Erosion – chemical and biological factors of importance to the dental practitioner

Domenick T. Zero
Indianapolis, USA

Adrian Lussi
Berne, Switzerland

The intrinsic and extrinsic aetiology factors responsible for dental erosion are well understood as are the chemical events leading the initial mineral dissolution, softening and eventual loss of the dental surface. Of greatest importance are the pH, titratable acidity, phosphate and calcium concentration, fluoride content of the erosive challenge which determines the degree of saturation with respect to the tooth mineral, and thus the driving force for its dissolution. Of the biological modifying factors affecting the erosion process, the protective properties of saliva and its contribution to pellicle formation are considered of greatest importance. Unstimulated salivary flow rate and buffering capacity have been directly associated with dental erosion. The acquired pellicle has been shown to have a protective effect against acid erosion by acting as a diffusion barrier. There is considerable overlap between the aetiology of dental erosion and that of dentinal hypersensitivity. Patient education on the causes and prevention of dental erosion are essential to prevent progression. In addition to reducing or eliminating exposure to acidic soft drinks and juices, modified acid beverages with reduced potential to cause erosion can be recommended to patients. Frequent application of high concentration topical fluoride may be of some benefit in preventing further demineralisation and increase the abrasion resistance of erosion lesions.

Key words: Erosion, fluoride content, hypersensitivity, prevention

Tooth wear is becoming increasingly significant in the long term health of the dentition. Following the decline in tooth loss due to infectious diseases in the 20th century, the increasing longevity of teeth in the 21st century will mean the incremental and clinically deleterious effects of wear, especially by erosion, will become more demanding upon the preventive and restorative skills of the practitioner.

Defined as a surface dissolution of dental hard tissues by acids without the involvement of micro-organisms[1], dental erosion may be caused by a series of extrinsic and intrinsic factors[2]. Extrinsic factors largely include the consumption of acidic foods and carbonated beverages, sports drinks, red and white wines, citrus fruits and, to a lesser degree, occupational exposure to acidic environments. The most common intrinsic factors include chronic gastro-intestinal disorders such as gastro-oesophageal disease as well as health issues like anorexia and bulimia where regurgitation and frequent vomiting are common.

It has been known for a long time that acidic food and drinks may soften dental hard tissues[1,3-5]. The erosive activity of citric, malic, phosphoric and other acids as ingredients of beverages and foodstuffs has been demonstrated in many *in vitro*, *in situ* and *in vivo* studies[6]. Further, a series of studies indicates that the erosive potential of an acidic drink is not entirely dependent on its pH, but is also strongly affected by its titratable acid content (buffering capacity) and by the calcium-chelation properties of the food and beverages, as they efficiently bind released calcium. The greater the buffering capacity of the drink, the longer it will take for the saliva to neutralise the acid[7].

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Chemical modifying factors of erosion

The chemical events leading to erosion are complex. When a solution comes in contact with the enamel surface of a tooth, it has to first diffuse through the acquired pellicle, which is an organic film derived mainly from salivary proteins and glycoproteins which cover the surface of teeth. Only thereafter can it interact with the mineral phase of the tooth, which is a carbonated and calcium deficient hydroxyapatite. A developing young pellicle will hardly be a diffusion barrier to an erosive agent. Only when the pellicle has matured and has achieved a certain thickness can it slow down the diffusion process. Once in contact with enamel, the acid with its hydrogen ion (or with its chelating capacity) will start to dissolve the crystal. The un-ionised form of the acid will then diffuse into the interprismatic areas of enamel and dissolve mineral in the subsurface region[8]. This will lead to an outflow of tooth mineral ions (calcium and phosphate) and subsequently to a local pH rise in the tooth structure in close proximity to the enamel surface.

This process is stopped when no new acids and/or chelating substances are provided. An increase in agitation (e.g. when a patient is swishing a drink in the mouth) will enhance the dissolution process, because the solution on the surface layer adjacent to enamel will be readily renewed. Furthermore, the amount of drink in the mouth in relation to the amount of saliva present will modify the dissolution process. Citric acid common in many soft drinks may act as a chelator capable of binding minerals (calcium) of enamel or dentine, thus increasing the degree of undersaturation and favouring more demineralisation.

The events in dentine are in principle the same but are even more complex. Due to the high content of organic material the diffusion of the demineralising agent into deeper regions is hindered by the dentine matrix and so is the outward flux of dissolved tooth mineral[9]. It was assumed that the organic dentine matrix has a buffering capacity sufficient to retard further demineralisation. Therefore, chemical or mechanical degradation of the dentine matrix promotes the demineralisation[10,11].

