Risk Factors in Dental Erosion

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Dental erosion and factors affecting the risk of its occurrence were investigated with a case-control approach. One hundred and six cases with erosion and 100 randomly selected controls from the same source population were involved in the study. All cases and controls were evaluated by the recording of structured medical and dietary histories and by examination of the teeth and saliva. Erosion was classified according to pre-determined criteria. The relative importance of associations between factors and erosion was analyzed by a logistic multivariable model. Adjusted odds ratios (AOR) were estimated. There was considerable risk of erosion when citrus fruits were eaten more than twice a day (AOR 37), soft drinks were drunk daily (AOR 4), apple vinegar was ingested weekly (AOR 10), or sport drinks were drunk weekly (AOR 4). The risk of erosion was also high in individuals who vomited (AOR 31) or exhibited gastric symptoms (AOR 10), and in those with a low unstimulated salivary flow rate (AOR 5).

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Introduction.

Dental erosion is defined as loss of dental hard tissue by a chemical process that does not involve bacteria (Pindborg, 1970). Over the last two decades, interest in erosion has increased (Eccles and Jenkins, 1974; Hellström, 1977; Wöltgens *et al.*, 1985; Linkosalo and Markkanen, 1985; Asher and Read, 1987; Rytömaa *et al.*, 1988; Järvinen *et al.*, 1988; Sorvari, 1989). In developed countries, the incidence of the previous major dental disease, caries, has declined. More and more patients and teeth are therefore at risk of developing other dental lesions. The risk of erosion can increase as a result of changes in dietary habits and when gastric symptoms are exhibited, especially if certain psychological eating disorders are also present (Hellström, 1977; Hurst *et al.*, 1977; Eccles, 1978; Clark, 1985; Negus and Todd, 1986; Knewitz and Drisko, 1988).

Dental erosion can have extrinsic or intrinsic causes. Extrinsic factors include demineralizing acidic foods—such as citrus fruits and acidic beverages (Eccles and Jenkins, 1974; Smith and Knight, 1984; Asher and Read, 1987)—and some medicines—such as effervescent vitamin C preparations, chewable vitamin C tablets (Eriksson and Angmar-Månsson, 1986; Meurman and Murtomaa, 1986), and iron tonics (James and Parfitt, 1953). Another extrinsic cause of erosion is acids in the air breathed. Before effective occupational health measures were adopted, exposure to acids was common in the chemical and metal industries (Miller, 1907; Lynch and Bell, 1947; Malcolm and Paul, 1961; ten Bruggen Cate, 1968; Skogedal *et al.*, 1977). Nowadays, exposure to extrinsic acid can also be associated with leisure activities such as frequent swimming in chlorinated pool water (Centerwall *et al.*, 1986).

Intrinsic causes of erosion include recurrent vomiting as a result of psychological disorders, *e.g.*, in anorexia and bulimia (Hellström, 1977; Knewitz and Drisko, 1988), or regurgitation of gastric contents because of some abnormality in the gastrointestinal tract (Ismail-Beigi *et al.*, 1970; Eccles, 1978; Pope, 1982; Myllärniemi and Saario, 1985).

One important additional factor in dental erosion is low salivary flow, which, naturally, results in inadequate rinsing and buffering of demineralizing acids on tooth surfaces (Dawes, 1970; Wöltgens *et al.*, 1985). The roles of salivary calcium and phosphorus in the development of erosion are not yet known (Mannerberg, 1963; Frostell, 1973; Wöltgens *et al.*, 1985).

Although many causes of dental erosion are known, their relative degrees of importance are not clear, whether from the point of view of levels of risk associated with individual erosion-causing factors or from the point of view of their effects in populations. The aim of this study was to investigate factors relating to dental erosion, with emphasis on estimation of the quantitative contributions of non-industrial risk factors.

Materials and methods.

