The erosive effect of various drinks, foods, stimulants, medications and mouthwashes on human tooth enamel

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SUMMARY

Two forms of non-carious dental disorder – erosive tooth hard tissue loss and dental erosion – have been increasingly observed in recent years. Dental erosion is the chemical loss of dental hard substances caused by exposure to acids not derived from oral bacteria. Mechanical forces from, for example, the tongue, the cheeks or toothbrushing, increase loss of partly demineralized tooth surfaces and the cumulative loss of dental hard tissue is defined as erosive tooth wear (ETW). Dental hard tissue losses that occur because of very frequent acid exposure, such as through increased vomiting, but without mechanical stress, are also assigned to tooth erosion. Without prior softening, practically no loss of enamel takes place due to abrasion with the modern Western diet. The present work is a continuation of earlier work. A total of 226 beverages, foods, stimulants as well as medicines and mouthwashes were tested for their erosive potential on premolars and deciduous molars covered with a human pellicle. The influence of temperature, phosphate and calcium was also investigated in additional experiments. The change in hardness before and after immersion in the respective test substance was measured, and the erosive potential was classified. For each test product, we determined pH and other properties which were possibly related to erosive potential. There were considerable and sometimes surprising differences between the tested products. The addition of phosphate did not influence the erosive potential of the liquids, but calcium did. A modified erosion scheme that incorporates these and other new findings is presented.

Introduction

Non-carious dental disorders such as erosive tooth hard tissue loss have been increasingly observed in recent years, especially in industrialized countries. The prevalence of clearly visible defects is about 30% (Schlueter & Luka 2018). Causes include a changed lifestyle with increased intake of acidic foods and drinks, more stress and more reflux but also the better education and training of people in the oral health sector that has improved detection.

It is important to note that erosive disorders are multifactorial. Figure 1 shows an overview of the various etiological factors that must be considered. However, knowledge of the erosive potential of a range of products is essential. This knowledge provides a basis for advising patients on how to avoid tooth damage and for assessing the risks from diet and medication when working towards a diagnosis of erosion-related conditions.

Demineralization involves release of calcium, hydroxyl- and phosphate ions from hard tissue. In caries, acid produced by plaque bacteria causes subsurface demineralization, but in erosion demineralization affects the tooth surface and results from contact with exogenous acidic substances. Potentially erosive substances include not only foods and drinks but also other products that are taken into the mouth, such as medications. Unfortunately, prediction of erosive potential is not straightforward. The capacity of a simple acidic solution to dissolve dental hard tissue depends on its pH (Larsen & Nyvad 1999), but the products of interest are rarely simple solutions. Products may also contain substances that adsorb to the tooth surface and inhibit the demineralization process by interfering with the release of mineral ions. These inhibitory substances include various natural peptides and polymers.

It follows from the above discussion that the erosive potential of a particular product cannot be determined from a single property, such as a low pH, but has to be measured using a reliable procedure. The aim of this research was to provide such data, using a consistent in vitro methodology. A variety of drinks, foods and stimulants as well as medications and mouthwashes were tested for their erosive effects on human tooth enamel. Besides providing guidance to the erosive risk presented by products that are introduced into the mouth, the tables presented here should be helpful on the sometimes difficult path to a correct diagnosis of erosion-related oral conditions.

Two secondary aims of the research were: (1) to evaluate the possible usefulness of deliberately adding calcium or phosphate to liquids as a means of reducing erosive potential; (2) to test the effect of different temperatures on erosive potential.

Some data were published earlier (Lussi et al. 2019b).

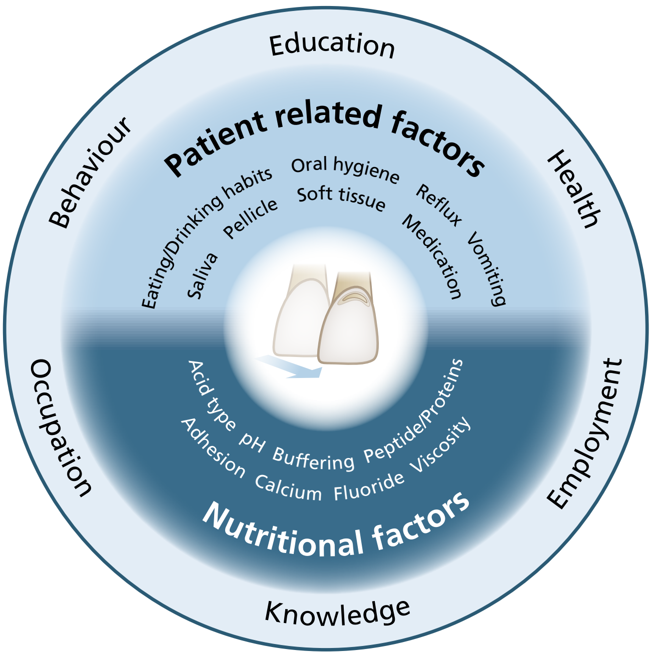

Fig. 1 The division into etiological factors on the patient side and into nutritional as well as into general factors has proven successful. Note that "Peptide/Proteins" are newly listed; the two factors "Phosphate" and "Chelation" are of secondary importance and are no longer listed in the new modified scheme (see text).

Materials and methods

Outline of experimental procedure

Specimens of human dental enamel were prepared to obtain a flat, polished surface suitable for Vickers microhardness measurements. These specimens were immersed in human saliva to create a pellicle to simulate in vivo conditions. After measuring baseline microhardness, the specimens were exposed to the test products and the microhardness was measured again. The difference in microhardness between baseline and post-exposure measurements was calculated and used as a measure of erosive potential.

Preparation of enamel specimens

From a pool of extracted teeth, 1684 caries-free human premolars and 300 deciduous molars with no cracks were selected. After the crowns of all teeth were separated from the roots, the buccal or lingual sites were ground flat under water-cooling on a LaboPol-21 rotary polishing machine (Struers, Ballerup, Denmark). Groups of six enamel slabs were embedded with resin (Paladur, Bad Homburg, Germany) in a two-part metal mold consisting of thick and thin plane-parallel components. Once the hardening process of the resin was complete, the thinner metallic mold (200 µm thick) was removed. The outer 200 µm of enamel, now standing proud, was serially polished on the polishing machine under constant cooling using silicon carbide paper discs with descending grain sizes. Thereafter, the enamel slabs were taken out of the larger mold and polished for 1 min with 3 µm diamond abrasive on a DP-Mol polishing cloth (LaboPol-6, DP-Mol Polishing, DP-Stick HQ; Struers, Copenhagen, Denmark). After each polishing step, the resin disks with the embedded teeth were rinsed and sonicated for 2 min in tap water. These preparation steps wore away exactly 200 µm enamel (the thickness of the thin metallic mold) in the center of the enamel window.

Just before the experimental procedures, the resin disks were further polished with a 1 µm diamond abrasive for 1 min (Struers), which ensured the removal of possible remnants from storage.

Saliva stimulated by chewing paraffin wax (Fluka; Sigma-Aldrich Chemie GmbH, Munich, Germany) was collected in an ice-cooled tube at least 1 h after any intake of drink or food from a single healthy donor (B. M.) with neither caries nor periodontitis. She gave informed consent, and saliva collection was performed in accordance with the protocol approved by the University of Bern (Bern, Switzerland). Before the erosive challenge, enamel specimens were immersed in 20 ml of freshly collected human saliva for 3 h to form the salivary pellicle. The temperature was held constant at 37 °C, and the saliva was carefully shaken. After being rinsed with tap water for 50 s and with deionized water for 10 s, the specimens were dried for 5 s with oil-free air.

Tested dietary substances and medications

In the present study, 226 various popular drinks, foods and stimulants as well as medications and mouthwashes available in Switzerland were included (Tab. I). According to their constituents and applications, these agents are ordered as follows.

Group 1: Mineral water, soft drinks, lemonades
Group 2: Energy drinks, sports drinks
Group 3: Fruits, juices, smoothies
Group 4: Dairy products
Group 5: Tea, ice tea, coffee
Group 6: Alcoholic beverages
Group 7: Medication
Group 8: Sweets, candy, chewing gum
Group 9: Children's articles
Group 10: Miscellaneous
Group 11: Mouthwashes

The pH value of the liquids was measured using a standard electrode, which was always calibrated immediately before use.

Non-liquid products required processing before they could be tested. Fruits were crushed, and the pulps and seeds were removed by pressing through a sieve. Medications (tablets and powders) were dissolved in tap water according to the suggestions of the manufacturers. Candies were dissolved in deionized water (1.7 g in 10 ml) at 45 °C while stirring and cooled again to 30 °C for the experiment. The different teas were prepared as indicated on the respective products. Chewing gums (12 g each) were ground in a mortar with artificial saliva for 5 min resulting in the same volume for all experiments of 60 ml. The composition of the artificial saliva (pH 7, 1L) was as follows: 0.213 g $CaCl_2$ $2H_2O$, 0.738 g KH_2PO_4, 0.381 g NaCl, 1.114 g KCl, 2.20 g mucine (Newby et al. 2006).

The enamel specimens (total 1684 premolars and 300 deciduous molars) were exposed to test products as follows. They were individually placed in 60 ml (or g) of the appropriate solution under constant agitation (95 rpm) at 30 °C (shaking bath Salvis; Renggli AG, Rotkreuz, Switzerland). After immersion for 2 min, the enamel samples were taken out of the solution, rinsed with tap water for 50 s and with deionized water for 10 s and then dried for 5 s with oil-free air.