The pH value, the calcium, and phosphate and to a lesser extent the fluoride content of a drink or foodstuff are important factors explaining the erosive attack[12,13]. They determine the degree of saturation with respect to the tooth mineral, which is the driving force for dissolution of the tooth mineral[14]. Solutions supersaturated with respect to dental hard tissue will not dissolve tooth mineral. A low degree of under saturation with respect to enamel or dentine will lead to an initial surface demineralisation, which is followed by a local pH rise and increased content of mineral in the fluid layer adjacent to the surface. This fluid layer will then become saturated with respect to enamel (or dentine) and not lead to further demineralisation. The deposition of salivary calcium and phosphate may lead to rehardening (remineralisation) of the initially acid softened enamel[15,16]. The rehardening process has been shown to be greatly enhanced by fluoride treatment followed by four hours of intraoral exposure, while pyrophosphate (a tartar control additive) appears to interfere with remineralising[17].

Table 1 gives an overview of the chemical properties of different beverages and foodstuffs. The pH, the amount of (titratable) acid required to raise the pH to 7.0, phosphate and calcium concentration, fluoride content and the extent of enamel softening as measured by surface microhardness (SMH) are given. Measurements of SMH were performed before and after immersion for six minutes in the foodstuffs or beverages using a Knoop diamond under a load of 50g and the change in SMH was calculated. A positive value denotes a hardening of the surface while a negative value represents softening.

Addition of calcium (and phosphate) salts to ero-

Table 1 Baseline pH, amount of base needed to raise the pH to 7.0, phosphate, calcium, fluoride concentration and surface microhardness (SMH) of different beverages

Beverage, Foodstuff	pH	OH^- to pH7 mmol/l	P mmol/l	Ca mmol/l	Fluoride ppm	SMH before immersion	SMH after immersion (6 min)	Change in SMH
Apple juice	3.00	102	1.7	2.3	0.220	352	151	- 201
Squeezed orange juice	3.64	136	5.7	2.1	0.030	353	209	- 144
Orange juice	3.74	124	2.9	1.9	0.125	348	289	- 59
Orange Yoghurt	4.08	101	43.0	32.0	0.050	354	355	+ 1
Ice Tea	3.00	26	0.1	0.6	0.825	338	187	- 151
Coca-Cola (degassed)	2.60	34	5.4	0.8	0.131	349	186	- 163

sive drinks have shown promising results. Orange juice (pH 4) supplemented with calcium (42.9mmol/l) and phosphate (31.2mmol/l) did not erode enamel after immersion for 7 days[18]. Only a relatively small change in the degree of saturation by adding calcium (and phosphate and/or fluoride), without changing the pH, may reduce the erosive potential *in vitro*[19,20]. There are, however, some clinical implications for the patient and the clinician, in that, while erosion was retarded, it was not completely prevented by the mineral additives.

Several calcium enriched soft drinks are currently on the market and may offer some benefit to patients at risk of dental erosion. However, these drinks may still have the potential to slightly soften the enamel surface (*Table 2*). Addition of calcium to a low pH blackcurrant juice drink has been shown to reduce the erosive effect of the drink[21,22]. Yoghurt is another example of a food with a low pH (≤ 4.0), yet it has very little erosive potential due to its high calcium and phosphate content, which makes it supersaturated with respect to enamel[7] (*Table 1*).

Theoretically, fluoride has some protective effect in a drink with a pH higher than that indicated by the saturation-curve of fluorapatite at given Ca and PO_4 concentrations. Lussi *et al.*[12,13] and Mahoney *et al.*[23] found an inverse correlation of the erosive potential with the fluoride content of different beverages. However, given the low pH in many drinks and health concerns, adding fluoride to drinks is not practical. After an initial demineralisation, an intensive fluoride treatment is capable of inhibiting the erosive mineral loss in dentine completely. This is probably due to the buffering capacity of the proteins in the dentine matrix[10].

The greater the buffering capacity of the acidic drink or food, the longer it will take for saliva to neutralise the acid. For squeezed orange juice, 124mmol/l of base is required to raise the pH to 7, whereas for degassed Coca Cola only 34mmol/l is required (*Table 1*). The buffer capacity of a solution has a distinct effect on the erosive attack when the solution stays in prolonged contact with the tooth surface and it is not replaced by saliva. A higher buffer capacity of a drink or foodstuff will enhance the dissolution process, because more mineral ions from the tooth are needed to render the acid inactive for further demineralisation.

