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## Relationship between dental erosion, soft drink consumption, and gastroesophageal reflux among Icelanders

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**Abstract** The aim of this study was to determine the prevalence of dental erosion in young Icelandic adults (19–22 years old) and patients with gastroesophageal reflux disease (GERD), in relation to their soft drink consumption and gastroesophageal reflux. Eighty subjects (40 males and 40 females), comprising 57 young adults (mean age  $21 \pm 2$  years) and 23 GERD patients (mean age  $35 \pm 10$  years), were enrolled in this study. All subjects answered a detailed frequency questionnaire of soft drink consumption and participated in a clinical examination. Erosion was scored for incisor and molar teeth separately. No significant difference was observed in the prevalence of dental erosion between young adults and GERD patients. However, by combining the two study groups a three-fold higher risk of having erosion in molars or incisors was found for subjects drinking Coca-Cola three times a week or more often ( $p < 0.05$ ). Additionally, significantly higher erosion scores were found in molars among subjects drinking more than 1 litre of carbonated drinks (all brands) per week ( $p < 0.05$ ). It is concluded that

the frequency of soft drink consumption is a strong risk factor in the development of dental erosion.

**Keywords** Reflux · Dental erosion · Young adults · Diet

### Introduction

Dental erosion is an acid-induced loss of dental hard tissue that does not involve bacteria, and is therefore, not associated with dental plaque. The aetiological factors of dental erosion are often categorised in two groups, intrinsic and extrinsic factors. Gastroesophageal reflux is a significant intrinsic factor of dental erosion. An early report of the relationship between gastric acid and dental erosion appeared in 1937 based on a case of a patient with chronic vomiting [3]. Later research suggested that intrinsic factors such as Gastroesophageal reflux, vomiting and regurgitation could account for up to 25% of all cases of dental erosion [13]. There is, however, conflicting information in the literature. Jarvinen et al. examined 109 patients with upper gastrointestinal symptoms and found only 6.4% to have erosion [12] while Meurman et al. found 26.2% out of 107 patients diagnosed with gastroesophageal reflux to have dental erosion [23].

Acidic drinks have long been recognised as a powerful extrinsic factor of dental erosion [11]. Studies have found that a high prevalence of dental erosion in children [16, 18] and young adults [15] relates to their soft-drink consumption or other dietary factors [1]. Additionally a 21.6% prevalence of dental erosion has been found in 15-year-old children in Iceland [2]. In parallel with these clinical findings, the Icelandic Statistical Bureau noted a 16-fold increase in the consumption of carbonated drinks from 1957 to 2000 [7], with adolescents having the largest consumption of carbonated drinks [5].

We hypothesised that both gastroesophageal reflux disease and soft drink consumption may be causal factors for erosion within selected groups of Icelanders. Thus, the aim of the present study was to determine the prevalence of dental erosion in Icelandic young adults and patients

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with known gastroesophageal reflux disease, with respect to their consumption of soft drinks and gastroesophageal reflux.

## Materials and methods

### Study group

The study group consisted of 80 Icelandic subjects (40 females and 40 males) that had not previously been examined for dental erosion. Of these 80 subjects, 57 were Icelandic adolescents (19–22 years old, 33 females and 24 males) living in urban, fishing and farming communities in Iceland. These subjects were randomly chosen from the Icelandic Nutritional Council Survey of Schoolchildren (INS) in 1992–1993. Additionally, these subjects were followed regularly in a longitudinal study of caries development and associated risk factors, including diet. The remaining 23 subjects were selected from the patient database of a gastroenterology clinic. All patients had been diagnosed with pathological reflux for more than 2 years and had been symptom free for around half a year prior to this study. Upon diagnosis patients had been examined by an oesophageal manometer and oesophagogastrroduodenoscopy. Pathological reflux was diagnosed when intraoesophageal pH was below 4.0 for longer than 50 min during a 24-h monitoring period [17]. Only fully dentate patients less than 50 years of age, living in or nearby Reykjavik were selected.