Additional experiments aimed to investigate the influence of temperature, calcium and phosphate on softening of the enamel were performed (Tab. II). In order to achieve the desired calcium or phosphate concentration in the sample solutions, a concentrated calcium chloride (20 g $CaCl_2$ $2H_2O$ in 100 ml) or potassium hydrogen phosphate solution (10 g KH_2PO_4 in 100 ml) was prepared and the required amount pipetted into the sample solution.

Surface hardness measurements

Surface hardness was determined with a Vickers diamond (force 50 mN for 15 s; Fischerscope HM 2000 XYp; Helmut Fischer, Hünenberg, Switzerland). The Vickers hardness was automatically calculated from the dimensions of the impressions. A total

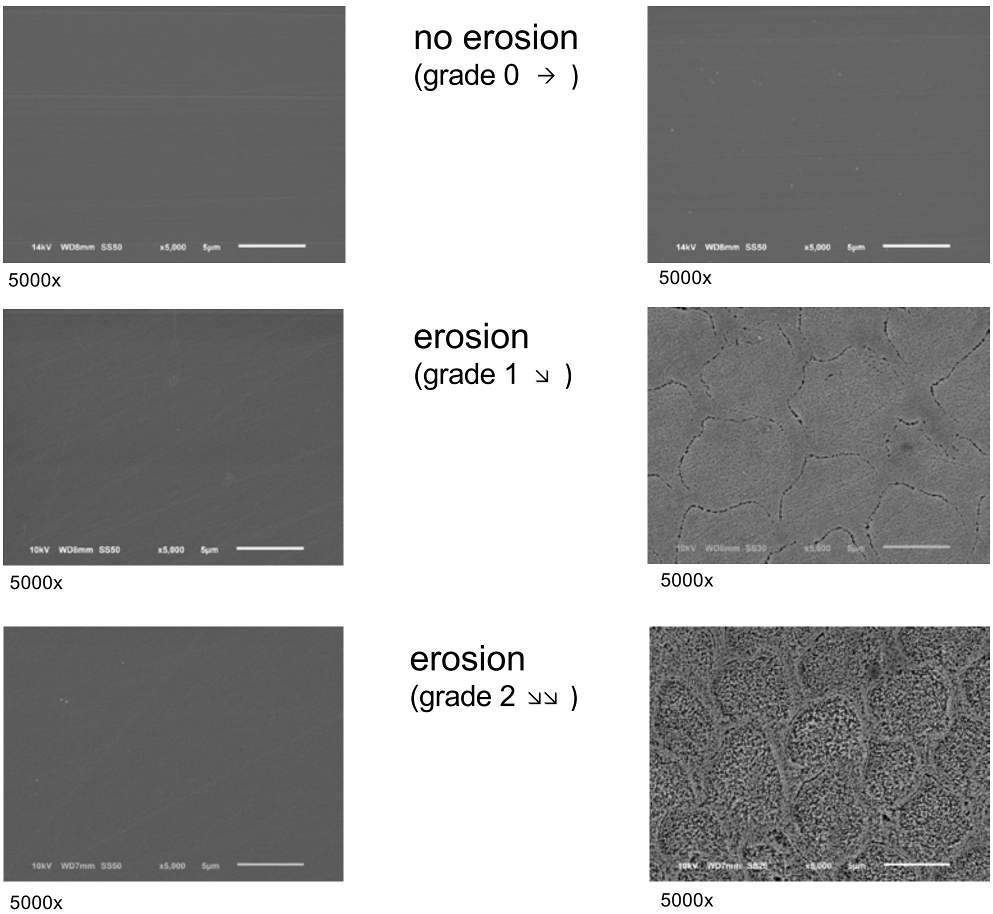

Fig. 2 Scoring of the different stages of enamel after immersion in different substances.
Left: Pictures of enamel before immersion in liquids.
Right: Pictures of enamel after immersion in liquids (Scanning Electron Microscope, magnification 5000×).
Top: No erosion (grade 0). Hardness increase or decrease of up to 2% after 2 min immersion in a solution.
Middle: Middle erosion (grade 1). Hardness decrease of up to 15% after 2 min immersion in a solution.
Bottom: Advanced erosion (grade 2). Hardness decrease of more than 15% after 2 min immersion in a solution.

of 6 baseline indentations were performed at intervals of 70µm. After exposure to the test products, a further series of 6 post-exposure measurements were taken, right next to the previous counterparts. For each sample, the mean baseline and post-exposure hardness values were calculated. With this procedure, the variations in hardness within a tooth were taken into account (Lussi et al. 2012a). We used first 12 teeth per group and later 6 teeth per group, as we had low standard deviations.

Data analysis

For each specimen, the change in hardness was calculated by subtracting the post-exposure hardness from the baseline hardness. A mean change in hardness was then calculated for the group of specimens exposed to each product. Numbers have been rounded according to the generally applicable rules.

To provide a quick overview of the erosive potential of the various products in the table, they were divided into 3 groups (Fig. 2). A product was classified as non-erosive (grade 0: horizontal arrow) if there was an increase in hardness or a decrease in hardness of ≤2% after 2min immersion in the test solutions. Erosive products (grade 1: one descending arrow) were those that reduced hardness by 2–15% after 2min Products with a highly erosive potential (grade 2: two descending arrows) were those that reduced hardness by more than 15% after 2min

Results

Table I shows possible ingredients (sorted by importance concerning dental erosion) for each substance tested, the pH value, the hardness, the change in hardness after 2min immersion (also in %) in the respective solutions. It is also mentioned whether a premolar or a deciduous molar was used. The tables are, as announced, in addition to the compilation of the erosivity of the products presented at that time, using the same measurement methods (Lussi et al. 2019b).

The results show that mineral waters with their slightly acidic pH values did not soften the enamel surface, which is correlated with their calcium content. Even with the addition of lemon flavor, this property did not change. If, on the other hand, citric acid was added and the pH value was significantly lowered down to 3.2, we found a significant softening of the enamel surface.

Most energy and sports drinks showed an erosive potential with pH values between 2.9 (Gatorade) and 3.9 (Isostar). Some of them contain casein or calcium and thus show virtually no softening. The softening of enamel by crushed blueberries (pH 3.7) was significantly greater when the latter were mixed with water. Without the addition of water, the hardness decrease was 11.7%, with the addition of water (1:1) it increased to 38.5%. Dilution resulted in a decrease in pH, to 3.1, but the increase in erosion is more likely due to the reduced viscosity, which enables better ion exchange with the enamel surface. Mucosolvon cough syrup for children is another example of a highly viscous and acidic medication (pH 3.1) that provoked no softening if undiluted. It is listed in the section «Medications».

Carrot juice with a pH of 4.2 hardly softened the enamel surface. All dairy products were acidic (pH between 3.8 and 6.7) but showed no erosive potential. Wild berries yogurt that had no added berries but only berry flavors even showed a hardening of the enamel by 5%. Rosehip tea showed in one product only together with hibiscus (pH around 3.1) a softening of the enamel surface, pure rosehip tea (pH 6.3) did not change the hardness of enamel.

In the case of alcoholic beverages, it is noticeable that all pure beers with pH values between 4.1 and 4.4 did not cause a change on the enamel surface hardness. However, addition of citric acid rendered them erosive. Cynar also has a pH of 4 but there was no softening. Some medications and sweets with pH values as low as 2.7 showed a large erosive potential. Chewing gums also revealed an erosive potential. In our selection of frequently used children's items, there was no product that did not soften the enamel. However, the two types of honey tested have pH values of 3.6 and 4.2, respectively, but did not cause any hardness change.

Sauerkraut with a pH value of 3.8, on the other hand, showed a large erosive potential. Mouthwashes showed pH values between 3.3 (Listerine Smart Kidz) and 6.1 (Elmex Sensitive Professional). Some of them softened the hardness of enamel after 2min immersion by up to 6.5%.

In Table II the impact of temperature and the effects of addition of calcium and phosphate are noted. We measured less softening on enamel when the temperature was decreased from 37 °C to 5 °C. Orange juices produced decreases in hardness of up to 16.5% at 37 °C. When the temperature was lowered to 5 °C the changes were lowered to 1.6%. A decrease with lower temperatures was also measured with smoothies, Red Bull and Coca-Cola.

Addition of calcium decreased surfaces softening in all tested substances. The more calcium was added the smaller the surface softening. Addition of $CaCl_2$ decreases the pH around 0.2 units due to chemical reasons. Even when the pH was not adjusted to the original value, less surface softening was found (Africa, Baobab and Pineapple Smoothie; Asia, Mangosteen and Passionfruit Smoothie; Orange juice hohes C). Innocent Kiwi Wonder Smoothie showed even a slight increase of hardness after the addition of 0.1% calcium (with adjustment of the pH). Softening of 17.2% using Red Bull (pH 3.5) was measured without added calcium. With addition of 0.1% calcium, the decrease in hardness was 1.4%. The same was true when calcium was added to orange juices. Orange juice hohes C had a decrease in hardness of 16.5%, addition of calcium with adjusting to the same pH value of 3.8 lowered the decrease to 2.3%. Addition of calcium to Coca-Cola with its pH of 2.6 hardly changed the softening.

