspirin as chewable tablets suffered from erosion of the occlusal surfaces of their teeth, while children who swallowed aspirin whole did not show evidence of erosion.

Oral hygiene products have also been implicated as a cause of dental erosion (92, 93). An anti-calculus mouthrinse containing ethylenediaminetetraaceticacid (EDTA) was found to have a marked enamel erosive effect after a 2-h *in vitro* exposure period (92). This was attributed to the calcium-chelating effect of the EDTA. The acidity levels of eleven commercially available mouthrinses have recently been evaluated (93). The pH of these products ranged from pH 3.4 to 8.3 and also varied widely in their titratable acidity. The investigators did not provide any data that these products cause dental erosion. Questions have also been raised about the erosion potential of saliva substitutes with a low pH (88) and products intended to stimulate saliva flow containing citric or malic acid (92), since these products are used by individuals who are more susceptible to erosion because of reduced salivary flow.

In summary, any medication or oral hygiene product, which has a low pH and come in frequent and/or sustained contact with the dentition, has the potential to cause dental erosion. However, most medications and oral hygiene products are only used several times a day and for short periods. Furthermore, their potential to cause erosion will be modified by many of the factors discussed above. Some concerns can be raised regarding the use of low pH medications by individuals with decreased salivary flow.

Lifestyle

Many of us commonly ingest fruit juices, fruit drinks, carbonated beverages and acidic foods that have the potential to cause dental erosion. The question is why do so many of us maintain our teeth for a lifetime, considering that we are exposed many times a day to acidic foods and beverages and many thousands of times during our lifetime? On the other hand, why do some individuals suffer rapid and irreversible destruction of their teeth?

While there is no simple answer to this question, the biological factors described above must play an important role. This section will address lifestyle and behavioral factors that must also be considered important in the etiology of dental erosion.

Behavioral factors – In the clinical case histories described above, there are many accounts of abusive or unusual behavior by individuals who frequently ingested acidic fruit juices or acidic beverages on a daily basis, which has been linked to excessive dental erosion (23–26, 28). Unusual eating, drinking and swallowing habits, which increase the direct contact time of acidic foods and beverages with the teeth, are obvious factors that increase the risk of dental erosion. The consumption of acidic beverages at bedtime has also been implicated (18, 27, 84). More recently there have been several reports that have raised a concern about an apparently higher prevalence of dental erosion or tooth wear in children (18,78,94). These reports are all from the same research group and are lacking any sound epidemiological data to support their concerns. These authors refer mainly to recent dramatic increases in the consumption of acidic fruit juices, fruit drinks and carbonated beverages as the basis for their concern. However, these reports do raise the question as to whether there have been lifestyle changes that may lead to dental erosion becoming a more significant problem.

Behavior can be strongly influenced by socioeconomic status. Several studies have evaluated the relationship between socioeconomic status and dental erosion (78,95). Millward *et al.* (78) reported that 4-yr-old children from a low socioeconomic group had statistically significantly less erosion than children from higher socioeconomic groups. It was conjectured that the observed differences between the groups may be due to differences in dietary patterns and oral hygiene practices (see below). In contrast to this finding, Milosevic *et al.* (95) reported that the prevalence of tooth wear in 14-yr-old children was slightly positively associated with the level of social deprivation in the area where the children were living. Direct comparison of these studies is problematic, since they involved different age groups and different methodologies. Clearly, there is a need for more definitive studies in this area.

Healthier lifestyle – Many individuals today are pursuing "healthier" lifestyles involving regular exercise and what is considered healthy diets with more fruits and vegetables. It has been suggested that individuals involved in strenuous sporting activities may be at higher risk of dental erosion because of more frequent ingestion of acidic sports drinks, fruit juices, and other carbonated and uncarbonated acidic beverages (96). Exercise increases the loss of body fluids and may lead to dehydration and decreased salivary flow. Satisfying an increased energy requirement and need for fluid intake with low pH sugar-containing beverages during a time of decreased salivary flow may be doubly dangerous to the dentition. There may also be an overlap with an intrinsic etiologic factor. Vigorous exercise has been shown to increase the possibility of gastroesophageal reflux in some individuals (97).