A case-control study was conducted. One hundred and six cases of erosion were noted between 1986 and 1987 by dentists in the Metropolitan Helsinki area. One hundred controls were randomly selected from the same source population as the cases; a control was the first patient visiting the same dentist on the next morning following the visit of a case. Both the cases and the controls were referred to the University Dental Clinic, where they were examined. Six controls did not attend for clinical examination. Five of the remaining 100 controls sent for examination by their dentists turned out to be erosion cases. Because the erosion cases were detected (according to strictly defined criteria) among 100 controls in the random sample from the source population (the patients of Helsinki dentists), the prevalence of erosion with 95% confidence limits was estimated from this sample. Interviews with the six controls who refused examination, and their dentists, did not suggest that they were suffering from obvious dental erosion. The five patients removed from the control series were replaced by other controls selected at random.

In the case-control series, men and women were about equally represented among both cases and controls. The mean age of the cases was 33.1 years (range, 13-73 years). The mean age of the controls was 36.3 years (range, 17-83 years).

Erosion was classified according to the criteria of Eccles and Jenkins (1974). The following findings characterized an erosion case: (i) absence of developmental ridges on the enamel, resulting in a smooth glazed enamel surface; (ii) concavities in the cervical region on the labial enamel surfaces whose breadth greatly exceeded their depth, thus distinguishing them from cervical abrasion lesions; (iii) edges of amalgam restorations raised above the level of the adjacent tooth surface; and (iv) depression of the cusps of posterior teeth, producing 'cupping'. In more severe cases, dentin was also involved. A more detailed description of the lesions seen by us is reported elsewhere.

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Structured medical and dietary histories were taken. Emphasis was placed on past and present gastric complaints such as vomiting, belching, heartburn, an acid taste in the mouth, stomach-ache, and gastric pain on awakening. Dietary habits were carefully evaluated by questions relating to special diets and to the quantity and frequency of consumption of citrus fruits, berries and other fruits, soft drinks, sport drinks, vitamin C, acid sweets, apple vinegar, pickles, and other acidic foods.

Unstimulated and stimulated (by the chewing of paraffin) saliva samples were collected over five-minute periods. The unstimulated salivary flow rate was classified as low when it was 0.1 mL/min or less. For stimulated salivary flow, the corresponding limit was set at less than 1 mL/min. The acidity (pH) of the saliva was measured with pH electrodes. Buffering capacity was measured by the Dentobuff method (Orion Diagnostica, Finland). Salivary calcium was measured with an atomic absorption spectrophotometer (Perkin-Elmer, Norwalk, CT), by the method of Trudeau and Freier (1967), in samples that had been stored in a deep-freeze. Phosphorus was measured as described by Fiske and Subbarow (1925), and protein by the method of Lowry *et al.* (1951).

The association between exposure and dental erosion was first described in terms of unadjusted odds ratios (OR), which indicate the risk of erosion in exposed (as opposed to non-exposed) subjects, taking no account of the effects of other factors. Cases and controls were classified as exposed or non-exposed with respect to extrinsic and intrinsic factors, as indicated below and in the "Results" section.

The relative importance of associations between erosion and different risk factors was determined with a logistic multivariable model fitted to the data by means of the Glim 3 computer program (Nelder and Wedderburn, 1972). For this analysis, the factors were dichotomized (limits are given in Table 4). Confounding factors such as age and gender were included in the model. Initially, all factors were analyzed. Later, once more realistic models had been constructed, non-significant factors were dropped from the model. Interactions between factors could also be assessed on the basis of the model. After 15 different models were tested, it was concluded that the factors eliminated did not change the order of importance of the remaining factors. When low unstimulated salivary flow rates were included in the model, odds ratios for other factors, especially the consumption of citrus fruits, increased considerably. The final aim was to arrive at a logistic multivariable model that would facilitate computation of adjusted odds ratios (AOR) and 95% confidence limits for each significant factor (Adena and Wilson, 1982).

For determination of threshold limits for consumption of common citrus fruits and soft drinks, unadjusted odds ratios were estimated based on five dichotomization values (limits are given in Table 5).

The population-attributable risk (PAR) is defined as the percentage decrease in the occurrence of dental erosion in the source population if the erosion-causing factor is eliminated. Population in this study means the patients of Metropolitan Helsinki dentists. PAR values were calculated from the formula $a(AOR-1)/[a(AOR-1)+1)]$ where "a" is the occurrence of exposure in the control group.

Results.

The prevalence of dental erosion in patients of dentists in the greater Helsinki area was 5% (95% confidence interval from 1 to 9%).

