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INSIGHTS INTO PREVENTIVE MEASURES FOR DENTAL EROSION

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ABSTRACT

Dental erosion is defined as the loss of tooth substance by acid exposure not involving bacteria. The etiology of erosion is related to different behavioral, biological and chemical factors. Based on an overview of the current literature, this paper presents a summary of the preventive strategies relevant for patients suffering from dental erosion. Behavioral factors, such as special drinking habits, unhealthy lifestyle factors or occupational acid exposure, might modify the extent of dental erosion. Thus, preventive strategies have to include measures to reduce the frequency and duration of acid exposure as well as adequate oral hygiene measures, as it is known that eroded surfaces are more susceptible to abrasion. Biological factors, such as saliva or acquired pellicle, act protectively against erosive demineralization. Therefore, the production of saliva should be enhanced, especially in patients with hyposalivation or xerostomia. With regard to chemical factors, the modification of acidic solutions with ions, especially calcium, was shown to reduce the demineralization, but the efficacy depends on the other chemical factors, such as the type of acid. To enhance the remineralization of eroded surfaces and to prevent further progression of dental wear, high-concentrated fluoride applications are recommended. Currently, little information is available about the efficacy of other preventive strategies, such as calcium and laser application, as well as the use of matrix metalloproteinase inhibitors. Further studies considering these factors are required. In conclusion, preventive strategies for patients suffering from erosion are mainly obtained from *in vitro* and *in situ* studies and include dietary counseling, stimulation of salivary flow, optimization of fluoride regimens, modification of erosive beverages and adequate oral hygiene measures.

Key words: Dental erosion, prevention. Tooth wear.

INTRODUCTION

The term tooth wear is defined as loss of dental hard tissues due to the processes of dental erosion, attrition and abrasion⁵⁷. Dental attrition is the wear of tooth resulting from tooth to tooth contact⁵⁷, while abrasion is caused by oral habits or abrasive substances, such as highly abrasive toothpastes⁵⁷. Dental erosion is defined as the loss of tooth substance by chemical processes (acid exposure) not involving bacteria⁶⁰. The acidic attack leads to an irreversible loss of dental hard tissue, which is accompanied by a progressive softening of the surface⁶⁰. This softened zone is more susceptible to mechanical forces, such as abrasion⁸², which in turn have little or no effect on sound dental hard tissues¹. The chemical and mechanical processes can occur

individually or together, although the effect of erosion is often dominant².

Clinically, early enamel erosion appears as a smooth silky-shining glazed surface (Figure 1). Typical for erosions of the facial aspects of teeth is a ridge of enamel that separates the defect from the marginal gingiva. Occlusal erosion is characterized by rounded cusps and concavities. Further progression of occlusal erosion lead to a distinct grooving of the cusps (Figure 2), and restorations are rising above the level of the adjacent tooth surface. In cases of severe erosion, the whole occlusal or facial morphology disappears. Erosion can be distinguished from wedge shaped lesions, which present a sharp margin in the coronal part and cuts at right angles into the enamel surface as well as from attrition. Attrition appears often glossy and has distinct



FIGURE 1- Clinical appearance of tooth wear in enamel. Enamel erosion in a 36-year-old female patient caused by frequent consumption of a cola soft drink. Erosion can be detected by the presence of a wedge-shaped defect, which shows a sharp margin on the coronal portion



FIGURE 2- Clinical appearance of tooth wear in dentin in a 25-year-old athlete due to frequent consumption of acidic sport drinks

margins and corresponding features at the antagonistic teeth. In cases of occlusal tooth wear, the distinction between erosion and abrasion is often difficult, as both are of similar shape²⁹.

The etiology of erosion is multifactorial and not fully understood. The most important sources of acids are those found in the diet, such as acidic foods and drinks⁵⁹ and those originated from the stomach, like gastric acids from

regurgitation and reflux disorders¹⁶. Currently, the increased consumption of acidic foods and soft drinks is becoming an important factor for the development of erosive wear⁶⁰.

As erosive tooth wear is a multifactorial condition, preventive strategies has to be applied which account for chemical, biological and behavioral factors involved in the etiology and pathogenesis of erosion⁶⁰ (Figure 3). However, information is lacking about all possible preventive measures for erosion including those already known and the new ones. Therefore, the objective of this paper is to present an overview of the current literature and to summarize the preventive strategies relevant for patients suffering from dental erosion.