Healthier diets include the consumption of more fruits and vegetables. As discussed above, a lacto-vegetarian diet, which includes the consumption of acidic foods, has been associated with a higher prevalence of dental erosion (15). Vegetarianism is also common in certain ethnic and religious groups (9). Interestingly, there is currently a vegetarian fad among teenagers in the United States (Newsweek, August 28, 1995). It is not possible to establish whether this type of eating pattern is causing an increase in the prevalence of dental erosion, because of the lack of epidemiological data.

At the other end of the spectrum, an unhealthy lifestyle may also be associated with dental erosion. Duxbury (98) suggested that the use of the illegal designer drug know as "ecstasy" (3,4 methylenedioxy-methamphetamine), commonly taken at "raves", may be a contributing factor to dental disease. The combination of drug-induced dry mouth from taking ecstasy, dehydration from the vigorous physical activity of the "rave", and excessive consumption of low pH soft drinks may increase the likelihood of dental erosion and dental caries.

Dieting – At least in the United States, there is a rampant obsession with weight loss. It has been pointed out that a high consumption of citrus fruits and fruit juices may be part of weight reduction plans (10, 99). Furthermore, individuals with eating disorders, such as bulimia, may compound their erosion problem caused by regurgitation, with the consumption of large quantities of citrus fruits and juices (100) or carbonated soft drinks (101). ANGMAR-MÅNSSON & OLIVEBY (57) pointed out that individuals in Sweden undergoing fasting for health reasons frequently consumed herbal teas. Some herbal teas, particularly brands containing rose hip, lemon and mallow, were found to be very acidic (pH, 2.6–3.9), with a relatively high buffering capacity and a low fluoride concentration. They suggested that the combination of consuming acidic drinks and reduced salivary flow associated with fasting may increase the risk of dental erosion.

Oral hygiene practices – Another aspect of our healthier lifestyle, which may be a contributing factor to dental erosion, is our modern obsession with cleaning our teeth. By definition, dental erosion occurs in the absence of plaque. Tooth surfaces that are accessible to natural cleansing forces and the action of a toothbrush are prone to erosion, while the opposite of this is true for dental caries. Acidic foods and beverages containing fermentable carbohydrates have been shown to cause caries in rats (40) and to depress the pH of human dental plaque (30, 59). The question of whether there is an interaction between dental caries and dental erosion has been with us a long time but remains unanswered. Dental plaque is known to have a much higher buffering capacity than saliva and may actually protect the tooth surface from acids of non-bacterial origin.

Oral hygiene practices have long been considered a contributing factor in tooth wear (1). Several studies have shown that the loss of tooth substance after exposure to citrus fruit juice is accelerated by toothbrushing (76, 81, 102). LEVITCH *et al.* (85) suggested that a combination of erosion and abrasion may work synergistically to promote development of non-carious cervical lesions. The clinical implication of this is that toothbrushing immediately after ingestion of acidic foods or beverages may accelerate tooth loss.

The initial demineralization of the tooth surface may be considered a reversible stage of the process, which can be repaired by saliva. Toothbrushing immediately after an acid challenge removes this partially demineralized tooth structure before saliva can repair it, and thus results in irreversible loss of tooth material. Perhaps the dental profession needs to reexamine the standard message of "brush after every meal". However, the alternate message of brushing before every meal may also be problematic. As discussed above, brushing with a dentifrice will remove the acquired pellicle (79) and render the enamel surface more susceptible to acid erosion (103). Through removal of dental plaque once per day is generally considered sufficient for the prevention of periodontal disease. The major benefit from tooth brushing, in regard to caries prevention, is the delivery of fluoride to the mouth. Perhaps recommending other methods of fluoride delivery, such as fluoride dental rinses, may provide adequate caries protection without the possibility of contributing the tooth wear.

