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## **INSIGHTS INTO PREVENTIVE MEASURES FOR DENTAL EROSION**

CONCEITOS ATUAIS SOBRE ESTRATÉGIAS PREVENTIVAS PARA EROÇÃO DENTÁRIA

### **Ana Carolina MAGALHÃES**

DDS, MS, PhD, Department of Biological Sciences, University of São Paulo, School of Dentistry at Bauru, São Paulo, Brazil.

### **Annette WIEGAND**

Dr Med Dent, Clinic for Preventive Dentistry, Periodontology and Cariology, University of Zurich, Switzerland

### **Daniela RIOS**

DDS, MS, PhD, Department of Biological Sciences, University of São Paulo, School of Dentistry at Bauru, São Paulo, Brazil.

### **Heitor Marques HONÓRIO**

DDS, MS, PhD, Associate Professor, Department of Pediatric Dentistry, Alfenas Federal University, Alfenas, Minas Gerais, Brazil

### **Marília Afonso Rabelo BUZALAF**

DDS, MS, PhD, Department of Biological Sciences, University of São Paulo, School of Dentistry at Bauru, São Paulo, Brazil.

## INSIGHTS INTO PREVENTIVE MEASURES FOR DENTAL EROSION

### CONCEITOS ATUAIS SOBRE ESTRATÉGIAS PREVENTIVAS PARA EROSÃO DENTÁRIA

#### **Abstract**

*Introduction:* 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. *Objective:* Based on an overview of the current literature the paper presents a summary of the preventive strategies relevant for patients suffering from dental erosion. *Review of Literature:* 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 demineralisation. Therefore, the production of saliva should be enhanced, especially in patient with hyposalivation or xerostomia. With regard to chemical factors, the modification of acidic solutions with ions, especially calcium, was shown to reduce the demineralisation, but the efficacy depends on the other chemical factors, such as the type of acid. To enhance the remineralisation of eroded surfaces and to prevent further progression of dental wear, high-concentrated fluoride applications are recommended. Currently, little information about the efficacy of other preventive strategies, such as calcium and laser application, as well as use of inhibitors for matrix metalloproteinases, is available. Further studies considering these factors are required. *Conclusion:* Preventive strategies for patients suffering from erosion are mainly obtained from in vitro and in situ studies and include dietary advice, stimulation of salivary flow, optimization of fluoride regimens, modification of erosive beverages and adequate oral hygiene measures.

**Uniterms:** Dental erosion; Prevention; Tooth wear

#### **1. Introduction**

The term tooth wear is defined as loss of dental hard tissues due to the processes of dental erosion, attrition and abrasion<sup>57</sup>. Dental attrition is the wear of tooth resulting from tooth to tooth contact<sup>57</sup>, while abrasion is caused by oral habits or abrasive substances, such as highly abrasive toothpastes<sup>57</sup>. Dental erosion is defined as the loss of tooth substance by chemical processes (acid exposure) not involving bacteria<sup>60</sup>. The acidic attack leads to an

irreversible loss of dental hard tissue, which is accompanied by a progressive softening of the surface<sup>60</sup>. This softened zone is more susceptible to mechanical forces, such as abrasion<sup>82</sup>, which in turn have little or no effect on sound dental hard tissues<sup>1</sup>. The chemical and mechanical processes can occur individually or together, although the effect of erosion is often dominant<sup>2</sup>.

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 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 shape<sup>29</sup>.

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 drinks<sup>59</sup> and those originated from the stomach, like gastric acids from regurgitation and reflux disorders<sup>16</sup>. Currently, the increased consumption of acidic foods and soft drinks is becoming an important factor for the development of erosive wear<sup>60</sup>.

As erosive tooth wear is a multifactorial condition (TABLE 1), preventive strategies has to be applied which account for chemical, biological and behavioral factors involved in the etiology and pathogenesis of erosion<sup>60</sup> (FIGURE 3). However, the informations about the all possible preventive measures for erosion including those already known and the new ones are missing. Thus, 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.

## **2. Review of Literature and Discussion**

### **2.1 Preventive strategies for behavioral factors**

The behavioral factors have a decisive influence on the appearance and the progression of dental erosion<sup>106</sup>. 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 influences, such as toothbrushing, are known to remove the fragile surface of demineralised dental hard tissues. Thus, the time point of toothbrushing after an erosive attack<sup>8,10</sup> as well as the kind of toothbrush and toothpaste used might influence the progression of dental wear<sup>40</sup>.

### *2.1.1 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<sup>25,94</sup>. 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 properties<sup>45</sup>.