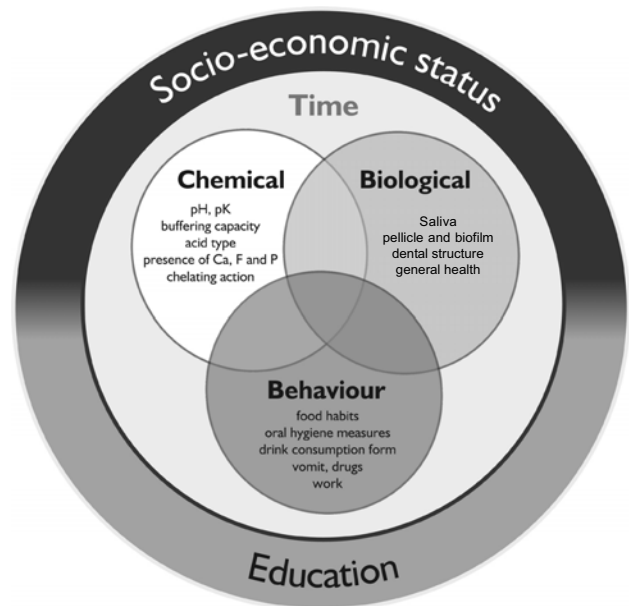


FIGURE 3- Diagram proposed by Lussi (2006), modified

REVIEW OF LITERATURE AND DISCUSSION

Preventive Strategies for Behavioral Factors

Behavioral factors have a decisive influence on the appearance and progression of dental erosion¹⁰⁶. The frequent and excessive consumption of acids is associated with an increased risk for dental erosion. Special drinking habits, such as nipping from a bottle, might enhance the acid contact time and, thus, increase the erosive attack. Oral hygiene measures might also influence the progression of erosive lesions. Abrasive procedures, such as toothbrushing, are known to remove the fragile surface of demineralized dental hard tissues. In this way, the moment of toothbrushing after an erosive attack^{8,10} as well as the kind of toothbrush and toothpaste used might influence the progression of dental wear⁴⁰.

· Measures to Reduce the Acid Exposure

Of major importance for the prevention of dental erosion

is the reduction of the acid exposure. The frequency and duration of acid contact might be important variables for the development of erosive lesions^{25,94}. Moreover, the adhesiveness and displacement of liquids might influence the erosive process, as an increased adherence of an acidic substance is associated with a longer contact time on the tooth. The ability of beverages to adhere on enamel is based on their thermodynamic properties⁴⁵.

Extrinsic acid sources of erosion are mainly dietary acids, but also lifestyle factors (e.g. drugs) or occupational acid exposure (Figure 4). To decrease the risk of dietary induced erosive lesions, patients should be advised to refuse from acidic snacks between the principal meals to allow the saliva to rehardened eroded tooth surfaces. Special drinking habits, such as holding or moving the liquid in the mouth prior to swallowing, sucking from a straw or nipping from a bottle, lead to an increased acid contact time in the oral cavity and, thus, to prolonged duration of an acidic pH-value in the environment of the teeth¹⁷. Therefore, it seems advisable to avoid these drinking habits to reduce the duration of the erosive attack (Figure 5). In addition to the dietary acids, patients should be aware of unhealthy lifestyle factors, such as consumption of drugs, alcohol abuse and lactovegetarian diet, which might increase the risk for erosion¹⁰⁶ (Figure 4). However, as it is difficult to control possible etiological factors, such as the intake of acidic beverages or special drinking habits, other strategies have been developed for the prevention of dental erosion.

With regard to environmental acid exposure, an increased risk for dental erosion is reported for battery, charging and galvanizing workers, which are commonly exposed to sulphuric or hydrochloric acid (Figure 4). The risk for erosive

tooth wear and the severity of erosion increase with increasing concentration of the acid or the acidic fumes, increasing exposure time and duration of employment. Personal protective equipments (respiratory masks) and adherence to threshold limit values recommended by occupational health legislations are considered as important preventive strategies to decrease occupational erosion⁹⁶.

The intrinsic etiologic factors of erosion include disorders that are associated with the presence of gastric acid in the oral cavity, such as vomiting or gastroesophageal reflux (Figure 4). Therefore, erosive tooth wear is a common manifestation in patients suffering from organic or psychosomatic disorders like anorexia or bulimia nervosa or alcohol abuse. These disorders require a causal therapy (general medicine, psychological therapy) for a permanent reduction of the intrinsic acid exposure. However, dental professionals are often the first to discover and diagnose eating disorders by detecting structural changes of dental hard tissues and, thus, to induce general diagnostics and therapeutics (Figure 5).

· *Measures to Reduce the Mechanical Impact*

From *in vitro*⁹¹ and *in situ* studies^{31,98} it is concluded that the mechanical stress of eroded surfaces may be mainly induced by toothbrushing but also by attrition due to tooth-tooth-contact, tongue friction or abrasion of surrounding soft tissues under clinical conditions.

Attin, et al.^{8,10} showed that the resistance of eroded enamel and dentin to toothbrushing abrasion was significantly decreased after erosion, but was enhanced with increasing remineralization time. However, even after a remineralization period of 60 min the wear of enamel

Diet	Frequency of consumption of acid drinks (soft drinks, fruit juices, sport drinks) and foods (citrus fruits, salad dressing), eventually diet diary
General diseases	Gastrointestinal diseases (reflux) Eating disorders Alcohol abuse General diseases affecting salivary flow rate <ul style="list-style-type: none"> - Diseases of salivary glands - Radiation of the head and neck region - Sjögren-Syndrome - Diabetes mellitus - Chronic renal failure
Medication	Acidic medicaments (acetylsalicylic acid, vitamin C) Reduction of saliva secretion as a side effect of: <ul style="list-style-type: none"> - Psychotropic drugs - Anticholinergics - Antihistaminics - Antiemetics - Parkinson medication - Drugs abuse
Occupation/Sports	Occupational acid exposure Sports (swimming pool, increased consumption of acidic sport drinks)

FIGURE 4- Factors retrieved from a clinical interview indicating an increased risk for dental erosion