Influence of phosphate was measured with orange juice only and showed no protective effect on softening of human enamel. The influences of calcium and phosphate is also discussed in the study by Shellis et al. (2023, this volume).

Tab. I The effect of various drinks, foods, stimulants as well as medications and mouthwashes on human tooth enamel coated with salivary pellicle. Possible relevant ingredients (maximum 3, sorted by importance), pH, hardness before and after immersion for 2 min, the change in percentage as well as the classifications are given. P: Premolar, D: Deciduous molar.

Group	Product	Possible relevant ingredients (maximum 3) ordered by importance	pH	Hardness	Hardness after 2 min	Change (%)	Classification (change in hardness)	Tooth
	Mineral water, soft drinks, lemonades							
1	Aproz Lemon mineral water	Carbonic acid, aroma	5.1	432.8	426.7	**−1.4**	→	P
1	Aproz Mint-Lime mineral water	Carbonic acid, aroma	5.4	435.8	433.9	**−0.4**	→	P
1	Aproz O_2 Aroma Zitrone	Citric acid, carbonic acid, aroma	3.2	437.7	380.0	**−13.2**	↘	P
1	Carpe Diem	Malic acid, citric acid, carbonic acid	3.0	526.8	336.7	**−36.1**	↘↘	P
1	Citron M Budget	Citric acid, carbonic acid, aroma	3.0	451.3	297.4	**−34.1**	↘↘	P
1	Coca-Cola 1	Phosphoric acid, citric acid, carbonic acid	2.5	501.0	410.8	**−18.0**	↘↘	D
1	Coca-Cola 2	Phosphoric acid, citric acid, carbonic acid	2.4	513.4	356.1	**−30.7**	↘↘	P
1	Coca-Cola 3	Phosphoric acid, citric acid, carbonic acid	2.6	489.2	268.9	**−45.0**	↘↘	P
1	Coca-Cola light	Phosphoric acid, citric acid, carbonic acid	2.6	600.3	323.6	**−46.1**	↘↘	P
1	Coca-Cola zero	Phosphoric acid, citric acid, carbonic acid	2.6	494.7	403.7	**−18.4**	↘↘	P
1	Evian Fruits & Plantes Lemon Elderflower	Citric acid, carbonic acid, aroma	3.2	484.5	371.4	**−23.3**	↘↘	P
1	Fanta Citron	Citric acid, carbonic acid, aroma	2.8	450.1	207.9	**−53.8**	↘↘	P
1	Fanta Orange	Citric acid, ascorbic acid, carbonic acid	2.7	513.3	268.5	**−47.7**	↘↘	P
1	Fanta regular Orange	Citric acid, ascorbic acid, carbonic acid	2.6	491.2	390.5	**−20.5**	↘↘	D
1	Guaraná antartica 1	Citric acid, carbonic acid	2.6	502.5	470.2	**−6.4**	↘	D
1	Guaraná antartica 2	Citric acid, carbonic acid	3.0	507.5	460.1	**−9.3**	↘	P
1	Henniez limes and lemon mineral water	Carbonic acid, calcium, aroma	5.6	458.7	451.2	**−1.6**	→	P
1	Henniez blue mineral water	Carbonic acid, calcium	7.7	543.0	546.8	**0.7**	→	P
1	Henniez red mineral water	Carbonic acid, calcium	6.1	501.3	500.3	**−0.2**	→	P
1	Lemon M Classic	Citric acid, carbonic acid, aroma	3.1	464.3	348.7	**−24.9**	↘↘	P
1	ok.– flavoured water lemon	Citric acid, carbonic acid, aroma	4.3	469.4	450.0	**−4.1**	↘	P
1	Orange Water Naturaplan Coop	Citric acid, carbonic acid, aroma	3.7	473.6	437.1	**−7.7**	↘	P
1	Orangina	Citric acid, malic acid, carbonic acid	3.1	566.4	449.4	**−20.6**	↘↘	P
1	Pepsi Cola 1	Phosphoric acid, citric acid, carbonic acid	2.4	563.3	372.5	**−33.9**	↘↘	P
1	Pepsi Cola 2	Phosphoric acid, citric acid, carbonic acid	2.5	497.6	436.9	**−12.2**	↘	D
1	Pepsi Cola light	Phosphoric acid, citric acid, carbonic acid	2.8	512.7	332.3	**−35.2**	↘↘	P
1	Rhäzünser Plus Lemon mineral water	Citric acid, carbonic acid, aroma	3.9	463.9	447.8	**−3.5**	↘	P
1	Rivella blue	Lactic acid, carbonic acid	3.3	530.2	276.4	**−47.9**	↘↘	P

Grade 0: Horizontal arrow: Hardness increase or hardness decrease of up to 2% after 2 min immersion in a solution
Grade 1: One descending arrow: Hardness decrease of up to 15% after 2 min immersion in a solution
Grade 2: Two descending arrows: Hardness decrease of more than 15% after 2 min immersion in a solution
Some products were purchased at different times. They are numbered with Arabic numerals.

Tab. I The effect of various drinks, foods, stimulants as well as medications and mouthwashes on human tooth enamel coated with salivary pellicle. Possible relevant ingredients (maximum 3, sorted by importance), pH, hardness before and after immersion for 2 min, the change in percentage as well as the classifications are given. P: Premolar, D: Deciduous molar.

Group	Product	Possible relevant ingredients (maximum 3) ordered by importance	pH	Hardness	Hardness after 2 min	Change (%)	Classification (change in hardness)	Tooth
1	Rivella green	Lactic acid, carbonic acid	3.2	505.6	360.6	**–28.7**	↘↘	P
1	Rivella red 1	Lactic acid, carbonic acid	3.3	491.1	446.3	**–9.1**	↘	D
1	Rivella red 2	Lactic acid, carbonic acid	3.3	532.0	320.9	**–39.7**	↘↘	P
1	Rivella elderflower	Lactic acid, carbonic acid	3.4	466.7	300.3	**–35.6**	↘↘	P
1	Schnitz Water / Lemon Water Naturaplan	Citric acid, aroma	3.6	469.3	431.4	**–8.1**	↘	P
1	Spritzer Lemon Lime Naturaplan	Citric acid, aroma	3.0	476.2	290.1	**–39.1**	↘↘	P
1	Schweppes	Citric acid, ascorbic acid, carbonic acid	2.3	454.3	240.3	**–47.1**	↘↘	P
1	Sinalco classic	Citric acid, ascorbic acid, carbonic acid	3.1	514.3	347.7	**–32.4**	↘↘	P
1	Sprite 1	Citric acid, carbonic acid	2.6	511.0	386.7	**–24.3**	↘↘	D
1	Sprite 2	Citric acid, carbonic acid	2.5	513.2	320.3	**–37.6**	↘↘	P
1	Sprite zero	Citric acid, carbonic acid	2.9	488.9	314.6	**–35.6**	↘↘	P
1	Valser mineral water 1	Carbonic acid, calcium	6.5	509.5	504.5	**–1.0**	→	D
1	Valser mineral water 2	Carbonic acid, calcium	5.6	491.7	490.2	**–0.3**	→	P
1	Valser original limelite mineral water	Citrate, aroma, calcium	5.4	488.4	483.8	**–0.9**	→	P
1	Valser lemon and herbs mineral water	Citric acid, carbonic acid, herbs	3.3	506.3	425.3	**–16.0**	↘↘	P
1	Volg citro	Citric acid, carbonic acid, herbs	3.1	441.6	300.3	**–32.0**	↘↘	P
1	Volvic lemon-apple	Citric acid, carbonic acid, herbs	3.2	473.0	422.1	**–10.8**	↘	P
	Energy drinks, sports drinks							
2	Gatorade	Citric acid, carbonic acid	3.2	513.8	389.1	**–24.3**	↘↘	P
2	Gatorade cool blue	Citric acid, carbonic acid	3.0	464.9	350.6	**–24.6**	↘↘	P
2	Gatorade gusto limone	Citric acid, carbonic acid	2.9	541.8	426.4	**–21.3**	↘↘	D
2	Gatorade mandarine	Citric acid, ascorbic acid, carbonic acid	3.2	502.1	377.3	**–24.9**	↘↘	P
2	Gatorade red orange	Citric acid, apple extract, carbonic acid	3.1	456.2	342.6	**–24.9**	↘↘	P
2	Isostar	Citric acid, carbonic acid, calcium	3.9	539.9	504.6	**–6.5**	↘	P
2	Isostar Hydrate fresh	Citric acid, carbonic acid, calcium	3.8	460.0	450.0	**–2.2**	→	P
2	Isostar Hydrate lemon	Citric acid, carbonic acid, calcium	3.8	499.8	493.6	**–1.2**	→	P
2	Isostar Hydrate orange	Citric acid, carbonic acid, calcium	3.8	462.9	456.1	**–1.5**	→	P
2	Isostar orange	Citric acid, carbonic acid, calcium	3.6	533.5	487.4	**–8.6**	↘	P
2	Monster	Citric acid, sorbic acid, carbonic acid	3.3	509.9	458.4	**–10.1**	↘	D
2	Monster Energy (green)	Citric acid, sorbic acid, carbonic acid	3.4	495.0	437.8	**–11.6**	↘	P