Risk factors.—In the 106 cases of erosion, at least one risk factor was found in 105 patients. In three cases (a typographer, a laboratory technician, and a research assistant), an occupational cause was possible. All were, however, also exposed to dietary and gastric risk factors. None of the controls was exposed to occupational risk factors. When exposure groups were formed according to the limits given in Table 4, an acid diet was associated with erosion in 26 cases, with occurrence of gastric symptoms in another 26 cases, and with both factors in 46 cases. Among the remaining eight cases not exceeding the exposure limits given in Table 4, one had used hydrochloric acid as a medicine, two had very low unstimulated salivary flow rates and had consumed acid diets for a long time, and four had eaten citrus fruits or other acidic foodstuffs daily or weekly for many years. In one 61-year-old man with erosion, no risk factor could be identified. When the control patients were grouped in the same way, dietary exposure was found to be present in 21, gastric exposure in 19, and both factors in five. Fifty-five of the controls did not exceed any of the exposure limits.

Dietary factors.—All of the 106 cases and 98 of the controls had consumed some acidic food. There was no detectable difference in the duration of consumption of acidic foodstuffs between the two groups, but the intake frequency was much higher among cases than among controls. Details of the intake frequencies and of unadjusted odds ratios are given in Table 1.

Special diets had been eaten by 13 of the erosion cases and seven of the controls. Three cases, but no controls, had eaten a weight-reducing diet. Ten cases and seven controls were vegetarian.

A subjective feeling of dry mouth was reported by 33 erosion cases and 22 controls. Nine of the cases had sought relief from this feeling by consuming acidic drinks. None of the controls had done so.

Gastric symptoms.—Among the erosion cases and controls, 35 and 12, respectively, had experienced gastric disease diagnosed by a physician. Seven of the cases were suffering from anorexia nervosa. None of the controls suffered from this disorder. The types and frequencies of the various gastric symptoms, and unadjusted odds ratios, are shown in Table 2.

Saliva.—Salivary flow rates, salivary pH values, and salivary buffer capacities are given in Table 3. Male erosion cases had lower calcium and phosphorus levels in their saliva than did male controls (Table 3). The stimulated salivary flow rate was low in 16 cases and six controls. The unstimulated salivary flow rate was low in seven cases and in six controls.

The more important associations with erosion are listed in Table 4 on the basis of the final multivariable logistic model arising from the data of the study. In this Table, the adjusted odds ratios are given. No interactions between the various risk factors were found in the analyses. The population-attributable risks give percentage decreases in the occurrence of dental

TABLE 1
DAILY CONSUMPTION OF ACIDIC PRODUCTS AND UNADJUSTED ODDS RATIOS

	Daily Consumers		
Product	No. of Cases	No. of Controls	Odds Ratio
Citrus fruits	53 (17)	38 (1)	2 (19)
Other fruits, berries	42 (11)	29 (0)	2
Soft drinks	32 (12)	10 (2)	4 (6)
Sport drinks	8 (1)	2 (1)	4 (1)
Pickles	4 (0)	0 (0)	
Apple vinegar	9 (0)	2 (0)	5

Figures in parentheses show those eating the indicated product more than twice a day and related odds ratios.

TABLE 2
SUBJECTS WITH GASTRIC SYMPTOMS AND UNADJUSTED ODDS RATIOS

Symptoms	No. of Cases Weekly	No. of Cases Daily	No. of Controls Weekly	No. of Controls Daily	Odds Ratio*
Vomiting	11	5	1	0	18
Sour taste	32	8	5	0	12
Belching	28	17	7	0	10
Heartburn	30	16	15	0	4
Stomach-ache	34	1	10	1	4
Pain on awakening	8	1	2	0	5
Total#	72		24		7

*Odds ratios for those with gastric symptoms weekly or more often.
#Numbers of persons with one or more gastric symptoms weekly or more often.

erosion in the source population, *i.e.*, patients visiting dentists in the Helsinki district, when the erosive factor was eliminated.