Aim	Recommendation/Measure
<p>Reduction of acid exposure</p> <ul style="list-style-type: none"> - Extrinsic factors (e.g. diet) - Intrinsic factors 	<ul style="list-style-type: none"> · Reduction of the intake of acidic drinks and snacks · Acidic beverages should be drunk quickly and cooled · Consumption of acidic drinks with a high content of calcium, phosphate, fluoride and xylitol · Evaluation of the etiology of acid exposure, therapy of organic (e.g. reflux, xerostomia) or psychosomatic (e.g. bulimia nervosa) disorders
<p>Reduction of demineralization, enhancement of remineralization</p>	<ul style="list-style-type: none"> · Increase of salivary flow <ul style="list-style-type: none"> - Chewing of sugar-free gums - Patients with xerostomia: systemic medication (cholinergic drugs), use of saliva substitutes · Behavior after acid contact <ul style="list-style-type: none"> - Rinsing of the oral cavity with water, milk or low concentrated fluoride solutions - Consumptions of neutralizing food (cheese, milk) · Frequent fluoridation <ul style="list-style-type: none"> - Use of fluoridated toothpaste, solution and gel
<p>Reduction of abrasion</p>	<ul style="list-style-type: none"> · No toothbrushing immediately after acid consumption · Use of manual toothbrushes or electric toothbrushes applied with gentle pressure · Use of fluoridated toothpastes with low REA/RDA-value

FIGURE 5- Preventive measures for patients with increased risk for erosion

samples was significantly increased as compared to the demineralized, but not brushed control⁸. In contrast, dentin wear was not significantly higher than in unbrushed controls after intra-oral periods of 30 and 60 min¹⁰. Thus, patients who present high risk for dental wear should be recommended to avoid toothbrushing immediately after an acidic attack, but wait at least 30-60 min (Figure 5).

In addition to the moment of toothbrushing, abrasion of eroded enamel and dentin is dependent on the type of toothbrush, the applied brushing force and several toothpaste factors^{40,97,99,101,103,105}. Previous studies^{97,99,101} have shown that powered and manual toothbrushes as well as manual toothbrushes applied with different brushing loads vary in their ability to remove the fragile surface of demineralized enamel and dentin. On the basis of the observation that enamel and dentin wear increase with increasing toothbrushing force⁹⁹, patients with erosive lesions should apply their toothbrushes with slight pressure to minimize loss of dental hard tissues (Figure 5).

The stiffness of the toothbrush bristles seems to be of minor importance for the abrasion of eroded dental hard tissues. Wiegand, et al.¹⁰³ showed that the ability of toothbrushes with filament diameters of 0.15, 0.20 and 0.25 mm to remove eroded enamel did not differ significantly when toothpaste slurries of REA 2, 6 and 9 were used.

In contrast, toothbrushing abrasion is mainly influenced

by the toothpaste used¹⁰³. The abrasivity of the toothpaste is determined by the size and amount of abrasives, pH, buffering capacity and fluoride concentration. Generally, enamel and dentin loss increases with increasing abrasivity (determined by the REA and RDA-value of the toothpaste)^{40,103}. Fluoridated toothpastes might not only reduce the erosive demineralization, but also reduce the abrasion of eroded tissues^{64,67}. Therefore, patients with erosive lesions should use fluoridated toothpastes with low abrasivity for their oral hygiene measures.

Preventive Strategies for Biological Factors

With regard to biological factors, the quality of dental tissues, properties of saliva, tooth position and anatomy of the soft tissues might affect the development of dental erosion. Severe erosive lesions affect not only the enamel surface, but also might lead to the exposure of coronal or radicular dentin and, thus, to painful hypersensitivity. Moreover, erosive tooth wear is not only found in permanent teeth, but also is increasingly reported in the primary dentition³⁹.

· Progression of Erosion In Different Tissues

The interaction between erosive agents and dental tissues is different for enamel and dentin, and for primary and permanent teeth. Basically, permanent enamel is composed

by mineral (85% volume), in the form of (hydroxy or fluor) apatite crystals organized in prisms. At a pH less than 4.5, the apatite crystals are easily dissolved by acids, generating a surface lesion (Figure 6) with concave clinical appearance (Figures 1 and 2). Permanent dentin contains inorganic-47% (apatite), organic-33% (collagen) components and water-20%. Studies have shown that demineralization of dentin is firstly apparent at the interface between inter- and peritubular dentin. With increasing exposure time, the erosive attack results in a hollowing and funneling of the tubules. Finally, the peritubular dentin is completely dissolved. Erosive demineralization results in exposure of an outer layer of fully demineralized organic matrix followed by a partly demineralized zone until the sound inner dentin is reached⁵⁰ (Figure 7). The dentin demineralization rate decreases when the amount of degradable collagen increases, whereby the demineralized matrix is attributed to hamper ionic diffusion into and out of the demineralizing area^{27,28}. On the other hand, the erosion time of enamel is linear over time²⁶.

In addition, primary enamel and dentin are thinner than permanent. Therefore, the erosive process reaches the dentin earlier and leads to an advanced lesion after a shorter exposure period to acids, compared to permanent teeth⁴. However, studies about the susceptibility of these teeth to erosive softening have revealed conflicting results. While several authors found an increased susceptibility to erosion in primary teeth, others found no difference between primary and permanent dental hard tissues^{4,44,56}.