Biological modifying factors

The biological modifying factors affecting the erosion process include saliva, tooth composition and structure, dental anatomy and occlusion, the anatomy of oral soft tissues in relationship to the teeth and physiological soft tissue movements such as swallowing pattern[6]. Of these, the natural protective properties of saliva and its contribution to pellicle formation can be considered of greatest importance. The erosion protective functions of saliva include:

- Dilution and clearance of erosive substances from the mouth
- The neutralisation and buffering of acids
- Maintaining a supersaturated state next to the tooth surface due to the presence of calcium and phosphate in saliva
- Providing calcium, phosphate and possibly fluoride necessary for remineralisation. Both the quantity and quality of saliva may be responsible for some of the observed differences in the susceptibility of different patients to erosion.

Of the many salivary parameters that have been considered, only the unstimulated salivary flow rate and buffering capacity have been directly associated with dental erosion.

Another important role of saliva is related to the formation of the acquired pellicle. The pellicle which forms rapidly has been shown to have a protective effect against acid demineralisation[24-29]. Any procedure that removes or reduces the thickness of the pellicle may compromise its protective properties and accelerate the erosion process. Procedures such as tooth brushing with

Table 2: Minimally erosive beverages available in the United Kingdom, mid-2005. All beverages listed are ready to drink as purchased (no dilution required). This permits a more accurate comparison between different beverages.

Available Beverage	pH	Ingredients used to obtain low erosive effect	Added level of Calcium [mg/L]
Ribena Really Light Blackcurrant	3.7 – 4.0	$Ca(OH)_2$ and xanthan gum	630
Ribena Really Light Apple	3.7 – 4.0	$CaCO_3$	440
Ribena Really Light Berry Burst	3.7 – 4.0	$Ca(OH)_2$	400
Ribena Really Light Strawberry	3.7 – 4.0	$CaCO_3$	400
Ribena Really Light Orange Tropical	3.7 – 4.0	$CaCO_3$	200
Lucozade Sport Hydroactive Citrus Fruits Flavour	3.7 – 4.0	$CaCO_3$	370
Lucozade Sport Hydroactive Summer Fruits Flavour	3.7 – 4.0	$CaCO_3$	370

abrasive dentifrice products, professional cleaning with prophylaxis paste, and tooth whitening will remove the pellicle and may render teeth more susceptible to erosion[6]. The time required for the pellicle to reform to provide optimal protection is still the subject of debate with studies reporting protective effects with pellicles formed for as little as 3 minutes[29] to as long as 7 days[26]. This can be explained by methodological differences, mainly the conditions for pellicle formation (*in situ* vs. *in vitro*) and analytical methods.

Relationship to dentine hypersensitivity

By definition, dentine hypersensitivity is associated with dentine exposed to the oral environment[30]. Dentine may become exposed by two processes – loss of enamel or gingival recession and subsequent loss of cementum[31]. In particular, loss of enamel occurs by attrition associated with occlusal function, abrasion from dietary components or toothbrushing or erosion due to environmental or dietary components such as acid[32]. Evidence, largely from studies *in vitro* and *in situ,* suggests acid erosion has the potential to both localise and initiate lesions facial-cervically, the most common site for dentine hypersensitivity[33].

A synergy exists between the aetiology of dental erosion and dentine hypersensitivity. As indicated, dentine hypersensitivity represents a symptom of presumably multi-factorial pathology consisting mainly of abfractive, abrasive, or erosive components (or a combination)[34]. The same causes of dental erosion also may be considered culprits in relation to dentine hypersensitivity. Consuming fruit drinks or other acidic beverages with frequency or maintaining a vegetable-laden diet may lead to erosive effects removing dentine and/or smear layer, thereby opening tubules[34].

These open tubules are in turn susceptible to outside stimuli. According to the hydrodynamic theory[35], a stimulus applied to a tooth surface featuring patent or open dentinal tubules causes fluid movement within the tubule, changing the pressure on the mechano-receptors of the A-beta and A-delta fibres around the odontoblast process. Alteration of fluid movement is perceived as short, sharp pain by the patient. Because dentine has to be exposed and the dentine tubule network opened to permit fluid movement under stimulation[33], some authors, while allowing that much remains unknown or unproven about the aetiology of the condition, have suggested that dentine hypersensitivity is a tooth wear phenomenon[36, 37].