The role of fluoride in modifying the erosion process must also be considered, since most dentifrices sold today contain fluoride. Although fluoride anti-caries effectiveness is well established, its ability to prevent erosion cannot be presumed, because the acidic challenge in erosion is stronger (104). The addition of fluoride to acid solutions and beverages has been shown to decrease the amount of erosion in animal models (35, 42, 105). Topical application with high concentration fluoride varnish or solution was effective in inhibiting enamel softening by a carbonated cola beverage *in vitro* (104). BARTLETT *et al.* (106) reported that less tooth wear was produced with a fluoride dentifrice than a non-fluoride dentifrice, when compared in an *in vitro* erosion/abrasion tooth wear model. However, the clinical validity of this model has not been established. While there is limited direct evidence that brushing with fluoride dentifrice is affecting the erosion process, its use must still be highly recommended because of its proven anti-caries effects.

Concerns can be raised, however, about the widespread use of tartar control dentifrices in regard to dental erosion. RAPP *et al.* (107) reported that there was a relationship between the presence of clinical dental erosion and the accumulation of pyrophosphate in the salivary debris in the mouth. Preliminary findings from my laboratory using an *in situ* remineralization model indicated that pyrophosphate may interfere with the effectiveness of fluoride to enhance the remineralization of surface softened enamel (unpublished data). This suggests that individuals who are susceptible to dental erosion may not receive the benefit of enhanced enamel remineralization by fluoride if they use a dentifrice containing pyrophosphate. The importance of this finding as it relates to clinical dental erosion deserves further investigation.

Professional tooth cleaning – Concerns about the repeated use of abrasive materials by dentists and dental hygienist have been with us for a long time (108). Conscientious dental patients who seek regular care routinely get their teeth polished as part

Table 1

Extrinsic etiological factors

Environmental (Occupational)
munitions factor workers[2,3]
battery factory workers[2]
galvanizing factory workers[2]
workers exposed to etching and cleaning processes involving acids [2]
fertilizer factory workers[2]
research laboratory workers[3]
professional wine tasters[3]
competitive swimmers[3]
Diet
citrus fruit juices and other acidic fruit juices[1,2,3,4,5,6]
acidic carbonated beverages[1,2,3,4,5,6]
acidic uncarbonated beverages[1,2,3,4,5,6]
acidic sports drinks[2,3,5,6]
wines[3,6]
cider[4]
acidic herbal teas [6]
citrus fruits and other acidic fruits and berries[2,3,5,6]
salad dressing[2,6]
vinegar conserves[2]
acidic fruit-flavored candies[3,6]
Medicaments
iron tonics[6]
liquid hydrochloric acid[3]
vitamin C[3,6]
aspirin[2]
acidic oral hygiene products or products with a calcium chelator[6]
acidic saliva substitutes and salivary flow stimulants[6]
Lifestyle
behavioral factors involving excessive consumption of acid foods and drinks[3]
nighttime baby bottle feeding with acidic beverages[3]
healthier lifestyle involving diets high in acidic fruits and vegetables[2]
strenuous sporting activities[3]
dieting[3]
oral hygiene practices[3]

Evidence supporting role in dental erosion: [1]clinical trials; [2]epidemiological studies; [3]case reports; [4]experimental clinical studies; [5]animal studies; [6]*in vitro* studies.

of their regular checkup. Besides the permanent loss of several microns of enamel each time the procedure is performed (109), it may also increase susceptibility to erosion, because the removal of the outer fluoride-rich surface layer is known to increase enamel solubility (66). This routine dental procedure needs to be reevaluated, considering that its oral health benefit has never been substantiated, and it is likely to be contributing both directly and indirectly to tooth wear.

Pearly white teeth have been associated with youth, health and beauty. The use of tooth bleaching agents to whiten teeth has become increasingly popular, both as professional products and as over-the-counter products. These agents work by removing the organic deposits on the teeth, including the acquired pellicle. This practice may be increasing the susceptibility of teeth to acid erosion. In some cases this procedure is combined with the use of abrasives and may even involve the use of strong acids. Since tooth whitening procedures have only cosmetic benefits, the potential risk of increasing tooth wear deserves further attention.