· Measures to Increase the Quality and the Quantity of Saliva and Pellicle

Saliva seems to play an important role in minimizing enamel and dentin wear in erosive/abrasive attacks due to its buffering and remineralizing capacities as well as the ability to form a protective pellicle layer on dental hard tissues^{35,69}. Xerostomia or hyposalivation is a condition frequently observed in patients undergoing radiation therapy on the head and neck region, but is also common in patients suffering from diseases of the salivary glands (Sjögren syndrome) or can be induced by several systemic medications (Figure 4). In these patients, the decreased salivary flow rate is associated with a low pH of the saliva and a decreased buffering capacity⁷⁰. It has been shown that low salivary flow rate and low buffering capacity are strongly associated with dental erosion⁷⁵.

Salivary flow stimulation can yield an increase in bicarbonate buffer and in salivary mineral content, which can facilitate calcium and phosphate redeposition onto the enamel and dentin surface and reduction of dental tissue loss²⁴ (Figure 5). Rios, et al.⁸³ showed that saliva stimulated by the use of sugar-free chewing gum promoted a remineralizing action in the erosive/abrasive phenomena. In contrast, sucking of acidic candies might change the whole-mouth saliva composition so that it may have erosive potential⁴⁶.

This remineralizing effect might be increased by rinsing with milk or eating cheese, which are of interest as they contain higher levels of calcium and phosphate than water

or saliva and, therefore, may act as donor of calcium and phosphate for remineralization³³ (Figure 5). Although the consumption of milk or cheese is frequently recommended to enhance the rehardening of demineralized dental hard tissues, only few authors have yet investigated their effects on enamel demineralization³³.

Besides local saliva stimulators like chewing gum, the salivary flow rate can also be increased systemically. Thus, patients suffering from xerostomia are often treated by cholinergic drugs, such as pilocarpine. Moreover, saliva substitutes might provide relief of the oral symptoms. Saliva substitutes should be of neutral pH to prevent dental hard tissue demineralization and should be saturated with respect to calcium and phosphate to gain remineralizing potential⁷¹ (Figure 5).

Saliva is also responsible for the formation of the acquired pellicle, which is a physical barrier that protects the tooth against erosive attacks. It is composed of a protein layer formed on tooth surface, acting as a diffusion barrier or permeability membrane^{39,69}. This selective barrier prevents the direct contact between acids and the tooth surface, thus reducing the dissolution of hydroxyapatite. Protection of the tooth surface by the acquired pellicle is well established in the literature and has been demonstrated by several studies^{37,38}.

Pellicle thickness varies within the dental arches and among individuals³. An inverse relationship was observed between the degree of erosion and pellicle thickness. This relationship suggests that the thickness of the acquired salivary pellicle may be an important factor for site-specificity of dental erosion^{3,6}. Conflicting results have been published regarding the impact of the formation time on the protective properties of the pellicle layer³⁸. However, it is generally accepted that the function of the pellicle as a diffusion barrier to ionic conductivity on the enamel surface is improved with the process of pellicle maturation³⁷.

It is important to point out that the pellicle is not totally dissolved from the enamel surface, but rather gradually from its external to basal components. This fact suggests a partial acid resistance of the *in vivo* formed pellicle layers³⁷. As toothbrushing can remove parts of the salivary pellicle⁴⁷, patients at risk of dental erosion should diminish the frequency of toothbrushing and use dentifrice with low abrasiveness to avoid damaging of the acquired pellicle (Figure 5).

Preventive Strategies for Chemical Factors

The chemical factors relevant for the erosion capacity of an acid solution are the type and quantity of the acid, the pH, buffering capacity and temperature as well as the presence of chelating agents and the concentration of phosphate, calcium and fluoride^{58,94}. Fruit juices, soft drinks, vinegar and ice tea are known as highly erosive, as they are composed of acids (citric, phosphoric, acetic acids) with a pH lower than 4.5. Usually they are unsaturated regarding to apatite and present a high buffering capacity⁵⁹.