Odds ratios for commonly consumed citrus fruits and soft drinks in relation to the consumption frequencies are shown in Table 5. Because the unadjusted odds ratios increased markedly when frequency of consumption of citrus fruits exceeded twice a day, and when the frequency of consumption of soft drinks was once a day or more, these frequencies may be taken as threshold values for erosion.

Discussion.

Samples drawn from the population of the Metropolitan Helsinki area were studied. The erosion patients were found by private dentists and dental health centers in the area. Dental erosion may be more common than generally thought, since the prevalence in this dental patient population proved to be as high as 5% in the careful examination by one dentist who applied strictly defined erosion criteria.

The 106 cases and 100 controls were numerous enough to allow for estimation of the effects of risk factors, despite the fact that the confidence intervals for the odds ratios were relatively wide.

More subjects were studied than in any previously reported investigation in which potential causes of erosion were non-industrial. So far, the largest sample size came from a study in Wales: It consisted of 72 patients referred to the Conservative Department of the Dental Hospital, Cardiff, during a period of nine years, and was based on a population of between one and two million (Eccles, 1979). When interest in the study of erosion cases was made public in the Helsinki district, which has a population of about 800,000, 106 erosion cases were referred for examination in one year. This suggests either that the prevalence of erosion has increased or that the lesion is becoming better recognized by dentists.

The present study was subject to some potential sources of error. The case series is likely to present proportionally more severe forms of dental erosion than in the population at large. First, cases were found in a dental patient population. Second, only 106 erosion cases were found in one year in this large population. When strict criteria were applied to a random sample of 100 patients from the same population, five new cases were found. Thus, the study may overestimate the relative importance of at least some risk factors. On the other hand, the controls were also from the patient population, which reduces the risk of overestimation.

Another potential source of error is the interview procedure. In many instances, the subject's recollection could have been inaccurate. However, the same interviewer asked the same questions of all 106 cases and 100 controls, using a standard form. Note that none of the cases had been interviewed before regarding the possible causes of erosion. If answers were inaccurate, they were likely to have been similarly so for both cases and controls.

TABLE 3
STIMULATED AND UNSTIMULATED SALIVARY FLOW RATES, pH, BUFFERING CAPACITY, CALCIUM, PHOSPHORUS, AND PROTEIN LEVELS

	Erosion Cases Mean	Erosion Cases SD	Controls Mean	Controls SD
Men				
Salivary secretion (mL/min)				
Unstimulated	0.6	0.3	0.5	0.3
Stimulated	2.1	1.1	2.1	1.1
pH				
Unstimulated	7.2	0.3	7.1	0.5
Stimulated	7.4	0.2	7.3	0.2
Buffering capacity	5.3	1.1	5.4	1.0
Ca unstim. (mmol/L)	0.9	0.3**	1.3	1.0
Ca stim. "	0.8	0.3***	1.2	0.5
P unstim. "	4.1	1.5**	5.2	2.1
P stim. "	2.4	1.0**	3.0	1.0
Proteins, unstim. (mg/mL)	1.5	0.5*	1.8	0.7
Proteins, stim. "	1.2	0.4	1.3	0.4
Women				
Salivary secretion				
Unstimulated	0.5	0.9	0.5	0.3
Stimulated	1.7	0.9	1.7	0.7
pH				
Unstimulated	7.1	0.3	7.1	0.3
Stimulated	7.4	0.2	7.4	0.2
Buffering capacity	5.2	1.2	5.0	1.0
Ca unstim. (mmol/L)	1.1	0.5	1.2	0.7
Ca stim. "	0.9	0.3*	1.0	0.4
P unstim. "	5.4	2.5	4.7	1.9
P stim. "	2.6	1.2	2.9	1.2
Proteins, unstim. (mg/mL)	1.7	0.8	1.5	0.8
Proteins, stim. "	1.1	0.5	1.2	0.5

Significance of differences between means: *$p<0.05$; **$p<0.01$; ***$p<0.001$.

The study findings suggest that the most likely cause of dental erosion can normally be found if a patient's history is taken carefully. The existence of idiopathic erosion, with no obvious cause, is doubtful. In only one instance could a cause of erosion not be identified.