Extrinsic acid sources of erosion are mainly dietary acids, but also lifestyle factors (e.g. drugs) or occupational acid exposure (TABLE 1). 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 reharder 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 teeth<sup>17</sup>. Therefore, it seems advisable to avoid these drinking habits to reduce the duration of the erosive attack (TABLE 2). Besides 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 erosion<sup>106</sup> (TABLE 1). 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 an 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 (TABLE 1). Thereby, 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 erosion<sup>96</sup>.

The intrinsic aetiology factors of erosion include disorders which are associated with the occurrence of gastric acid in the oral cavity, such as vomiting or gastroesophageal reflux (TABLE 1). Therefore, erosive tooth wear is a common manifestation in patients suffering from organic or psychosomatic disorders such as 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 (TABLE 2).

### 2.1.2 Measures to reduce the mechanical impact

~~Eroded dental hard tissues are characterized by a partly demineralised, softened surface layer, which is susceptible to mechanical wear<sup>85,109</sup>. From in vitro<sup>91</sup> and in situ studies<sup>31,98</sup> 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 the surrounding soft tissues in the clinical situation.~~

Attin et al.<sup>8,10</sup> showed that the resistance of eroded enamel and dentin to toothbrushing abrasion was significantly decreased after erosion, but was enhanced with increasing remineralisation time. However, even after a remineralization period of 60 min the wear of enamel samples was significantly increased as compared to the demineralized, but not brushed control<sup>8</sup>. In contrast, dentin wear was not significantly higher than in unbrushed controls after intra-oral periods of 30 and 60 min<sup>10</sup>. 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 (TABLE 2).

Besides the time point of toothbrushing, abrasion of eroded enamel and dentin is dependent on the kind of toothbrush, the applied brushing force and several toothpaste factors<sup>40,97,99,101,103,105</sup>.

In previous studies it was 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 demineralised enamel and dentin<sup>97,99,101</sup>. On the basis of the observation that enamel and dentin wear increased with increasing toothbrushing force<sup>99</sup>, patients with erosive lesions should apply their toothbrushes with slight pressure to minimize loss of dental hard tissues (TABLE 2).

The hardness of the toothbrush seems to be of minor importance for the abrasion of eroded dental hard tissues. Wiegand et al.<sup>103</sup> 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 used<sup>103</sup>. The abrasivity of the toothpaste is determined by the size and amount of abrasives, the pH, buffering capacity and fluoride concentration. Generally, the enamel and dentin loss increase with increasing abrasivity (determined by the REA and RDA-value of the toothpaste)<sup>40,103</sup>. Fluoridated toothpastes might not only reduce the erosive demineralisation, but might also

reduce the abrasion of eroded tissues<sup>64,67</sup>. Therefore, patients with erosive lesions should use fluoridated toothpastes with low abrasivity for their oral hygiene measures.

## **2.2 Preventive strategies for biological factors**

With regard to the biological factors, the quality of dental tissues, the properties of saliva, the tooth position and the anatomy of the soft tissues might affect the development of dental erosion. Severe erosive lesions affect not only the enamel surface but might also 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 dentition<sup>39</sup>.

### *2.2.1 Progression of erosion in different tissues*

The interaction between erosive agents and dental tissues is different for enamel and dentin, and for deciduous 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 4) 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 demineralisation 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. The erosive demineralisation results in the exposure of an outer layer of fully demineralised organic matrix followed by a partly demineralised zone until the sound inner dentin is reached<sup>50</sup> (FIGURE 5). The dentin demineralisation rate decreases when the amount of degradable collagen increases, whereby the demineralised matrix is attributed to hamper ionic diffusion into and out of the demineralising area<sup>27, 28</sup>. On the other hand, the erosion time of enamel is linear over time<sup>26</sup>.

In addition, deciduous 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 with permanent teeth<sup>4</sup>. 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 deciduous teeth, others found no difference between deciduous and permanent dental hard tissues<sup>4,44,56</sup>.

### *2.2.2 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 remineralising capacities as well as the ability to form a protective pellicle layer on dental hard tissues<sup>35,69</sup>. Xerostomia or hyposalivation is a condition frequently observed in patients undergoing a radiation treatment of the head and neck, but is also common in patients suffering from diseases of the salivary glands (Sjögren syndrome) or can be induced by several systemic medications (TABLE 1). In these patients, the decreased salivary flow rate is associated with a low pH of the saliva and a decreased buffering capacity<sup>70</sup>. It has been shown that low salivary flow rate and low buffering capacity are strongly associated with dental erosion<sup>75</sup>.

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 tissues loss<sup>24</sup> (TABLE 2). Rios et al.<sup>83</sup> showed that saliva stimulated by the use of sugar-free chewing gum promoted a remineralising 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 potential<sup>46</sup>.