· Fluoride and Metal Fluoride Application

The impact of fluoride treatment on the progression of

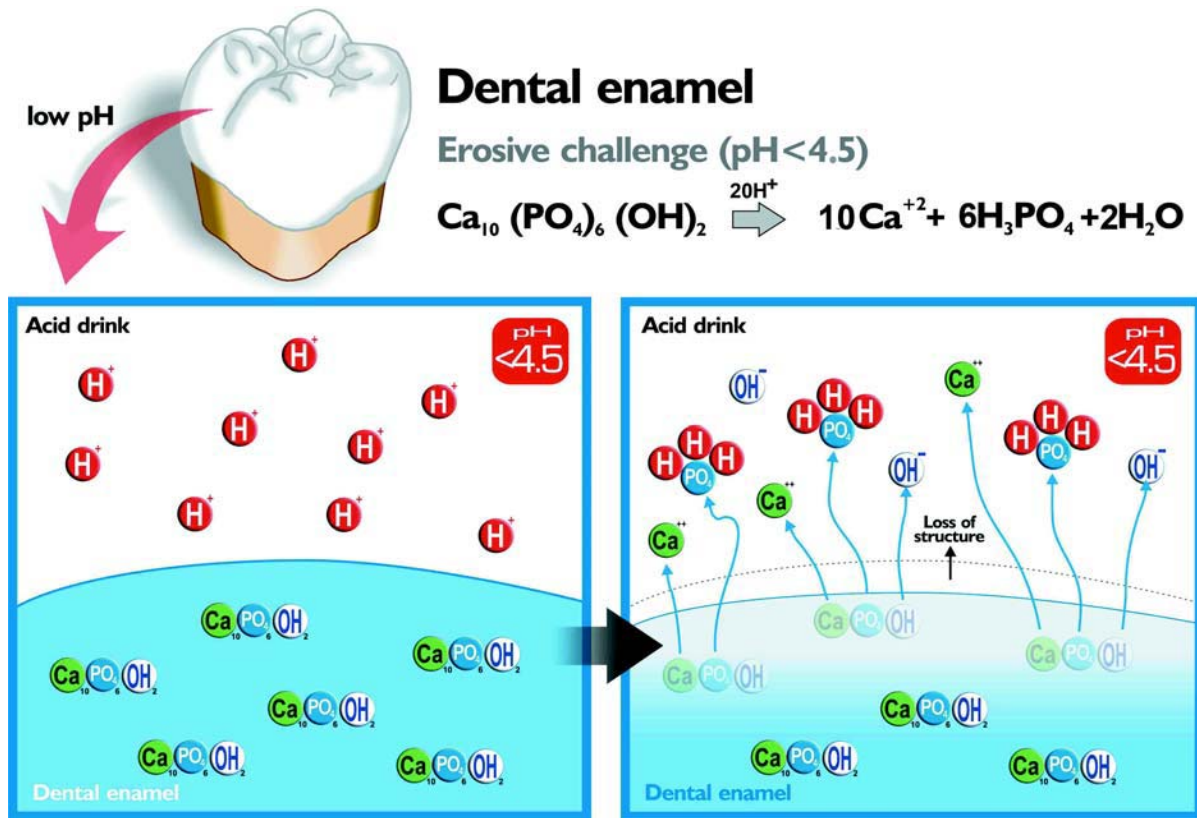


FIGURE 6- Erosive demineralization of dental enamel (pH < 4.5)

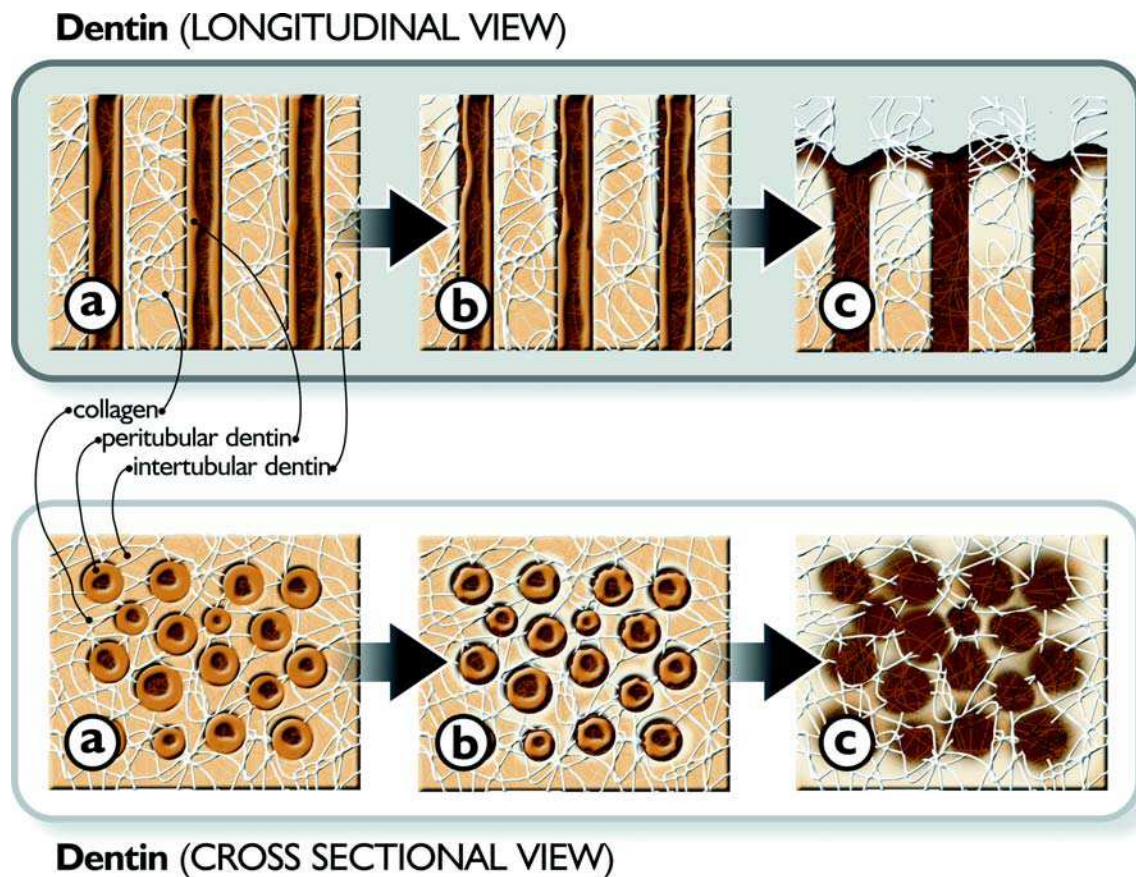


FIGURE 7- Erosive demineralization of dentin (longitudinal and cross-sectional view). a-c. Progression of the erosion process in dentin (a. sound dentin, b. initial demineralization, c. exposure of organic matrix)

enamel and dentin erosion has been analyzed in several studies. The action of fluoride is mainly attributed to a precipitation of CaF_2 -like material on eroded dental surfaces^{26,27}. The formation of the CaF_2 -like layer and its protective effect on demineralization depend on the pH, F concentration and type of F salt of the agent⁸⁶. However, the role of fluoride application on the prevention of dental erosion is still controversially discussed⁹⁵, since the deposited calcium fluoride-like material from topical fluoride application is supposed to be readily dissolved in most acidic drinks³⁰.