Prevention

Erosion is an insidious process that patients do not become aware of until it reaches an advanced stage, so the early clinical detection by dental professionals is of utmost importance[38]. Clearly the most effective way of preventing erosion is to eliminate the aetiological factors, whether they are of intrinsic or extrinsic origin or a combination of the two. A careful review of the patient's medical history and dietary/behavioural predisposing factors is essential. Evaluating patients' salivary gland function is also important, due to the strong association between decreased salivary flow and susceptibility to erosive tooth wear. In many cases it may prove to be difficult to isolate one factor due to the multifactorial nature of tooth wear. Education is the first line of defence as most patients are unaware of how their behaviours are contributing to the destruction of their teeth. While the benefits of topical fluorides for caries prevention are beyond refute, the ability of fluoride to prevent erosion cannot be presumed, because the acidic challenge in erosion is often stronger. Recent evidence from *in vitro* studies suggests that high concentrations of topical fluoride are able to limit progress of erosion and increase abrasion resistance[39]; however, these findings need to be confirmed in clinical studies. Based on an understanding that the chemical properties of soft drinks, such as pH, type of acid, pKa, and titratable acidity, affect their erosive potential, product modification has been initiated over the past few years. *Table 2*, for example, provides a list of minimally erosive beverages available in the United Kingdom in 2005.

The most common patient recommendations are the following:

- Refer patients or advise them to seek appropriate medical attention when intrinsic factors, such as anorexia/bulimia or gastro-oesophageal reflux disease are involved
- Reduce or eliminate frequent exposure to acidic soft drinks and juices
- Avoid erosive-inducing habits such as sipping, swishing or holding drinks in the mouth and drink with a straw, ensuring the flow is not aimed directly at any individual tooth surface (if acid drinks are consumed)
- Avoid tooth brushing immediately before an erosive challenge (vomiting, consumption of acid beverages). As discussed above the acquired pellicle provides protection against erosion, and tooth brushing, especially with a high abrasive (whitening) toothpaste, will remove the pellicle. However, it has been shown *in situ* that gentle application of slightly acidic F- gel (10,000ppm) before the erosive challenge does increase resistance to subsequent abrasion[40].
- Avoid tooth brushing immediately after an erosive challenge. Enamel remains softened and susceptible to mechanical tooth wear (abrasion, attrition) for at least one hour after an erosive challenge[41-43]
- Use a soft toothbrush and low abrasion dentifrice to minimise any additional tooth wear
- Avoid dentifrices with a low pH[44]
- Use a remineralising/neutralising fluoride rinse, sodium bicarbonate (baking soda) solution, milk or

food such as cheese or sugar-free yoghurt after an erosive exposure

- Stimulate saliva flow with, for example, a sugar-free chewing gum, or lozenge designed for such purpose. The use of a sugar-free lozenge may be more advisable, since gum chewing may have an abrasive effect on softened tooth structure.
- Consider using modified acid beverages with reduced erosive potential instead of regular products.

Summary

The chemical and biological factors modifying the dental erosion process are well understood. A much lower and wider range of acid pH conditions are involved compared to dental caries. The degree of saturation is the main determinant of whether or not dissolution will occur and this is dependent not only on the pH but on many other factors. The interplay of different parameters such as Ca, PO_4, F, pH in close proximity to the dental surface as well as the buffering capacity determines if erosion will occur or not. Even at a low pH, it is possible that other factors may come into play to prevent erosion. A patient's salivary flow rate and buffering capacity are the most important biological modifying factors. Patients with low salivary flow are considered to be more susceptible to erosive tooth wear. Patient education on the causes and prevention of dental erosion are essential to prevent progression. In addition to reducing or eliminating exposure to acidic soft drinks and juices, modified acid beverages with reduced potential to cause erosion can be recommended to patients. Tooth brushing, particularly with more abrasive toothpastes, should not occur either immediately before or after and erosive challenge. Frequent application of high concentration topical fluoride may be of some benefit in preventing further demineralisation and increase the abrasion resistance of erosion lesions.

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Correspondence to: Domenick T. Zero, DDS, MS Department of Preventive and Community Dentistry, Indiana University School of Dentistry, 415 Lansing Street Indianapolis, IN, 46202-2876, USA Email: dzero@iupui.edu