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 remineralisation<sup>33</sup> (TABLE 2). Although the consumption of milk or cheese is frequently recommended to enhance the rehardening of demineralised dental hard tissues, only few investigated their effects on enamel demineralisation as yet<sup>33</sup>.

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 demineralisation of the dental hard tissues and should be saturated with respect to calcium and phosphate to gain remineralising potential<sup>71</sup> (TABLE 2).

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 the tooth surface, acting as a diffusion barrier or permeability membrane<sup>39,69</sup>. 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<sup>37,38</sup>.

Pellicle thickness varies within the dental arches and among individuals<sup>3</sup>. 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<sup>3,6</sup>. Conflicting results have been published



regarding the impact of the formation time on the protective properties of the pellicle layer<sup>38</sup>. 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 maturation<sup>37</sup>.

It is important to point out that the pellicle is not dissolved in total 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 layers<sup>37</sup>. As toothbrushing can remove parts of the salivary pellicle<sup>47</sup>, patients at risk of dental erosion should diminish the frequency of toothbrushing and use dentifrice with low abrasivity to avoid damaging of the acquired pellicle (TABLE 2).

### **2.3 Preventive strategies for chemical factors**

The chemical factors relevant for the erosivity 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<sup>58,94</sup>. 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 buffer capacity<sup>59</sup>.

#### *2.3.1 Fluoride and metal fluoride application*

The impact of fluoride treatment on the progression of enamel and dentin erosion has been analyzed in several studies. The action of fluoride is mainly attributed to a precipitation of CaF<sub>2</sub>-like material on eroded dental surfaces<sup>26,27</sup>. The formation of the CaF<sub>2</sub>-like layer and its protective effect on demineralisation depend on the pH, F concentration and type of F salt of the agent<sup>86</sup>. However, the role of fluoride application on the prevention of dental erosion is still controversially discussed<sup>95</sup>, since the deposited calcium fluoride-like material from topical fluoride application is supposed to be readily dissolved in most acidic drinks<sup>30</sup>.

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*<sup>26,51</sup>. Most studies focusing on the preventive effect of fluoride on erosion used fluoride compounds which have been used over years in caries prevention, such as NaF, AmF, SnF<sub>2</sub> or acidulated phosphate fluoride (APF) (12.300 to 22.600 ppm F, pH 1.0 to 7.0). Although the results of an *in vitro* study by Ganss et al.<sup>32</sup> suggest considerable differences between NaF, AmF and SnF<sub>2</sub>, the impact of different fluoride compounds on erosion was not analysed under clinical conditions as yet. The efficacy of fluorides to affect de- and remineralisation is related to its concentration and depends on the pH of the fluoride agent. It is known that the formation of a CaF<sub>2</sub> reservoir is increased under acidic compared to neutral conditions<sup>88</sup>. Depending on the design of the

study, 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<sup>64,78</sup>. However, in a recent *in situ* study, it was shown that a 5,000 ppm F dentifrice had the same effect as a 1,100 ppm F dentifrice on eroded and eroded and abraded dentin<sup>67</sup>. Also for enamel wear, no significant differences were found among 1,100 and 5,000 ppm F dentifrices<sup>84</sup>. 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<sup>67,84</sup>.

More recently, other agents, such as tetrafluorides (TiF<sub>4</sub>, ZrF<sub>4</sub>, HfF<sub>4</sub> in a concentration between 0.4 to 10%, pH 1-2), especially titanium tetrafluoride, have been investigated for erosion prevention<sup>41,42,65,87,91,92,100,102</sup>. With regard to TiF<sub>4</sub> solution, several *in vitro* studies have shown an inhibitory effect on dental erosion<sup>41,42,87</sup>, 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<sup>72,81</sup>. Moreover, it is suggested that titanium interacts with the enamel surface, thus leading to an increased fluoride uptake by enamel<sup>72</sup>. However, other studies have not found a protective effect of TiF<sub>4</sub> against erosion or combined erosion and abrasion<sup>65,91,92</sup>. Recently, an *in vitro* study comparing the efficacy of a 4 % TiF<sub>4</sub> solution, an experimental 4 % TiF<sub>4</sub> varnish and commercial NaF varnishes on the progression of enamel erosion was performed. The experimental TiF<sub>4</sub> varnish showed the best protective effect when compared to commercial NaF varnishes, while TiF<sub>4</sub> solution was not effective to reduce the enamel wear<sup>62</sup>. However, TiF<sub>4</sub> agents have a very acidic pH (pH 1-2), which do not allow for self-application of the patient.