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2	Monster Energy Rehab	Citric acid, sorbic acid, carbonic acid	3.5	489.7	448.7	**−8.4**	↘	P
2	Monster Energy the Doctor	Citric acid, sorbic acid, carbonic acid	3.4	440.8	414.5	**−6.0**	↘	P
2	Monster Energy Zero	Citric acid, sorbic acid, carbonic acid	3.4	451.5	365.3	**−19.1**	↘↘	P
2	Powerade	Citric acid, carbonic acid	3.7	510.0	447.3	**−12.3**	↘	P
2	Red Bull 1	Citric acid, carbonic acid	3.3	515.5	462.9	**−10.2**	↘	D
2	Red Bull 2	Citric acid, carbonic acid	3.3	534.9	446.2	**−16.6**	↘↘	P
2	Red Bull 3	Citric acid, carbonic acid	3.5	466.8	386.7	**−17.2**	↘↘	P
	Fruits, juices, smoothies							
3	Africa, Baobab and Pineapple Smoothy	Citric acid, malic acid	3.7	473.7	399.0	**−15.8**	↘↘	P
3	Pineapple juice fresh	Citric acid, malic acid, ascorbic acid	3.4	548.0	461.9	**−15.7**	↘↘	P
3	Apple juice (spritzer)	Malic acid, lactic acid, citric acid	3.5	494.8	360.6	**−27.1**	↘↘	P
3	Apple juice Ramseier 1	Malic acid, lactic acid, citric acid	3.2	480.2	442.7	**−7.8**	↘	D
3	Apple juice Ramseier 2	Malic acid, lactic acid, citric acid	3.4	560.9	415.5	**−25.9**	↘↘	P
3	Apricots (fruit)	Malic acid, citric acid	3.3	519.1	398.8	**−23.2**	↘↘	P
3	Asia, Mangosteen and Passionfruit Smoothy	Citric acid, malic acid	3.8	514.3	416.4	**−19.0**	↘↘	P
3	Biotta Pomegranate juice	Citric acid, malic acid	3.3	501.1	461.9	**−7.8**	↘	P
3	Biotta Karotte, Mango, Orange juice	Citric acid, malic acid	4.0	462.7	425.5	**−8.0**	↘	P
3	Biotta Superfruit juice	Citric acid, malic acid	3.4	506.5	461.9	**−8.8**	↘	P
3	Grapefruitsaft juice	Citric acid, malic acid	3.2	491.0	338.1	**−31.1**	↘↘	P
3	Blueberries	Malic acid, citric acid	3.7	451.5	398.8	**−11.7**	↘	P
3	Blueberries and H_2O (1:1) (fruit)	Malic acid, citric acid	3.1	457.5	281.3	**−38.5**	↘↘	P
3	Raspberries and H_2O (1:1) (fruit)	Citric acid, malic acid	3.1	481.1	369.3	**−23.2**	↘↘	P
3	Innocent Berry Good Smoothy	Malic acid, citric acid	3.5	468.7	431.1	**−8.0**	↘	P
3	Innocent Kiwi Apple Lemon Smoothy	Malic acid, citric acid	3.3	532.6	493.7	**−7.3**	↘	D
3	Innocent Kiwi Wonder Smoothy	Malic acid, citric acid	3.6	476.6	409.6	**−14.1**	↘	P
3	Innocent Carrot Prince Smoothy	Citric acid, malic acid	3.9	474.3	461.3	**−2.7**	↘	P
3	Innocent Super Smoothie Antioxidant	Malic acid, citric acid	3.7	503.8	456.8	**−9.3**	↘	P
3	Kaki and H_2O (1:1) (fruit)	Fruit acids, fatty acids	5.9	483.8	477.2	**−1.4**	→	P
3	Carrot juice	Malic acid	4.2	531.9	518.5	**−2.5**	→	P
3	Kiwi 1 (fruit)	Citric acid, quinic acid, malic acid	3.2	498.9	438.1	**−12.2**	↘	D

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Group	Product	Possible relevant ingredients (maximum 3) ordered by importance	pH	Hardness	Hardness after 2 min	Change (%)	Classification (change in hardness)	Tooth
3	Kiwi 2 (fruit)	Citric acid, quinic acid, malic acid	3.2	499.8	383.0	**−23.4**	↘↘	P
3	Mango and H_2O (1:1) (fruit)	Citric acid, malic acid	4.2	484.4	466.8	**−3.6**	↘	P
3	Multivitamin Sun Queen juice	Citric acid, malic acid	3.6	560.2	557.0	**−0.6**	→	P
3	Orange juice fresh squeezed	Citric acid, aspartic acid, malic acid	3.9	502.0	485.8	**−3.2**	↘	D
3	Orange juice fresh squeezed	Citric acid, malic acid	3.6	561.2	463.9	**−17.3**	↘↘	P
3	Orange juice Del Monte	Citric acid, malic acid	3.7	500.6	465.4	**−7.0**	↘	P
3	Orange juice Granini	Citric acid, malic acid	3.9	493.4	452.2	**−8.3**	↘	P
3	Orange juice hohes C 1	Citric acid, malic acid	3.6	499.4	480.3	**−3.8**	↘	D
3	Orange juice hohes C 2	Citric acid, malic acid	3.6	590.8	531.0	**−10.1**	↘	P
3	Orange juice hohes C 3	Citric acid, malic acid	3.8	471.0	393.4	**−16.5**	↘↘	P
3	Peach yellow and H_2O (1:1) (fruit)	Citric acid, malic acid	4.6	553.8	531.0	**−4.1**	↘	P
3	Ribena blackcurrant juice	Ascorbic acid, citric acid, polyphenols	2.5	506.8	456.7	**−9.9**	↘	D
3	South America, Acerola and Mango Smoothy	Ascorbic acid, citric acid	3.9	494.0	457.2	**−7.5**	↘	P
	Dairy products							
4	Yogurt Citron	Lactic acid, calcium, flavors	4.1	526.3	526.0	**−0.1**	→	P
4	Yogurt Kiwi Tropicana	Lactic acid, calcium, flavors	4.0	548.3	555.6	**1.3**	→	P
4	Yogurt nature	Lactic acid, calcium	3.9	524.3	527.1	**0.5**	→	P
4	Yogurt Slimline	Lactic acid, calcium, flavors	4.0	529.8	526.5	**−0.6**	→	P
4	Yogurt Wild Berries 1	Lactic acid, calcium, flavors	4.1	494.5	519.2	**5.0**	→	D
4	Yogurt Wild Berries 2	Lactic acid, calcium, berries	3.8	525.0	518.8	**−1.2**	→	P
4	Sour milk LC1	Lactic acid, calcium, flavors	4.2	481.0	490.2	**1.9**	→	P
4	Whole milk UHT	Lactic acid, calcium, flavors	6.7	521.3	527.7	**1.2**	→	P
	Tea, ice tea, coffee							
5	Coffee Espresso (freshly ground)	No ingredients relevant for erosion	5.8	516.5	520.2	**0.7**	→	P
5	Ginger Green Tea (bottle)	Ginger	3.9	432.2	427.6	**−1.1**	→	P
5	Green Tea classic Tetley (bag, activated for 5 min)	No ingredients relevant for erosion	6.7	509.5	571.2	**12.1**	→	P
5	Green Tea Lemongrass (bottle)	Calcium, different acids	4.0	435.9	430.1	**−1.3**	→	P
5	Green tea lemon balm (bag, activated for 3 min)	No ingredients relevant for erosion	6.8	494.8	494.1	**−0.1**	→	P
5	Ice tea classic 1 (bottle)	Citric acid, ascorbic acid	2.4	500.8	437.1	**−12.7**	↘	D
5	Ice tea classic 2 (bottle)	Citric acid, ascorbic acid	2.9	517.0	432.7	**−16.3**	↘↘	P
5	Ice tea lemon (bottle)	Citric acid, ascorbic acid	3.0	511.7	425.6	**−16.8**	↘↘	P
5	Ice tea 1 Peach (bottle)	Citric acid, malic acid, ascorbic acid	2.7	483.6	458.1	**−5.3**	↘	D