High-concentrated fluoride agents, such as oral rinses, gels or varnishes, have been demonstrated to increase abrasion resistance and decrease the development of enamel and dentin erosion *in vitro* and *in situ*^{26,51}. Most studies focusing on the preventive effect of fluoride on erosion used fluoride compounds that have been used over years in caries prevention, such as NaF, AmF, SnF_2 or acidulated phosphate fluoride (APF) (12,300 to 22,600 ppm F, pH 1.0 to 7.0). Although the results of a recent *in vitro* study³² suggest considerable differences between NaF, AmF and SnF_2 , the impact of different fluoride compounds on erosion has not yet been analyzed under clinical conditions. The efficacy of fluorides to affect de- and remineralization is related to its concentration and depends on the pH of the fluoride agent. It is known that the formation of a CaF_2 reservoir is increased under acidic compared to neutral conditions⁸⁸. Depending on the study design, the application of high-concentrated fluoride agents might lead to a nearly complete reduction of dental erosion.

In contrast to the application of highly fluoridated agents, a 1,000 ppm F dentifrice was shown to have a limited beneficial effect compared to non-fluoridated dentifrices on abrasion of eroded dentin and enamel^{64,78}. However, a recent *in situ* study showed that a 5,000 ppm F dentifrice had the same effect as a 1,100 ppm F dentifrice on eroded and eroded and abraded dentin⁶⁷. Also for enamel wear, no significant differences were found among 1,100 and 5,000 ppm F dentifrices⁸⁴. Overall, the efficacy of a fluoridated dentifrice is not increasing along with the F concentration in dentifrices containing more than 1,000 ppm F and the reduction of wear seems to be less than 30% for this fluoride vehicle compared to placebo^{67,84}.

More recently, other agents, such as tetrafluorides (TiF_4 , ZrF_4 , HfF_4 in a concentration between 0.4 to 10%, pH 1-2), especially titanium tetrafluoride, have been investigated for erosion prevention^{41,42,65,87,91,92,100,102}. With regard to TiF_4 solution, several *in vitro* studies have shown an inhibitory effect on dental erosion^{41,42,87}, which is attributed not only to the effect of fluoride, but also to the action of titanium. It is speculated that the titanium ions might play an important role as they might substitute calcium in the apatite lattice and show a strong tendency to complex with phosphate groups, forming a stable titanium dioxide layer^{72,81}. Moreover, it is suggested that titanium interacts with the enamel surface, thus leading to an increased fluoride uptake by enamel⁷². However, other studies have not found a protective effect of TiF_4 against erosion or combined erosion

and abrasion^{65,91,92}. Recently, an *in vitro* study comparing the efficacy of a 4% TiF_4 solution, an experimental 4% TiF_4 varnish and commercial NaF varnishes on the progression of enamel erosion was performed. The experimental TiF_4 varnish showed the best protective effect when compared to commercial NaF varnishes, while TiF_4 solution was not effective to reduce the enamel wear⁶². However, TiF_4 agents have a very acidic pH (pH 1-2), which does not allow for patient self-application.

Overall, the protective impact of high-concentrated fluoride applications on the progression of erosive lesions has been shown both *in vitro* and *in situ*, but clinical studies giving support for this observation are not yet available. It is interesting that the fluoridation effects might be more enhanced in dentin than in enamel²⁶. The buffering effect of the demineralized matrix reduces the pH drop within this layer. Together with the presence of high concentrations of fluoride, this might reduce further dentin demineralization²⁷. Also, metal fluorides might be more effective in dentin than in enamel^{87,102}, since it is assumed that the metals (titanium ion) might play an essential role because of its complex ability and protein-binding properties⁷². Based on the findings of *in vitro* and *in situ* studies, it seems valid to recommend high-concentrated fluoride applications for prevention of dental erosion (Figure 5). The application of high-concentrated agents has to be done by a dentist, taking care for the quantity and for avoiding that the patient swallows the product. If these cares are taken, even the frequent application of high-concentrated agents seems to be safe. However, clinical and epidemiological studies are required to confirm the promising results found *in vitro* and *in situ*.

· Modification of acid solutions and beverages

In the daily life situation, preventive strategies influencing biological and behavioral factors might be of limited impact as they are highly dependent on the patient's compliance. Thus, it seems to be of great interest to develop preventive strategies, which are less dependent on the patient's behavior.

One preventive strategy might be the reduction of the erosive potential of acidic beverages by ions supplementation (calcium, phosphate and fluoride). The addition of calcium has been shown to reduce the erosive potential of pure acids and acidic drinks, especially on enamel erosion^{14,15,43} (Figure 5).

Orange juice (pH 4.0) supplemented with 40 mmol/L calcium and 30 mmol/L phosphate did not erode the enamel as calcium and phosphate saturated the drink with respect to apatite⁵³. Attin, et al.⁹ showed that Ca supplementation of 0.5-1.5 mmol/L was effective in reducing the erosive potential of citric acid, while the addition of F and P failed to reduce the erosive capacity. Saturation with CaF_2 reduced the *in vitro* development of erosions by 28% induced by drinks with pH above 3; in drinks with pH below 3, erosions were not affected by fluoride concentrations up to 20 ppm⁵⁴.