Extrinsic and intrinsic causes of erosion were equally common. Each was observed alone in 26 instances. In a previous study, simultaneous exposure to both extrinsic and intrinsic causes of erosion was recorded in 10% of cases (Eccles and Jenkins, 1974). In the study reported here, the two types of risk factor were detected simultaneously in 46 cases, *i.e.*, about twice as often as either alone. It is important for each patient's history to be taken with respect to both dietary and gastric factors, so that the overlooking of any significant exposure can be avoided. On the other hand, occupational exposure is now rare. In this study, three instances of possible occupational exposure were seen. In only one of them, a typographer, was the severe erosion detected likely to have been caused by the sulfuric and nitric acid fumes to which the patient had been exposed for 15 years in the 1940's and 1950's.

Demineralizing acidic foods commonly consumed by the erosion cases were citrus fruits, soft drinks, sport drinks, and apple vinegar. When citrus fruits were consumed more than twice a day, this was associated with an erosion risk 37 times greater than that in those who consumed citrus fruits less often. It also appears risky to consume apple vinegar or sport drinks

TABLE 4
FACTORS ASSOCIATED WITH DENTAL EROSION, ADJUSTED ODDS RATIOS, AND POPULATION-ATTRIBUTABLE RISK

Factor	Adjusted Odds Ratio	95% Confidence Interval	Population-attributable Risk (%)
Citrus fruits (more than twice a day)	37	4-369	26
Vomiting (weekly or more often)	31	3-300	23
Other gastric symptoms (weekly or more often)	10	4-22	67
Apple vinegar (weekly or more often)	10	2-57	15
Soft drinks (four to six or more *per* week)	4	2-10	26
Sport drinks (weekly or more often)	4	1-14	15
Saliva unstim. (≤0.1 mL/min)	5	1-18	19

once a week or more often, or soft drinks daily. These habits resulted in the risk of erosion being ten, four, and four times greater, respectively, than when the habit did not exist.

Although it has been known for a long time that acids can cause dental erosion, the frequency of exposure and the magnitude of the risks have remained essentially unknown. The odds ratios reported here indicate threshold values for commonly consumed acidic dietary components, such as citrus fruits and soft drinks, which resulted in a marked increase in erosion risk. For citrus fruits, for instance, the critical frequency of consumption was more than twice a day. For soft drinks, it was once a day or more.

Many previous reports have indicated that dental erosion can be caused by the eating of citrus fruits (Miller, 1907; Pickerill, 1926; Eccles and Jenkins, 1974; Linkosalo and Markkanen, 1985; Smith and Shaw, 1987). Demineralization by citric acid has also been shown *in vitro* (Miller, 1952; Davis and Winter, 1977; Linkosalo *et al.*, 1988; Rytömaa *et al.*, 1988). Citrus fruits and their juices are strongly acidic (pH less than 4.0) (Miller, 1952; Touyz and Glassman, 1981; Meurman *et al.*, 1987). The demineralizing effect of citric acid is exceptionally great because its chelating action on enamel calcium continues even after the pH increases at the tooth surface (McClure and Ruzicka, 1946; Elsbury, 1952). Very frequent consumption of citrus fruit juices can affect the enamel, even over a short term. For instance, 350 g of grapefruit juice daily for four weeks produced detectable changes in the enamel surface (Thomas, 1957).

Many soft drinks contain citric, phosphoric, carbonic, and other acids. Their pH value is often less than 4.0 (Eccles and Jenkins, 1974; Touyz and Glassman, 1981). Soft drinks, except those containing just carbonic acid, have been reported to cause dental erosion, both in case studies (Eccles and Jenkins, 1974; High, 1977; Mueninghoff and Johnson, 1982) and *in vitro* (Rytömaa *et al.*, 1988). Over the last 20 years, sales of soft drinks in Finland have increased three-fold (Pallari, 1988). Among those taking strenuous physical exercise, special drinks are commonly consumed for the maintenance of fluid balance and the provision of carbohydrates for energy. In studies in animals and *in vitro*, such sport drinks have turned out to be strongly erosive (Rytömaa *et al.*, 1988; Sorvari and Kiviranta, 1988; Sorvari, 1989). The most important erosive component in these drinks is citric acid, included for its refreshing taste. However, citric acid could be replaced by the less erosive malic acid (Meurman *et al.*, 1990). As far as we know, no erosive effect of apple vinegar has previously been reported.