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Group	Product	Possible relevant ingredients (maximum 3) ordered by importance	pH	Hardness	Hardness after 2 min	Change (%)	Classification (change in hardness)	Tooth
5	Ice tea 2 Peach (bottle)	Citric acid, malic acid, ascorbic acid	2.9	541.0	458.6	**−15.2**	↘↘	P
5	Tea alpine herbs naturaplan (bag, activated for 5 min)	Nihil	7.4	456.5	461.8	**1.2**	→	P
5	Tea Cranberry Hibiscus, Yogi Tea (bag, activated for 5 min)	Hibiscus (small amount)	4.5	473.2	466.9	**−1.3**	→	P
5	Tea rosehip with hibiscus 1 (bag, activated for 5 min)	Hibiscus, ascorbic acid	3.2	545.6	364.5	**−33.2**	↘↘	P
5	Tea rosehip with hibiscus 2 (bag, activated for 3 min)	Hibiscus, ascorbic acid	3.1	474.8	291.6	**−38.6**	↘↘	P
5	Tea rosehip with hibiscus 3 (bag, activated for 5 min)	Hibiscus, ascorbic acid	3.1	478.7	273.8	**−42.8**	↘↘	P
5	Tea rosehip pur (bag, activated for 8 min)	Ascorbic acid	6.3	500.4	493.6	**−1.3**	→	P
5	Tea hibiscus pur (bag, activated for 8 min)	Hibiscus	2.8	520.6	196.0	**−62.4**	↘↘	P
5	Tea lime blossoms naturaplan (bag, activated for 5 min)	No ingredients relevant for erosion	7.8	467.3	462.0	**−1.1**	→	P
5	Tea peppermint (bag, activated for 6 min)	No ingredients relevant for erosion	7.5	519.5	520.3	**0.1**	→	P
5	Tea Rooibos naturaplan (bag, activated for 8 min)	No ingredients relevant for erosion	7.4	498.6	495.4	**−0.6**	→	P
5	Tea black (bag, activated 3 min)	No ingredients relevant for erosion	6.6	507.4	506.2	**−0.2**	→	P
5	Tea forest fruit (bag, activated for 2.5 min)	No ingredients relevant for erosion	6.8	603.7	605.8	**0.4**	→	P
5	Tea vert menthe (bottle)	Citric acid	3.6	469.8	455.7	**−3.0**	↘	P
	Alcoholic beverages							
6	Bacardi Breezer orange	Citric acid, carbonic acid	3.2	572.1	347.2	**−39.3**	↘↘	P
6	Beer Calanda Radler Zitrone	Citric acid, carbonic acid	3.3	469.3	379.7	**−19.1**	↘↘	P
6	Beer Calanda Radler, Gletscher Zitrone	Citric acid, carbonic acid	3.4	452.8	377.6	**−16.6**	↘↘	P
6	Beer Calanda Tandem Limette	Citric acid, carbonic acid	3.7	476.3	446.0	**−6.4**	↘	P
6	Beer Carlsberg	Protein, calcium, carbonic acid	4.2	511.1	509.4	**−0.3**	→	P
6	Beer Eichhof	Protein, calcium, carbonic acid	4.1	520.6	521.1	**0.1**	→	P
6	Beer Erdinger (non-alcoholic)	Protein, calcium, carbonic acid	4.4	511.7	524.0	**2.4**	→	P
6	Beer Eve Litchi	Citric acid, malic acid, carbonic acid	3.0	488.2	298.5	**−38.8**	↘↘	P
6	Beer Feldschlösschen Braufrisch	Protein, calcium, carbonic acid	4.4	484.1	480.2	**−0.8**	→	P
6	Beer Feldschlösschen Citron 0.0% (non-alcoholic)	Citric acid, carbonic acid	3.2	460.7	348.7	**−24.3**	↘↘	P

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Group	Product	Possible relevant ingredients (maximum 3) ordered by importance	pH	Hardness	Hardness after 2 min	Change (%)	Classification (change in hardness)	Tooth
6	Beer Feldschlösschen Pale Ale	Protein, calcium, carbonic acid	4.4	455.2	455.1	**0.0**	→	P
6	Champagner Freixenet	Tartaric acid, lactic acid, carbonic acid	3.0	531.3	404.4	**−23.9**	↘↘	P
6	Cynar	Protein	4.0	519.1	520.3	**0.2**	→	P
6	Red wine Merlot	Lactic acid, malic acid, tartaric acid	3.5	466.3	429.7	**−7.9**	↘	P
6	Rosé Merlot	Lactic acid, malic acid, tartaric acid	3.5	451.3	411.9	**−8.7**	↘	P
6	White wine Merlot	Malic acid, lactic acid, tartaric acid	3.4	447.2	398.1	**−11.0**	↘	P
6	Red wine Vieux Salquenen, Pinot noir de Salquenen	Lactic acid, malic acid, tartaric acid	4.0	451.9	447.3	**−1.0**	→	P
6	White wine Vieux Salquenen, Blanc noir de Salquenen	Malic acid, lactic acid, tartaric acid	3.5	465.0	437.6	**−5.9**	↘	P
6	Red wine Collivo	Lactic acid, malic acid, tartaric acid	3.4	543.4	512.4	**−5.7**	↘	P
6	Red wine Montagne	Lactic acid, malic acid, tartaric acid	3.7	556.2	535.7	**−3.7**	↘	P
6	Smirnoff Ice Vodka	Lemon juice	3.1	565.3	391.4	**−30.8**	↘↘	P
6	White wine La Côte	Malic acid, lactic acid, tartaric acid	3.6	505.0	480.1	**−4.9**	↘	P
	Medication							
7	Alca C effervescent tablets	Acetylsalicylic, ascorbic acid	4.2	533.6	520.4	**−2.5**	→	P
7	Alcacyl 500 sachet	Acetylsalicylic acid	6.9	527.8	525.4	**−0.4**	→	P
7	Alka-Selzer effervescent tablets	Acetylsalicylic, citric acid	6.2	512.3	508.4	**−0.8**	→	P
7	Aspirine-C effervescent tablets	Acetylsalicylic acid, ascorbic acid	5.5	534.6	517.2	**−3.3**	↘	P
7	Berocca effervescent tablets	Ascorbic acid	4.2	511.4	509.8	**−0.3**	→	P
7	Claritine syrup	Citric acid	3.0	527.9	517.1	**−2.0**	↘	D
7	Dafalgan syrup	Citric acid	5.3	478.9	496.0	**3.6**	→	D
7	Diasporal Magnesium effervescent tablets	Citric acid	4.5	472.8	450.5	**−4.7**	↘	P
7	Fluimucil 200 effervescent tablets	Citric acid	4.7	530.8	521.5	**−1.8**	→	P
7	Fluimucil 600 effervescent tablets	Citric acid	4.5	496.4	484.5	**−2.4**	→	D
7	Maltofer syrup	Acid	4.9	501.7	511.6	**2.0**	→	D
7	Mucosolvon cough syrup for children	Becoic acid	3.1	520.1	512.3	**−1.5**	→	D
7	Neocitran sachet	Ascorbic acid	2.8	541.5	292.0	**−46.1**	↘↘	P
7	SiccOral	No ingredients relevant for erosion	5.4	525.7	518.3	**−1.4**	→	P
7	Tossamin syrup no sugar	No ingredients relevant for erosion	4.4	510.5	526.3	**3.1**	→	D

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Group	Product	Possible relevant ingredients (maximum 3) ordered by importance	pH	Hardness	Hardness after 2 min	Change (%)	Classification (change in hardness)	Tooth
7	Ventolin syrup	Citric acid	3.2	512.9	458.8	**−10.6**	↘	D
7	Vitamin C effervescence tablets Actilife	Citric acid, ascorbic acid	3.9	509.5	421.3	**−17.3**	↘↘	P
7	Vitamin C effervescent tablets Streuli	Citric acid, ascorbic acid	3.6	549.4	410.3	**−25.3**	↘↘	P
	Sweets, candy, chewing gum							
8	Cola Fröschli candy	Citric acid, aroma	2.5	456.1	291.0	**−36.2**	↘↘	P
8	Cola Fröschli candy (in artificial saliva)	Citric acid, aroma	3.0	463.2	297.6	**−35.7**	↘↘	P
8	Fisherman's Friend Eucalyptus-Menthol candy	Aroma	5.2	462.6	455.0	**−1.7**	→	P
8	Fisherman's Friend Mint candy	Aroma	7.8	494.5	485.3	**−1.9**	→	P
8	Fisherman's Friend Spearmint candy	Aroma	6.4	481.0	473.0	**−1.7**	→	P
8	Halsfeger Herbal candy	Citric acid, aroma	4.1	472.9	465.8	**−1.5**	→	P
8	Halter Dental Drops, sugarfree candy	Citric acid, aroma	7.7	504.4	493.2	**−2.2**	→	P
8	Chewing gum Extra Strong Mint	Aroma, calcium phosphate	6.8	437.6	435.9	**−0.4**	→	P
8	Chewing gum Extra White	Aroma, calcium phosphate	6.8	449.8	447.5	**−0.5**	→	P
8	Läkerol Dents menthol candy	Aroma	4.8	458.5	455.0	**−0.8**	→	P
8	Chewing gum Orbit Strawberry White	Citric acid, malic acid, calcium	4.1	449.5	443.3	**−1.4**	→	P
8	Ricola Mountain Mint candy	Aroma	5.5	435.6	435.8	**0.1**	→	P
8	Ricola Green Tea-Lime candy	Citric acid, ascorbic acid	2.7	485.8	385.6	**−20.6**	↘↘	P
8	Ricola Green Tea-Lime candy (in artificial saliva)	Citric acid, ascorbic acid	3.4	475.6	395.0	**−17.0**	↘↘	P
8	Ricola Herbs candy	Aroma	5.2	484.4	477.5	**−1.4**	→	P
8	Ricola Orange Mint candy	Citric acid, ascorbic acid, aroma	2.8	481.7	370.7	**−23.1**	↘↘	P
8	Ricola lemon balm candy	Citric acid, aroma	2.7	488.6	362.2	**−25.9**	↘↘	P
8	TicTac fresh mint candy	Aroma	6.4	496.7	469.8	**−5.4**	↘	P
8	Chewing gum Trident mega mystery	Citric acid, aroma	2.7	490.3	436.4	**−11.0**	↘	D
8	Vicks Blue menthol candy	Aroma	6.3	481.5	481.6	**0.0**	→	P
	Children's articles							
9	Baby Jus, apple pear	Malic acid, citric acid	3.6	494.6	479.3	**−3.1**	↘	D
9	Brain Licker sour candy roll-on drink	Citric acid, lactic acid, malic acid	1.8	503.3	481.1	**−4.4**	↘	P
9	Capri Sonne multi vitamin juice	Citric acid, malic acid, ascorbic acid	3.3	500.4	429.0	**−14.3**	↘	P
9	Capri Sonne safari fruits juice	Citric acid, malic acid, ascorbic acid	3.3	488.2	401.9	**−17.7**	↘↘	P