Larsen and Nyvad⁵³ and Larsen and Richards⁵⁴ showed that fluoride admixtures in a concentration excluding

toxicological side effects seem unable to reduce erosive lesions. The supplementation of low levels of calcium, phosphate and fluoride was not effective in decreasing the erosive potential of solutions with a pH below 4.0 in the above-mentioned studies. Amaechi, et al.⁵ found that the supplementation of an orange juice with xylitol (25% w/v) and fluoride (0.5 ppm) had an additive effect on the reducing dental erosion *in vitro*. Xylitol might form complexes with calcium, penetrate into demineralized enamel and interfere with the transport of dissolved ions from the lesion to the demineralizing solution by lowering the diffusion coefficient of calcium and phosphate ions from the lesion into the solution^{7,68}.

Alternatively, acidic solutions can be supplemented with metal ions, such as iron, which seems to decrease the erosive potential of acidic solutions^{18,48}. Iron can participate in the remineralization of human enamel, in the nucleation of apatite, substitution of calcium in apatite and inhibition of demineralization¹². In addition, rinsing with an iron solution after an erosive attack can significantly reduce dentin wear by erosion or combined erosion-abrasion⁸⁵. It is important to highlight that studies analyzing the effect of iron supplementation to soft drinks or acid solutions, used high concentrations of iron, which might exhibit toxic effects^{18,48}. Buzalaf, et al.¹⁸ investigated the protective effect of crescent concentrations (0-120 mmol/L) of iron on dissolution of enamel by acetic acid and showed that the 15 mM Fe was able to reduce the enamel dissolution. Kato, et al.⁴⁸ showed that iron (10 mM Fe) can interfere with the dissolution of dental enamel powder in the presence of acidic beverages. This effect seems to be modulated by the type of acid. Interestingly, these authors found that higher concentrations of Fe were effective to inhibit dental erosion by a cola drink (Coke, phosphoric acid), but not by a drink containing citric acid (Sprite). On the other hand, the admixture of low concentrations of Fe (1 mM) into a soft drink (Sprite Zero) was not able to reduce the enamel loss⁶³. In addition, the supplementation of iron may lead to a metallic taste of the soft drink and might affect tooth color and the taste of other foods.

Due to the possibility of a synergistic effect among different ions, it could be speculated that it might be possible to increase their beneficial effects with much lower doses by using the adequate combination of these ions^{9,11}. Attin, et al.¹¹ showed that the combination of low levels of Ca (0.5 mM), P (0.5 mM) and F (0.037 mM) is able to reduce enamel loss. These authors revealed that the mixture of Ca alone or in combination with P and F was effective to reduce the dental loss by Sprite, but not by Coke. On the other hand, the admixture 1 mM Ca, 1 mM Fe, 1 mM P and 0.047 mM F to a soft drink (Sprite Zero) was not effective to decrease the erosive potential⁶³.

The erosive potential of soft drinks and acidic beverages can be also decreased by replacing highly erosive acids by acids with lower erosive capacity. Citric acid is for instance known to exhibit a greater erosive capacity than hydrochloric and phosphoric acids^{36,94,104}. The greater erosive potential of citric acid might be related to its ability to form chelating

complexes with calcium. Moreover, differences in their specific interaction with hydroxyapatite might influence the erosive potential of different mono-, di- and tri-carboxylic acids¹⁰⁴.

To summarize the above mentioned-studies critically, the efficacy of ion supplementation depends not only on the mineral content, but also on various factors, such as acid type, pH, amount of titratable acid and buffering capacity of the acid solution^{53,58}. Therefore, further research taking into account these factors is required, with special emphasis on the consequences of taste alterations, stability of the solution and systemic effects for the patients. Studies evaluating the effects of soft drink modification on dentin erosion should also be performed.

Further Studies

· Calcium Application

Studies involving dental caries suggest that increased salivary and plaque calcium concentrations might enhance fluoride uptake and retention and, thus, increase the action of fluoride in the de- and remineralization process. In order to increase the saliva or plaque calcium content, several calcium compounds in form of rinses, dentifrices or chewing gums have been investigated^{20,61,76,93}. Regarding dental erosion, it is reasonable to increase the salivary calcium concentration, which might enhance fluoride deposition on the dental tissues by formation of a CaF₂-like reservoir.

There are currently only few studies about the effect of calcium-rich toothpastes on dental erosion. Lennon, et al.⁵⁵ analyzed the effect of a casein/calcium phosphate-containing tooth cream (Topacal) on enamel erosion *in vitro*. Topacal or a combination of Topacal and a 250 ppm fluoride solution provided only little protection against erosion and were significantly less effective than a highly fluoridated amine fluoride gel. In contrast, Rees, et al.⁷⁹ and Piekarz, et al.⁷⁷ found that Tooth Mousse (CPP-ACP: Casein phosphopeptide - amorphous calcium phosphate) significantly reduced enamel erosion *in vitro*. Due to the lack of available data, final conclusions about the efficacy of calcium-rich products on dental erosion can not be drawn so far. Further studies must be performed testing the preventive effect of calcium solutions and calcium-rich dentifrices on enamel and dentin erosion.