### Questionnaire

A questionnaire was developed to determine the consumption of beverages. Fifty-six beverages comprising most soft drinks available on the Icelandic market were included in the questionnaire, which was pre-tested on a group of 30 University students and modified as necessary. The self-completed questionnaire focused on the consumption of various groups of beverages including carbonated beverages, milk-based beverages, pure fruit juices, juices from concentrate, energy and sport drinks. Each subject was required to fill out this part of the questionnaire following an introduction from the investigator. The questionnaire was based on closed questions such as a multiple-choice for each specific category of beverage as well as a multiple choice for specific brand marks of beverages.

### Erosion score

The clinical examiner recorded the presence of erosion and its degree. The clinical examiner was blinded to the results of the questionnaire. Erosion was classified according to location in anterior or posterior teeth as shown in Table 1, slightly modified from an index described by Lussi [20] with all surfaces on the examined teeth included in the examination (Table 1). Subjects

were examined in a dental chair, using a dental light and mirror. If the subject was diagnosed with erosion, a second examiner confirmed the degree of erosion and the agreed score entered the record. In case of disagreement, the lower erosion score was given; however, disagreement was only found in less than 10% of the examined cases.

### Statistics

Statistical analyses were made with SPSS (www.spss.com) (descriptive statistics) and with the R statistical freeware downloaded from www.r-project.org (bivariate and multivariate statistics). Comparison of anamnestic data and erosion scores between two groups was done by a Wilcoxon rank sum test; comparison of age between two groups was done by two-sample t-test. Yes/no data for two groups was analysed as 2x2 tables by Fisher's exact test (less than ten subjects in one of the four categories) and by the Chi-square-test (more than ten subjects in each of the four categories). Correlations were analysed by Spearman's rank correlation analysis with correlation coefficients ( $r_s$ ) and  $p$ -values given. The effect of GERD (yes/no) and age on the presence and severity of dental erosion was determined by multiple regression analysis with adjusted R-squared values given. The level of significance was set at  $p < 0.05$ .

## Results

### Erosion in young adults and reflux patients

Table 2 shows that the reflux patients were significantly older than the young adults ( $p < 0.01$ ). No difference was found, however, in either the prevalence of dental erosion, or erosion score, between the two study groups. Similarly, no difference was obtained regarding the consumption of carbonated drinks, sport drinks, fruit juice from concentrate, and milk based drinks between the two groups. However, the young adults had a slightly higher overall intake of pure fruit juice than the reflux patients ( $p < 0.01$ ) mainly due to a higher intake of pure orange juice ( $p < 0.001$ ).

Multiple regression analysis revealed that neither the diagnosis of reflux nor the age of the subjects could explain any of the variation in the prevalence of erosion or the erosion scores obtained in incisors and molars (adjusted R-squared  $-0.01$  and  $0.00$ , respectively). We therefore combined the two groups in order to perform an explorative analysis of possible relationships between soft drink consumption and dental erosion.

**Table 1** Criteria used for measurement of dental erosion

Score*	Criteria for anterior teeth	Criteria for posterior teeth
0	No evidence of erosion	No evidence of erosion
1	Loss of surface enamel, dentine not involved	Enamel erosion of fissure system or cusps that cannot be attributed to attrition, amalgam restorations stand proud above the enamel surface
2	Erosion extending into dentine in at least one tooth	Erosion into dentine that cannot be attributed to attrition, especially palatal aspects of maxillary molar cusps and buccal aspects of mandibular molar cusps
3	Severe dentine erosion in at least four anterior teeth and or pulp chamber visible	Erosion extending close to the pulp

\* In the case of disagreement between the two examiners, the lower score was given

**Table 2** Differences in age and erosion incidence and score between reflux patients and young adults (mean  $\pm$  SD or median and range)