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9	Dreh Drink apple juice	Malic acid, citric acid, ascorbic acid	3.4	543.2	435.1	**−19.9**	↘↘	P
9	Dreh Drink raspberry juice	Citric acid, malic acid, ascorbic acid	3.0	467.4	345.6	**−26.1**	↘↘	P
9	Dreh Drink lemon lime	Citric acid, malic acid, ascorbic acid	2.9	494.6	351.5	**−28.9**	↘↘	P
9	Freche Freunde mush	Malic acid, citric acid	4.2	495.8	468.7	**−5.5**	↘	P
9	Giant candy spray super sour	Citric acid, malic acid	1.9	456.9	351.7	**−23.0**	↘↘	P
9	Haribo pommes	Citric acid, malic acid	2.5	525.7	451.6	**−14.1**	↘	D
9	Hero kids	Malic acid, citric acid	3.9	467.8	435.5	**−6.9**	↘	D
9	Mega mouth candy spray	Citric acid	2.1	509.9	208.2	**−59.2**	↘↘	D
9	Drink Bärli apple juice	Citric acid	3.1	497.9	375.7	**−24.5**	↘↘	P
9	Drink Bärli raspberry juice	Citric acid	3.5	511.6	453.2	**−11.4**	↘	P
9	Trinketto bubble gum juice	Citric acid	3.0	467.6	346.6	**−25.9**	↘↘	P
	Miscellaneous							
10	Apple vinegar	Acetic acid, malic acid	3.4	523.0	381.0	**−27.2**	↘↘	P
10	Blossom honey	Calcium, polyphenols, protein	3.6	479.1	477.0	**−0.4**	→	P
10	Forest honey	Calcium, polyphenols, protein	4.2	495.1	496.0	**0.2**	→	P
10	Fruit vinegar	Acetic acid	3.2	627.1	308.0	**−50.9**	↘↘	P
10	Oliq Spray Energy Support	Vitamin, citrus oil	5.3	486.1	490.0	**0.8**	→	P
10	Oliq Spray Immune Support	Vitamin, citrus oil, ginger	4.7	518.0	499.2	**−3.6**	↘	P
10	Oliq Spray Inner Balance	Vitamin, aroma	4.2	494.5	483.5	**−2.2**	→	P
10	Salad dressing M classic French (without yogurt)	Vinegar	3.8	543.3	511.9	**−5.8**	↘	P
10	Salad dressing Thomy french classic	Vinegar, citric acid	4.0	548.6	527.4	**−3.9**	↘	P
10	Salad dressing Thomy french light	Vinegar, citric acid	3.8	509.1	476.5	**−6.4**	↘	P
10	Sauerkraut cooked	Organic acids	3.8	487.8	345.6	**−29.1**	↘↘	P
	Mouthwashes							
11	Elmex green rinsing solution	Fluoride	4.5	439.8	420.1	**−4.5**	↘	P
11	Elmex red rinsing solution	Fluoride	4.5	442.3	421.2	**−4.8**	↘	P
11	Elmex Sensitive Professional	Fluoride	6.1	475.4	470.8	**−1.0**	→	P
11	Listerine Cool Mint	No fluoride	4.2	465.9	452.1	**−3.0**	↘	P
11	Listerine Smart Kidz	Fluoride	3.3	466.8	436.5	**−6.5**	↘	P
11	Meridol gum protection	Fluoride	3.9	467.6	463.8	**−0.8**	→	P
11	BaLuMed Value Care	Fluoride	5.1	443.7	442.1	**−0.4**	→	P
11	BaLuMed Regular Care/ Airflow Mouthrinse	Fluoride, erythritol	5.0	453.2	449.3	**−0.9**	→	P
11	BaLuMed Intensive Care	Fluoride, erythritol	5.0	448.4	445.9	**−0.6**	→	P
11	Tebodont Wild	Tea tree oil, fluoride	5.6	475.8	476.9	**0.2**	→	P

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Tab. II The effect of temperature, calcium and phosphate content on the erosive potential of different drinks, smoothies and orange juices when applied on human premolars coated with salivary pellicle

Product	**Possible relevant ingredients** (maximum 3) ordered by importance	**Modification**	**pH**	**Hardness**	**Hardness after 2 min**	**Change** (%)	**Classification** (change in hardness)
Influence of the temperature							
Asia, Mangosteen and Passionfruit Smoothie	citric acid, malic acid	T = 37°C	3.8	514.3	416.4	**−19.0**	↘↘
	citric acid, malic acid	T = 5°C	4.1	470.8	461.2	**−2.0**	→
Coca-Cola	phosphoric acid, citric acid, carbonic acid	T = 37°C	2.6	489.2	268.9	**−45.0**	↘↘
	phosphoric acid, citric acid, carbonic acid	T = 5°C	2.6	465.9	368.1	**−21.0**	↘↘
Orange juice Granini	citric acid, malic acid	T = 37°C	3.9	493.4	452.2	**−8.3**	↘
	citric acid, malic acid	T = 5°C	3.9	455.1	447.7	**−1.6**	→
Orange juice hohes C	citric acid, malic acid	T = 37°C	3.8	471.0	393.4	**−16.5**	↘↘
	citric acid, malic acid	T = 5°C	3.8	470.5	458.1	**−2.6**	↘
Red Bull	citric acid, carbonic acid	T = 37°C	3.5	466.8	386.7	**−17.2**	↘↘
	citric acid, carbonic acid	T =5°C	3.5	454.6	418.1	**−8.0**	↘
Influence of calcium							
Africa, Baobab and Pineapple Smoothie	citric acid, malic acid	none	3.7	473.7	399.0	**−15.8**	↘↘
	citric acid, malic acid	addition of 0.03% Ca	3.5	470.7	421.8	**−10.4**	↘
	citric acid, malic acid	addition of 0.06% Ca	3.5	465.3	435.4	**−6.4**	↘
Asia, Mangosteen and Passionfruit Smoothie	citric acid, malic acid	none	3.8	514.3	416.4	**−19.0**	↘↘
	citric acid, malic acid	addition of 0.06% Ca	3.8	448.5	442.2	**−1.4**	→
	citric acid, malic acid	addition of 0.1% Ca	3.6	464.9	463.6	**−0.3**	→
Innocent Kiwi Wonder Smoothie	malic acid, citric acid	none	3.6	476.6	409.6	**−14.1**	↘
	malic acid, citric acid	addition of 0.1% Ca	3.6	465.8	467.9	**0.5**	→
Coca-Cola	phosphoric acid, citric acid, carbonic acid	none	2.6	489.2	268.9	**−45.0**	↘↘
	phosphoric acid, citric acid, carbonic acid	addition of 0.1% Ca	2.6	464.7	290.6	**−37.5**	↘↘
Red Bull	citric acid, carbonic acid	none	3.5	466.8	386.7	**−17.2**	↘↘
	citric acid, carbonic acid	addition of 0.1% Ca	3.5	458.0	451.4	**−1.4**	→
Orange juice hohes C	citric acid, malic acid	none	3.8	471.0	393.4	**−16.5**	↘↘
	citric acid, malic acid	addition of 0.1% Ca	3.8	496.0	484.7	**−2.3**	→
	citric acid, malic acid	addition of 0.1% Ca	3.6	483.7	469.5	**−2.9**	↘
Orange juice Granini	citric acid, malic acid	none	3.9	493.4	452.2	**−8.3**	↘
	citric acid, malic acid	addition of 0.1% Ca	3.9	470.5	459.5	**−2.3**	→
	citric acid, malic acid	addition of 0.15% Ca	3.9	468.7	464.5	**−0.9**	→
Influence of phosphate							
Orange juice Granini	citric acid, malic acid	none	3.9	493.4	452.2	**−8.3**	↘
	citric acid, malic acid	addition of 0.1% PO_4	3.9	455.4	416.3	**−8.6**	↘
	citric acid, malic acid	addition of 0.2% PO_4	3.9	448.8	399.7	**−10.9**	↘

Grade 0: Horizontal arrow: Hardness increase or hardness decrease of up to 2% after 2 min immersion in a solution.
Grade 1: One descending arrow: Hardness decrease of up to 15% after 2 min immersion in a solution.
Grade 2: Two descending arrows: Hardness decrease of more than 15% after 2 min immersion in a solution.

Discussion

The possible erosive potential was arbitrarily divided into three groups: no erosive potential, medium and distinct erosive potential. This classification does not include the many other factors that need to be considered when assessing potential damage. However, the tables presented here are an important tool on the sometimes difficult path to a correct diagnosis.

The discussion is structured according to the different possible factors involved in erosion or erosive tooth wear (ETW) (Fig. 1).

Patient-related factors

These factors include: eating and drinking habits, tooth cleaning, vomiting, saliva, pellicle, soft tissue, medication.