· Laser Application

The protective effects of laser application on enamel and dentin demineralization have gained increasing attention in the last years. Several types of lasers, such as ruby, CO₂, Nd:YAG and argon, with different operative modes and energy outputs have been investigated. The laser treatment causes several chemical changes on tooth surface, including the reduction of the carbonate content and the exchange of hydroxyapatite to fluorapatite when applied with fluoride vehicles⁷⁴. In addition, laser application melts and solidifies the dental surface, creating a smoother new surface^{52,74}. The melted enamel surface can show a crystal growth that can reduce the interprismatic spaces and consequently, the

diffusion of acids during an acid challenge²². All these chemical and morphological changes of the dental surface might lead to a decreased susceptibility to erosive demineralization.

However, there are few studies available testing the effect of the laser application on the prevention of erosive demineralization and most of them are related to carious and not erosive demineralization. Tsai, et al.⁹⁰ compared the effectiveness of laser treatment (pulsed CO₂ and pulsed Nd:YAG – 83.33 J/cm²) on the acid resistance of human enamel *in vitro*. The Nd:YAG laser was not able to increase the enamel resistance to an acid challenge (lactate buffer solution, pH 4.5, 24 and 72 h). In contrast, the application of Nd:YAG laser (0.5, 0.75 and 1 W) combined or not to fluoride application (fluoride gel and varnish) significantly reduced the enamel erosive wear in a 5-day-*in vitro* study¹⁹. Additionally, when the erosive challenge was extended to 10 days, the combined application of Nd:YAG laser and fluoridated gel was still effective on the reduction of the enamel wear, which could be attributed to the low pH of the fluoride agent¹⁹.

Regarding dentin, Naylor, et al.⁷³ showed that irradiation with Nd:YAG laser produces obliteration of dentinal tubules as well as a melting and resolidification, with the formation of recrystallization granules. The authors suggested that dentin irradiated with 0.6 W Nd:YAG laser presented a higher resistance to acidic beverages such as cola soft drink and passion fruit juice. On the other hand, Magalhães, et al.⁶⁶ showed that the application of Nd:YAG laser (0.5, 0.75 and 1 W) was unable to reduce the dentin erosive wear.

Due to the few data available so far, final conclusions about the efficacy of laser application on dental erosion cannot be drawn as yet. Further studies are necessary to clarify this topic.

· MMPs (matrix metalloproteinases) inhibitors agents

Matrix metalloproteinases (MMPs) are responsible for hydrolyzing the components of the extracellular matrix (ECM) during the remodeling and degradation processes in the oral environment. Thus, the organic matrix of dentin (collagen) can be degraded by MMPs present in dentin and saliva. The balance between activated MMPs and tissue inhibitors of metalloproteinases (TIMPs) controls the extent of ECM remodeling/degradation⁸⁰. The activation of MMPs seems to play a role in dentinal caries progression, since they have a crucial role in the collagen breakdown in caries lesions. Individuals with a high concentration of MMPs in saliva present an increased susceptibility to dental caries²³. MMPs implicated in collagen degradation in dentin are MMPs 2, 8, and 9⁸⁹. In addition, the phosphorylated proteins released during the dentin matrix demineralization could interact with TIMP-inhibited host MMPs within the lesion and reactivate them, thus enhancing the degrading activity. Despite the lack in studies investigating the role of MMPs in dental erosion, processes similar to the caries process can be assumed for erosive lesions.

Tjäderhane, et al.⁸⁹ found that the latent forms of MMP 2 and MMP 9 can be activated in acidic conditions followed

by neutralization, as it occurs during the carious process when the pH in dental plaque drops within minutes after sugar ingestion until neutralized by salivary buffers. The exposed demineralized dentin matrix is assumed to hamper ionic diffusion into and out of the demineralizing area. Therefore, a destruction of the collagen layer by host dentin MMPs is expected to increase the progression of dental caries in human teeth⁸⁹.

Due to the involvement of host MMPs to the progression of dental caries in human teeth, it might be interesting to find MMP inhibitors for patients with high risk for caries but also for erosion¹³. Green tea polyphenols, especially epigallocatechin gallate (EGCG), were found to have distinct inhibitory activities against MMPs²³. A recent study about the preventive effect of green tea on dentin wear has shown that the rinse with green tea reduced dentin erosion and abrasion *in situ*⁴⁹.

Other potential MMP inhibitors are chlorhexidine (CHX), an antibacterial agent, which was found to inhibit the activity of MMPs 2, 8 and 9³⁴, as well as natural products such as avocado, soya bean and oleic acid²³. CHX presents beneficial effects on the preservation of dentin bond strength *in vivo*, as an MMP inhibitor²¹, when applied between the acid attack and the bonding procedures. However, the mechanisms of action of these agents and their impact on dental erosion have not been investigated yet. Therefore, this topic might be of interest in further research on the prevention of dental erosion.

CONCLUSION

From the available data of *in vitro* and *in situ* studies, preventive strategies for patients suffering from erosion include dietary advice, stimulation of salivary flow, optimization of fluoride regimens, modification of erosive beverages and adequate oral hygiene measures. However, clinical trials are required to confirm the relevance of these measures. As erosive tooth wear cannot be prevented totally with the recommended strategies, further research is necessary to develop new measures with higher protective capabilities and good clinical acceptance.

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