	Reflux patients (n=23)	Young adults (n=57)	<i>p</i> -value
Age (years)	35 $\pm$ 10	21 $\pm$ 2	<0.01 <sup>a</sup>
Erosion in the incisors (%)	26.1 %	36.8%	0.44 <sup>b</sup>
Erosion in the molars (yes/no)	21.7%	19.3%	0.31 <sup>b</sup>
Erosion in both the incisors and molars (yes/no)	34.8%	40.4%	0.31 <sup>b</sup>
Mean incisor erosion score	0.30 $\pm$ 0.56	0.44 $\pm$ 0.63	0.35 <sup>c</sup>
Mean molar erosion score	0.22 $\pm$ 0.42	0.25 $\pm$ 0.54	0.84 <sup>c</sup>

*P*-value was obtained by:

<sup>a</sup> Two-sample t-test

<sup>b</sup> Fisher exact test

<sup>c</sup> Wilcoxon rank sum test

### Combined study group

The study group now comprised of 80 subjects (40 males and 40 females) who had a mean age of 25 $\pm$ 9 years. None of the 80 subjects had dental erosion of grade 3, while some had erosion of grade 1 and 2. The mean erosion score in the incisors was 0.40, which was nearly significantly higher ( $p < 0.06$ ) than the erosion score in the molars, which was 0.24. Of the 80 subjects, 39% had erosion somewhere in the dentition, 34% in the incisors, 20% in the molars, and 15% had erosion in both the incisors and the molars.

### Soft drink consumption

The questionnaire determined the intake of 56 different beverages that are available on the Icelandic market. When these beverages were subdivided into groups, milk-based beverages showed to be significantly more consumed than carbonated drinks ( $p < 0.001$ ), which were more consumed than pure fruit juice ( $p < 0.001$ ), which was more consumed than fruit juice from concentrate ( $p < 0.001$ ), which finally was more consumed than sport drinks ( $p < 0.001$ ).

Of the 56 different beverages five were consumed on average three times during the day or more. These frequently consumed beverages were Coca-Cola, mineral water, Diet Grape (a carbonated grapefruit soft drink),

orange juice from concentrate and Malt (a malt extract drink). Except for two milk-based drinks, Coca-Cola was by far the most frequently consumed soft drink by the participants in this study.

### Relation between dental erosion and soft drink consumption

There was no significant difference in age of the subjects with erosion (24 $\pm$ 8 years) and the subjects without erosion (25 $\pm$ 9 years). Although 18 males had erosion, compared with only 13 females, the difference between gender ratios was not significant. However, a trend was noted indicating higher erosion scores in molars in males than in females ( $p < 0.06$ ). Surprisingly, the only significant difference between subjects with erosion and subjects with no erosion was with respect to Coca-Cola consumption. Thus, the Coca-Cola consumption was significantly higher in subjects with erosion ( $p < 0.05$ ) than in subjects without. Accordingly, Coca-Cola consumption was used for further subdivision and analysis.

### Relation between dental erosion and Coca-Cola consumption

Table 3 presents the prevalence of erosion and erosion score in subjects with high and subjects with low Coca-

**Table 3** Differences in the prevalence of erosion and erosion score in subjects with high and low Coca-Cola intake (median and range)

	Intake of Coca-Cola more than three times a week (n=39)	Intake of Coca-Cola less than three times a week (n=41)	<i>p</i> -value	Odds ratio
Erosion in the incisors (yes/no)	17/22	10/31	0.11 <sup>a</sup>	2.4
Erosion in the molars (yes/no)	11/28	5/36	0.09 <sup>b</sup>	2.8
Erosion in the molars, the incisors or both (yes/no)	20/19	11/30	0.04 <sup>a</sup>	2.8
Erosion in both the molars and the incisors (yes/no)	8/31	4/37	0.22 <sup>b</sup>	2.4
Erosion score in the incisors (0,1,2,3)	0.54 (0–2)	0.27 (0–2)	0.06 <sup>c</sup>	ND.
Erosion score in the molars (0,1,2,3)	0.36 (0–2)	0.12 (0–1)	0.06 <sup>c</sup>	ND.