Because of changing dietary habits, acid-related tooth damage has gained in importance today, although tooth decay is still the most common oral disease. In particular, the frequent consumption of erosion-promoting beverages and foods can lead to a progressive erosive process. Progressive erosive loss of enamel or cement can expose dentin tubules and thus cause hypersensitivity of the teeth (West et al. 2013).

In a study of 3187 healthy European citizens aged 18–35 years, the frequency of ETW and the diet of the subjects were recorded (Bartlett et al. 2013). Rural residents showed more ETW than the urban population. While increased chewing gum had no effect on ETW, the intake of acidic drinks and fresh fruits was associated with a statistically significant increase in the occurrence of ETW ($p < 0.001$). Regurgitation and vomiting were also associated with increased ETW ($p < 0.001$).

An important finding was that a delay between breakfast and toothbrushing did not influence the occurrence of ETW. Even after a delay as long as 60 min, the same amount of ETW was found. Also, the frequency of brushing in the morning, at noon or in the evening had no significant influence on the prevalence of ETW. This epidemiological study showed that the recommendation to delay toothbrushing after eating can be abandoned. The recommendation was based on the concept that tooth surfaces that had suffered erosion during a meal could be remineralized if the surfaces were not subject to frictional forces (from toothbrushing or contact with tongue and cheeks) for a period. However, the short delay periods of 30–60 min sometimes suggested in the literature are mostly based on laboratory experiments using artificial saliva. Remineralization of tooth surfaces through natural saliva, to the extent that they are no longer vulnerable to cleaning forces, does not take place in a clinically relevant time, because natural saliva, in contrast to artificial saliva, contains proteins that inhibit remineralization. It therefore takes a long time (up to several weeks) for enamel to be remineralized (Garberoglio & Cozzani 1979; Ganss et al. 2007; Lussi et al. 2014; O'toole et al. 2017; Steiger-Ronay et al. 2019). The meta-analysis by Hong and coworkers clearly confirmed that the recommendation to delaye toothbrushing after the consumption of erosive foods or beverages is not capable of preventing erosive enamel wear (Hong et al. 2020).

After vomiting, it is important to rinse the mouth with a non-erosive mouthwash (Tab. I) or water. This dilutes the acid and thus protects against further dissolution of the tooth hard substance. Calculations from our original data when drinking a glass of orange juice showed a reduction of H^+ ion concentration by a factor of 4 if the mouth was rinsed with water 5 min after intake and by a factor of 9 2 min after intake. When the oral cavity was rinsed immediately with water after the acid intake, the reduction of H^+ increased to a factor of 16 (Lussi et al. 2012b).

Saliva, through its composition and flow rate and through pellicle formation, is partly protective against acid and can weaken an erosive event. Variations in pellicle formation in the different areas of the dentition could be responsible for the different distribution of ETW. Surfaces with thicker pellicle formation (lingual surfaces) and more saliva accumulation usually show less ETW than teeth with thin pellicle, such as palatal surfaces of anterior teeth. In addition, the clearance of acid is better in the lower jaw. Some of our results suggest that modification of the pellicle may protect against erosion. Beers are acidic (pH around 4) but do not cause erosion and nor does Cynar, a liqueur made of artichokes and herbs, also with pH of 4 (Tab. I). Neither of these drinks has a high calcium content to explain the lack of erosivity, so other factors, most likely peptides or proteins, must have an important protective effect, for example by modifying the pellicles or by adsorbing to the tooth surface. Protective proteins from sugar cane have recently been isolated, and their beneficial effect on dental erosions has been demonstrated (Pelá et al. 2022). Peptides and proteins are now included as a potential protective factor in the modified ETW scheme presented here (Fig. 1).

The abundance and flow rate of saliva can be reduced by radiotherapy of the head and neck area or by some medications, including tranquilizers, anticholinergics, antihistamines, antiemetics and antiparkinsonian drugs. Patients with ETW should therefore always be asked about regular medications and their side effects clarified. The above-mentioned study of over 3000 Europeans showed that the probability of ETW is significantly increased by taking antidepressants (odds ratio of 4). Taking antidepressants may reduce salivation and thus leads to increased susceptibility to dental hard tissue erosion (Bartlett et al. 2013). For erosive problems caused by medications, the treating family doctor or specialist should be consulted and efforts made to find possible alternatives with less effect on saliva secretion. It should be noted that prolonged and frequent tooth contact of medications or mouthwashes with low pH can directly cause erosion, or at least accelerate it (Tab. I).

Nutritional factors

These factors include: acid type, pH, buffering, peptides and proteins, adhesion, calcium, fluoride, viscosity.

The acid type, pH and buffer capacity of the foods and beverages are interrelated and cannot be discussed separately. The pH is a very important, though not the only, factor that determines the erosive potential of a beverage or food. In Table I, one can find soft drinks, sports drinks or even medicines that are acidic but do not cause erosion. The development of ETW is often incorrectly attributed only to a low pH of consumed beverages and foods. In tooth decay, demineralization occurs when the pH falls below a "critical pH" that is defined as the pH of a liquid that is in equilibrium with a dental tissue of interest. At this pH value, the fluid is saturated, and there is neither dissolution of the tooth nor precipitation of mineral. The critical pH is calculated from the concentrations of mineral ions in the liquid and from the solubility of the dental tissue. Dentine is more soluble than enamel, so the critical pH in relation to dentine is higher than that in relation to enamel. In caries, the relevant liquid is the "plaque fluid" that has an approximately constant electrolyte composition, so the critical pH in relation to enamel or dentine remains within a fairly narrow range (Shellis 2010). However, in dental erosion, the fluids surrounding the tooth contain a variety of dissolved substances and consequently a specific critical pH cannot be defined. Whether demineralization occurs depends not on the pH value itself but on the degree of saturation of the dissolved minerals in the liquid that contacts the teeth. The principal relevant mineral ions are calcium and phosphate because they are components of dental minerals. If the concentrations of these mineral ions is too low, it is undersaturated with respect to the dental hard tissues, which can then start to dissolve. However, if the concentration of these mineral ions in the liquid is high enough to produce saturation or even supersaturation, demineralization never occurs. For a technical discussion of these phenomena and other factors in erosion, see Barbour et al. (2011) and Shellis et al. (2014). The degree of saturation influences erosion at different pH values. Thus, at a low pH, it is possible that a high concentration of calcium counteracts erosion because the fluid is saturated or even oversaturated in terms of dental minerals. If only low calcium concentrations are present, erosive demineralization of the tooth substance can occur even at a higher pH value, as the fluid is undersaturated. Drinks such as calcium-added orange juice (Wegehaupt et al. 2011) or foods like yogurt have a high calcium content, which protects against erosion. Addition of calcium, however, has its limits due to solution problems, taste changes and legal regulations.

For hydroxyapatite [$Ca_{10}(PO_4)_6(OH)_2$], which is the type mineral for enamel, PO_4^{3-} is an important ion for the equilibrium and solubility. The lower the pH of a solution, the smaller the concentration of PO_4^{3-} (Shellis et al. 2014). However, at the low pH values common for erosion, the concentration of PO_4^{3-} is extremely small (10^{-10} to 10^{15} mmol/L) and for this reason has no clinical significance for the prophylaxis of erosion (Fig. 3). The concentration of calcium, on the other hand, does not vary with pH. It follows that the addition of calcium reduces the erosive potential, while the addition of phosphate has only a negligible effect. The results in Table II are in accordance with Shellis et al. (2023, this volume). They showed that calcium addition to soft drinks and other acidic products may reduce erosivity against enamel if pH is not too low. Phosphate, on the other hand, does not reduce the erosive potential of a liquid against enamel and is omitted from the modified scheme (Fig. 1).

Another missing factor in the new improved erosion scheme is "chelation". The importance of chelation (calcium-complex formation) is another property that has been and is still overestimated in connection with dental erosion. The reason is that erosion is associated with low-pH products. The anions of citric acid (contained in many juices) or phosphoric acid (contained in cola drinks), which have the highest affinities for calcium ions are the completely dissociated forms citrate^{3-} and PO_4^{3-}, and at low pH these anions are present at such low concentrations (Fig. 3) that this complexing effect is negligible (Shellis et al. 2014).

If an acid has a high buffering capacity, it takes longer to be neutralized by saliva, which leads to a higher risk of softening of the tooth surface (Shellis et al. 2013).The greater the buffer capacity, as measured, for example, by the amount of acid-neutralizing base needed to increase the pH to 7, the more erosive this substance will be compared to other acidic foods – provided that the other parameters are the same.

Depending on the concentration, the fluoride content of the drink or food seems to have a certain protective effect concerning dental erosion but compared to the protection against caries this protection is very small. Fluoride enrichment of foods and beverages to avoid tooth erosion is not advisable because of the possible side effects of fluoride at the high concentration required to protect against erosion (Lussi et al. 2019a).