TABLE 5
UNADJUSTED ODDS RATIOS IN RELATION TO FREQUENCY OF CONSUMPTION OF CITRUS FRUITS AND SOFT DRINKS

Consumption	Odds Ratio	95% Confidence Interval
Citrus fruits		
none	0.8	0-1
1-3 times a week	0.8	0-2
4-7 times a week	1.2	1-3
2 times a day	1.1	0-3
>2 times a day	19.0	2-155
Soft drinks		
none	0.6	0-1
1-3 times a week	1.7	0-3
4-7 times a week	3.5	1-8
2 times a day	14.2	2-109
>2 times a day	9.5	2-44

However, it has been observed that frequent consumption of pickles causes erosion in those eating lactovegetarian diets (Linkosalo and Markkanen, 1985).

In the study reported here, vomiting and other gastric disorders were important risk factors. In the logistic model, the adjusted odds ratios varied between gastric symptoms. Vomiting once a week or more was associated with an erosion risk 31 times greater than that in patients who vomited less frequently than once a week. The other relatively common gastric symptoms—*i.e.*, acid taste in the mouth, belching, heartburn, stomach-ache, and gastric pain on awakening—were associated with an erosion risk ten times greater when the frequency was once a week or more often, than when it was less. In all of these disorders, the origin of the acid is the same, but its consistency and adherence to the surface of the tongue differ. The intensity of a symptom is not necessarily associated with the severity of a disease. A morphologically mild condition can cause many symptoms (Salo, 1986). A patient may ignore the gastric symptoms of a minor disease, considering them normal.

Salivary calcium and phosphorus levels were lower in the erosion cases than in the controls, but the logistic model indicated that these factors were not associated with erosion. The low levels of calcium and phosphorus in the saliva must, therefore, be related to some other risk factor, such as a low unstimulated salivary flow rate. The study showed that this latter factor was important. A patient with an unstimulated salivary flow rate of 0.1 mL/min or less was at five-times-greater risk of erosion than those with higher flow rates. Other authors have also pointed out that the unstimulated salivary flow rate is an important factor determining whether dental erosion occurs (Hellström, 1977; Wöltgens *et al.*, 1985). At normal salivary flow rates, acidic drinks are eliminated from the mouth in about ten min, and the pH at the tip of the tongue remains low for only some two min after the drink has been consumed (Meurman *et al.*, 1987). In contrast, in patients with low salivary flow rates, the pH remains low for about 30 min (Tenovuo and Rekola, 1977). In this study, a low unstimulated salivary flow rate was associated with dental erosion even when the frequency of consumption of acidic foods was below the threshold limit. One patient, who did not secrete any unstimulated saliva, had eaten citrus fruit twice a week to stimulate salivary flow. Another patient had eaten citrus fruits weekly and other fruits daily. Salivary flow rate is rarely measured by dentists (Telivuo and Murtomaa, 1988), but the unstimulated salivary flow rate is particularly important because it is the rate at which saliva flows for most of the day (Sreebny, 1989).

The population-attributable risk of this study gives the over-all risk of dental erosion in the dental patient population. Although the relative effects of citrus fruits and vomiting on the risk of erosion were strong (AOR 37 and 31, respectively), the absolute decrease in the incidence of erosion would be fairly modest, because the proportion of dental patients frequently exposed to these factors was small. In contrast, many gastric factors are common among the population, and their relatively weak erosive effects (AOR 10) were associated with a high population-attributable risk (67%). In other words, elimination of these factors would reduce the prevalence of dental erosion. Apple vinegar was twice as powerful an erosion-causing factor as soft drinks, but, because it is not commonly drunk, its PAR is small (15%). The popularity of soft drinks is such that they are associated with a PAR of 26%, comparable with the level for citrus fruits, although the latter are much more erosive.

The present study illustrates the importance of non-industrial risk factors in dental erosion. Many such factors could be eliminated by general measures, such as increasing the availability of information about acidic products and gastric conditions, and through product development. It is also important for erosion to be diagnosed at an early stage and the risk factors to be identified. This increases the possibilities of successful treatment and reduces complications associated with mechanical intervention.

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