Odds ratio denotes the risk of having erosions if the Coca-Cola intake exceeds three times a week compared with having erosions if the Coca-Cola intake is less than three times a week. *ND* not determined. *P*-value was obtained by:

<sup>a</sup> Chi-squared test

<sup>b</sup> Fisher test

<sup>c</sup> Wilcoxon rank-sum test

**Table 4** Differences in the prevalence and severity of erosion between subjects with (i) high and (ii) low intake of carbonated drinks

	Intake of carbonated beverages more than 1 litre a week (n=28)	Intake of carbonated beverages less than 1 litre a week (n=52)	<i>p</i> -value	Odds ratio
Erosion in the incisors (yes/no)	11/17	16/36	0.47 <sup>a</sup>	1.5
Erosion in the molars (yes/no)	9/19	7/45	0.08 <sup>b</sup>	3.0
Erosion in the molars, the incisors or both (yes/no)	13/15	18/34	0.34 <sup>a</sup>	1.6
Erosion in both the molars and the incisors (yes/no)	7/21	5/47	0.10 <sup>b</sup>	3.1
Erosion score in the incisors (0,1,2,3)	0.46 (0–2)	0.37 (0–2)	0.46 <sup>c</sup>	ND
Erosion score in the molars (0,1,2,3)	0.39 (0–2)	0.15 (0–2)	0.04 <sup>c</sup>	ND

Odds ratio denotes the risk of having erosions if the intake of carbonated beverages exceeds 1 litre a week compared with if it is less than 1 litre a week. *ND* not determined. *P*-value was obtained by:

<sup>a</sup> Chi-squared test

<sup>b</sup> Fisher test

<sup>c</sup> Wilcoxon rank-sum test

Cola consumption. Thirty-nine subjects consumed Coca-Cola more than three times a week. Out of these 39 subjects, 20 had erosion. The risk of having dental erosion was approximately three times higher in either incisors or molars when drinking Coca-Cola more than three times a week ( $p < 0.05$ ) compared with drinking Coca-Cola less than three times a week. Males were shown to have a significantly higher intake of Coca-Cola than females ( $p < 0.05$ ).

#### Relation between carbonated drink consumption and dental erosion

In analysing the combined intake of carbonated drinks (Table 4), 28 subjects were found to consume more than 1 litre of carbonated beverages a week. Of these 28 subjects, 13 had erosion. The risk was found to be three times higher for erosion on the molars when 1 litre a week or more of carbonated drink was consumed. There was also a more than three-times higher risk of having erosion in both molars and incisors simultaneously when drinking 1 litre or more of carbonated drink a week. Significantly higher erosion scores were found for the molar teeth if the consumption of carbonated drinks was more than 1 litre a day compared with subjects with a consumption that was less than 1 litre a day ( $p < 0.05$ ).

#### Individual correlations

Table 5 shows a correlation matrix of all correlations obtained between the erosion score in incisors and molars and the intake of Coca-Cola and carbonated drinks. As shown in the matrix the erosion score in the incisors was significantly positively correlated with the erosion score in the molars. Thus, most subjects having high erosion scores in the incisors also had high scores in the molars.

Within the group of young adults, the erosion score in incisors and molars correlated significantly positively with the intake of Coca-Cola. Within the combined study group, the erosion score in the incisors was significantly

**Table 5** Correlations between erosion scores in incisors and molars and the consumption of Coca-Cola and carbonated drinks

	ESI	ESM	ICC	ICD
ESI	1.00	-	-	-
ESM	0.48* (0.51)*	1.00	-	-
ICC	0.20 (0.32)**	0.21 (0.32)**	1.00	-
ICD	0.25** (0.24)	0.12 (0.14)	0.71* (0.75)*	1.00