The above discussion of lifestyle is intended to raise concerns about aspects of our modern lifestyle, which may involve the interaction of increased consumption of acidic foods and drinks with improved oral hygiene. Due to a lack of sufficient epidemiological data on the prevalence of tooth wear, this concern is raised primarily on theoretical grounds. The intent here is not to challenge the main tenet of the dental profession regarding plaque removal for the prevention of dental caries and periodontal disease, but to point out that overzealous oral hygiene practices may be a contributing factor to tooth wear.

Summary

In summary, there are many possible extrinsic factors that can cause dental erosion (Table 1). These have been reviewed under the headings environmental, diet, medications, and lifestyle. However, a discussion of dental erosion without including the other etiological factors involved in tooth wear, namely, abrasion and attrition, is of limited clinical value. It is unlikely that any one etiological factor is operational in total isolation from the other factors. Tooth wear is a cumulative lifetime process, which to a large extent is irreversible.

The occupational environmental factors are mainly limited to those individuals who directly are exposed to acid fumes or aerosols. These include battery factory workers, galvanizing factory workers, workers exposed to etching and cleaning processes involving acids, and fertilizer factory workers. Other occupations at risk include laboratory workers who mouth pipette laboratory acids, and professional wine tasters. Tooth wear (attrition) of the posterior teeth may be accelerated by the combination of acid erosion and eating an abrasive diet. Although most industries in developed countries follow proper safeguards to protect workers, there may be an emerging problem in developing countries.

Dietary factors have received the most attention and are likely to affect the broadest segment of the population. Most all low pH foods and drinks have the potential to cause dental erosion in the human mouth. It appears that, as a rule, dietary substances with a pH above 4.5 have a low potential to cause dental erosion. However, food and beverages containing acids with calcium-chelating properties, such as citrate, may cause tooth damage at higher pH levels. It is not clear whether the chelating properties of citrate and other acids are operational in the mouth. The total acid level (titratable acid) of acidic dietary substances is considered more important than their pH, because it will determine the actual H^+ available to interact with the tooth surface. Other constituents of food and beverages will also have a modifying effect, including the calcium, phosphate and fluoride concentration, the acid type, and physical and chemical properties that may affect the clearance rate from the mouth. It is not possible to assign relative degrees of risk to the different dietary substances except in general categories, because of the many human biological and behavioral modifying factors discussed in this paper. Some beverages, such as soft drinks, may present a higher degree of risk of causing erosion than based solely on their chemical properties, because of a high consumption pattern.

Low pH medications and oral hygiene products may have the potential to cause dental erosion. However, as with the diet, the manner and frequency of use are likely to be of overriding importance. Most medications and oral hygiene products are only used several times a day and for short periods. Some concerns can be raised regarding the use of low pH medications by individuals with decreased salivary flow.

Lifestyle, as it relates to the types of foods and beverages consumed, the frequency and time of consumption, and oral hygiene practices, is considered the most important factor influencing the clinical development of dental erosion. The combination of frequent consumption of acidic foods and drinks and overzealous oral hygiene practices may be a high risk factor. Dental procedures, such as the dental prophylaxis and tooth whitening, need to be evaluated for their long-term effect on tooth wear.

Recommendations

Based on this review of the literature, the following recommendations can be made.

- There is a need to develop improved methods for studying the dental erosion, in particular the dietary risk factors. This should also include the development of *in situ* erosion models. Existing clinical, animal and laboratory methods of studying dental erosion need to be better standardized so that the results of different investigators can be compared.
- Research is required to develop an improved understanding of the biological factors that modify the erosion process, most importantly the role of saliva and pellicle formation.
- Research is required to better define the relationship between oral hygiene practices and dental erosion, including the role of polishing and whitening procedures.
- There is s clear need to establish a better understanding of the relation between certain lifestyles and dental erosion.

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