The influence of adhesion of components of a drink to tooth surfaces is still little researched. This property could well influence the erosive potential, as more adherent substances would promote a longer contact time on the teeth and thus a longer lasting erosive effect. Adhesion and viscosity appear to be correlated. Several studies have shown that a high viscosity has a protective effect because the supply of H^+ ions to the interface with the tooth is impaired(Aykut-Yetkiner et al. 2013; Aykut-Yetkiner et al. 2014; Jager et al. 2012). Brain Licker, which is offered as a roll-on liquid candy, is a good example of this. In the original version, it softened the enamel surface by

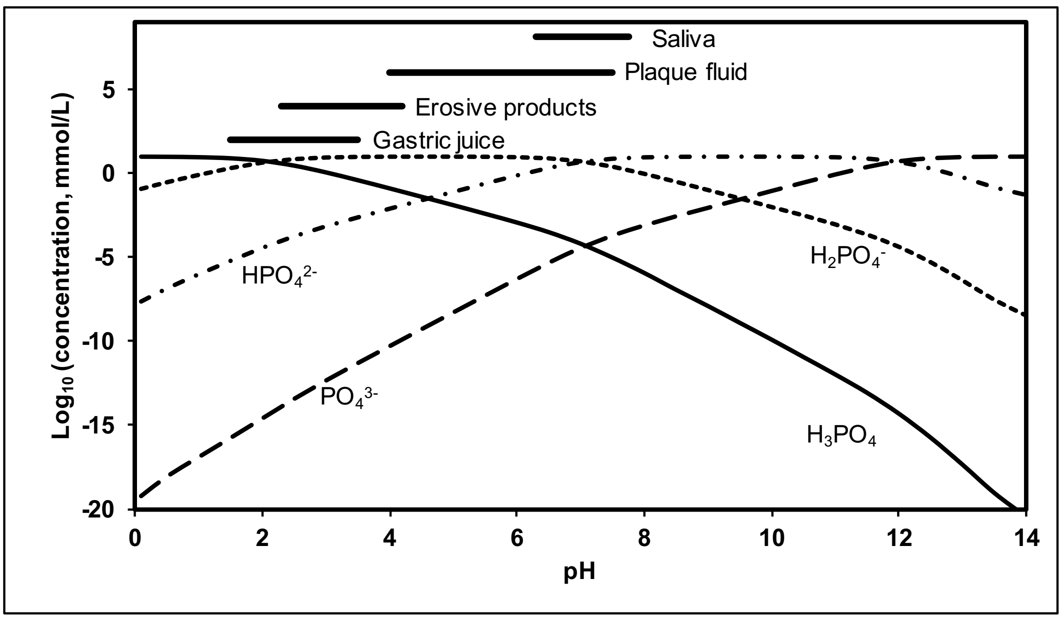

Fig. 3 The different protonation states of phosphate as a function of pH. Note the small PO_4^{3-} concentration of erosive products or stomach acid. Formula hydroxylapatit $Ca_{10}(OH)_2(PO_4)_6$.

4.4% (Tab. I). If it was diluted in a ratio of 1:1 with artificial saliva, the difference was 30%, with dilution 1:2 the softening even increased to 42.8%. With the Giant Candy Spray Super Sour, these values increased from 23% to 57% and then to 58% with the same dilution series (results not shown). This property must be seen in the context of other parameters promoting erosion such as pH or buffer capacity.

The temperature of drinks and foods must also be considered, as it has an influence on the degree of saturation (Tab. II). Higher temperatures accelerate the chemical reaction rate, which can lead to faster erosive dissolution of teeth (Barbour et al. 2006).

In summary, an exact anamnesis, early diagnosis and the determination of etiological factors on the nutritional and patient side combined with adequate prophylaxis measures are essential to avoid erosive dental hard tissue erosion or to stop its progression. As the above discussion demonstrates, many factors could influence erosion potential and their interactions are likely to be complex, so accurate prediction of the erosive properties of ingested products is at present elusive. Hence, reliance must be placed on empirical data, as presented in the tables here, to assess nutritional and patient-related etiological factors in ETW.

Zusammenfassung

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References

Aykut-Yetkiner A, Wiegand A, Bollhalder A, Becker K, Attin T: Effect of acidic solution viscosity on enamel erosion. J Dent Res 92(3): 289–294 (2013)

Aykut-Yetkiner A, Wiegand A, Ronay V, Attin R, Becker K, Attin T: In vitro evaluation of the erosive potential of viscosity-modified soft acidic drinks on enamel. Clin Oral Investig 18(3): 769–773 (2014)

Barbour M E, Finke M, Parker D M, Hughes J A, Allen G C, Addy M: The relationship between enamel softening and erosion caused by soft drinks at a range of temperatures. J Dent 34(3): 207–213 (2006)

Barbour M E, Lussi A, Shellis R P: Screening and prediction of erosive potential. Caries Res 45(Suppl 1): 24–32 (2011)

Bartlett D W, Lussi A, West N X, Bouchard P, Sanz M, Bourgeois D: Prevalence of tooth wear on buccal and lingual surfaces and possible risk factors in young European adults. J Dent 41(11): 1007–1013 (2013)

Ganss C, Schlueter N, Friedrich D, Klimek J: Efficacy of waiting periods and topical fluoride treatment on toothbrush abrasion of eroded enamel in situ. Caries Res 41(2): 146–151 (2007)

Garberoglio R, Cozzani G: In vivo Effect of Oral Environment on Etched Enamel: A Scanning Electron Microscopic Study. J Dent Res 58(9): 1859–1865 (1979)

Hong D Wei, Lin X Jiao, Wiegand A, Yu H: Does delayed toothbrushing after the consumption of erosive foodstuffs or beverages decrease erosive tooth wear? A systematic review and meta-analysis. Clin Oral Investig 24(12): 4169–4183 (2020)

Jager D H J, Vieira A M, Ruben J L, Huysmans M C D N J M: Estimated erosive potential depends on exposure time. J Dent 40(12): 1103–1108 (2012)

Larsen M J, Nyvad B: Enamel Erosion by Some Soft Drinks and Orange Juices Relative to Their pH, Buffering Effect and Contents of Calcium Phosphate. Caries Res 33(1): 81–87 (1999)

Lussi A, Buzalaf M, Duangthip D, Anttonen V, Ganss C, João-Souza S H, Baumann T, Carvalho T S: The use of fluoride for the prevention of dental erosion and erosive tooth wear in children and adolescents. Eur Arch Paediatr Dent 20(6): 517–527 (2019a)

Lussi A, João-Souza S H, Megert B, Carvalho T S, Baumann T: Das erosive Potenzial verschiedener Getränke, Speisen und Medikamente. Ein Vademecum. Swiss Dent J 129(6): 479–487 (2019b)

Lussi A, Lussi J, Carvalho T S, Cvikl B: Toothbrushing after an erosive attack: will waiting avoid tooth wear? Eur J Oral Sci 122(5): 353–359 (2014)

Lussi A, Megert B, Shellis R P, Wang X: Analysis of the erosive effect of different dietary substances and medications. Br J Nutr 107(2): 252–262 (2012a)

Lussi A, Von Salis-Marincek M, Ganss C, Hellwig E, Cheaib Z, Jaeggi T: Clinical study monitoring the pH on tooth surfaces in patients with and without erosion. Caries Res 46(6): 507–512 (2012b)

Newby C S, Creeth J E, Rees G D, Schemehorn B R: Surface microhardness changes, enamel fluoride uptake, and fluoride availability from commercial toothpastes. J Clin Dent 17(4): 94–99 (2006)

O'Toole S, Bernabé E, Moazzez R, Bartlett D: Timing of dietary acid intake and erosive tooth wear: A case-control study. J Dent 56: 99–104 (2017)

Pelá V T, Niemeyer S H, Baumann T, Levy F M, Henrique-Silva F, Lussi A, Carvalho T S, Buzalaf M A R: Acquired Pellicle Engineering Using a Combination of Organic (Sugarcane Cystatin) and Inorganic (Sodium Fluoride) Components against Dental Erosion. Caries Res 56(2): 138–145 (2022)

Schlueter N, Luka B: Erosive tooth wear – A review on global prevalence and on its prevalence in risk groups. Br Dent J 224(5): 364–370 (2018)

Shellis R P, Barbour M E, Jesani A, Lussi A: Effects of buffering properties and undissociated acid concentration on dissolution of dental enamel in relation to ph and acid type. Caries Res 47(6): 601–611 (2013)

Shellis R P, Barbour M E, Parker D M, Addy M, Lussi A: Effects of Calcium and Phosphate on Dissolution of Enamel, Dentin and Hydroxyapatite in Citric Acid. Swiss Dent J 133(7/8): 432–438 (2023)

Shellis R P, Featherstone J D B, Lussi A: Understanding the Chemistry of Dental ErosionIn Erosive Tooth Wear: From Diagnosis to Therapy (Vol. 25, pp. 163–179) S. Karger AG (2014)

Shellis R P: Formation of caries-like lesions in vitro on the root surfaces of human teeth in solutions simulating plaque fluid. Caries Res 44(4): 380–389 (2010)

Steiger-Ronay V, Tektas S, Attin T, Lussi A, Becker K, Wiedemeier D B, Beyeler B, Carvalho T S: Comparison of profilometric and microindentation analyses for determining the impact of saliva on the abrasion of initially eroded enamel. Caries Res 53(1): 33–40 (2019)

Wegehaupt F, Günthart N, Sener B, Attin T: Prevention of erosive/abrasive enamel wear due to orange juice modified with dietary supplements. Oral Dis 17(5): 508–514 (2011)

West N X, Sanz M, Lussi A, Bartlett D, Bouchard P, Bourgeois D: Prevalence of dentine hypersensitivity and study of associated factors: A European population-based cross-sectional study. J Dent 41(10): 841–851 (2013)