A correlation matrix of all correlations obtained between erosion score in incisors (ESI), erosion score in molars (ESM), intake of Coca-Cola (ICC), and intake of carbonated drinks (ICD). Correlation coefficients were obtained by Spearman's rank correlation analysis ( $r_s$ ). Correlation coefficients in brackets were obtained within the group of young adults only

\*  $p < 0.001$ , \*\*  $p < 0.05$

positively correlated with the overall intake of carbonated drinks. Interestingly, a strong positive correlation was obtained between the intake of Coca-Cola and the overall intake of carbonated drinks. Thus, subjects having a high intake of Coca-Cola also had a high intake of other carbonated drinks. This was also the case when Coca-Cola was excluded from the carbonated drinks group ( $r_s = 0.40$ ,  $p < 0.001$ ).

## Discussion

The results in this study are in agreement with previous studies showing low prevalence of dental erosion in GERD patients [12]. Furthermore, the diagnosis of GERD did not show explanatory power on either the prevalence or severity of dental erosion in this study. However, the results obtained in this study are in disagreement with other studies showing strong association between reflux symptoms and dental erosion [4]. Thus, within another or larger group of GERD patients, this condition might have shown an effect on dental erosion. The comparison of the GERD patients with another potential risk group like the young Icelanders may also have contributed to an underestimation of the effect of GERD on dental erosion. It could also be speculated that the erosion index, the clinical diagnosis of dental erosion, and the cross-sec-

tional design used in this study could not detect minor differences in dental erosion between the groups examined. Thus, it cannot be ruled out that some of the observed erosions were caused by GERD. Nevertheless, as we found no significant difference in the prevalence of dental erosion between young adults and reflux patients, as well as only minor differences in soft drink consumption, the two study groups were combined for further analysis. Analysis of the combined group found 39% to have dental erosion and the males to have slightly more erosion than the females. The prevalence of dental erosion found in this study is similar to the prevalence found in other studies [21, 22] and serves to endorse the general view that dental erosion is common [6, 9].

Despite the high prevalence of dental erosion sometimes found, the aetiological factors are not always apparent [6]. In this study the intake of carbonated drinks and especially Coca-Cola was found to be the plausible extrinsic factor of dental erosion. An increased risk was found both for developing erosion and for developing more severe erosion if consumption of (i) Coca-Cola was three times or more per week or (ii) if more than 1 litre of carbonated drink was consumed per week. The results also showed that the males had a higher intake of Coca-Cola than the females, which could explain the gender differences obtained in dental erosion. Furthermore significant correlations were obtained among the intake of Coca-Cola, the overall intake of carbonated drinks, and the erosion score in incisors and molars. These results support earlier findings of a relation between dental erosion and consumption of Cola-based drinks and other flavoured carbonated drinks [10, 15]. Coca-Cola was the only single beverage that could be related to dental erosion or the erosion score in this study. This finding is most likely due to Coca-Cola being the most popular carbonated drink in Iceland and probably less to its actual composition. Thus, although several other carbonated drinks in this study have low pH values similar to that of Coca-Cola [14], their consumption was simply lower than that of Coca-Cola. Thus the results in this study cannot determine which single drink is most erosive since the consumption rate of the drinks was highly varied.

The only group of drinks that could be related to dental erosion in this study was the carbonated drinks. We believe this finding is due to this type of drink having lower pH values than the other drinks analysed in this study. Interestingly, the clinical results from this study are not in agreement with many *in vitro* studies, which have suggested that fruit juices are more erosive than carbonated drinks due to a high buffer capacity [8, 19]. Thus, further research is needed to determine which qualities in soft drinks are most determining for their erosive potential.

## Conclusion

We conclude, that the reason for Coca-Cola being the only soft drink to relate significantly to dental erosion in

this study is due to its low pH and the popularity of this brand on the soft drink market in Iceland. Further, the prevalence of dental erosion in this study was high and the frequency of consumption of potentially erosive soft drinks with low pH values was the only plausible risk factor identified for the development of dental erosion.

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