Overall, the protective impact of high-concentrated fluoride applications on the progression of erosive lesions has been shown both *in vitro* and *in situ* studies, but clinical studies giving support for this observation are not available yet. It is interesting that the fluoridation effects might be more enhanced in dentin than in enamel<sup>26</sup>. The buffering effect of the demineralised matrix reduces the pH fall within this layer. Combined with the presence of high concentrations of fluoride, this might reduce further dentin demineralisation<sup>27</sup>. Also, metal fluorides might be more effective in dentin than in enamel<sup>87,102</sup>, since it is assumed that the metals (titanium ion) might play an essential role because of its complexing ability and protein-binding properties<sup>72</sup>. 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

(TABLE 2). The application of high-concentrated agents has to be done by 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.

### 2.3.2 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<sup>14,15,43</sup> (TABLE 2).

Orange juice (pH 4.0) supplemented with 40 mmol/l calcium and 30 mmol/l phosphate did not erode the enamel as the calcium and phosphate saturated the drink with respect to apatite<sup>53</sup>. Attin et al.<sup>9</sup> 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 erosivity. Saturation with CaF<sub>2</sub> 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 ppm<sup>54</sup>.

Larsen and Nyvad<sup>53</sup> and Larsen and Richards<sup>54</sup> 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.<sup>5</sup> 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 demineralised enamel and interfere with the transport of dissolved ions from the lesion to the demineralising solution by lowering the diffusion coefficient of calcium and phosphate ions from the lesion into the solution<sup>7,68</sup>.

Alternatively, acidic solutions can be supplemented with metal ions, such as iron, which seems to decrease the erosive potential of acidic solutions<sup>18,48</sup>. Iron can participate in the remineralisation of human enamel, in the nucleation of apatite, in the substitution of calcium in apatite and in inhibition of demineralisation<sup>12</sup>. In addition, rinsing with an iron solution after an erosive attack can significantly reduce dentin wear by erosion or combined erosion-abrasion<sup>85</sup>. 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<sup>18,48</sup>. Buzalaf et al.<sup>18</sup> 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.<sup>48</sup> 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 (1mM) into a soft drink (sprite zero) were not able to reduce the enamel loss<sup>63</sup>. Besides, the supplementation of iron may lead to a metallic taste of the soft drink and might affect the 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 benefic effects with much lower doses by using the adequate combination of these ions<sup>9,11</sup>. Attin et al.<sup>11</sup> 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. They 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, 1mM Fe, 1 mM P and 0.047 mM F to a soft drink (sprite zero) was not effective to decrease the erosive potential<sup>63</sup>.

The erosive potential of soft drinks and acidic beverages can be also decreased by replacing highly erosive acids by acids with lower erosivity. Citric acid is for instance known to exhibit a greater erosivity than hydrochloric and phosphoric acids<sup>36,94,104</sup>. 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 acids<sup>104</sup>.

To summarize the above mentioned-studies critically, the efficacy of the ions supplementation depends not only on the mineral content, but on various factors, such as acid type, pH, amount of titratable acid and buffering capacity of the acid solution<sup>53,58</sup>. Thus, more studies taking into account these factors have to be performed, with special emphasis on the consequences of the modification regarding taste, stability of the solution and systemic effects for the patients. Additionally, studies evaluating the effects of soft drink modification on dentin erosion have to be performed.

## **2.4 Further studies**

### **2.4.1 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 demineralisation and remineralisation process. For increasing the saliva or plaque calcium content, several calcium compounds in form of rinses, dentifrices or chewing gums have been investigated<sup>20,61,76,93</sup>.

Regarding dental erosion, it might be reasonable to increase of the salivary concentration of calcium, which might enhance the deposition of fluoride on the dental tissues by formation of a CaF<sub>2</sub>-like reservoir.

Nowadays, there are only few studies about the effect of calcium-rich toothpastes on dental erosion. Lennon et al.<sup>55</sup> analyzed the effect of a casein/calcium phosphate-containing tooth cream (Topacal) on enamel erosion *in vitro*. Thereby, 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.<sup>79</sup> and Piekarczyk et al.<sup>77</sup> found that Tooth Mousse (CPP-ACP: Casein phosphopeptide - amorphous calcium phosphate) significantly reduced enamel erosion *in vitro*. Due to the few data, available 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.

#### 2.4.2 Laser application

The protective effects of laser application on enamel and dentin demineralisation have gained increasing attention in the last years. Several types of lasers, such as ruby, CO<sub>2</sub>, Nd:YAG and argon with different operative modes and energy outputs have been investigated. The laser treatment causes several chemical changes on the tooth surface, such as the reduction of the carbonate content and the exchange of hydroxyapatite to fluorapatite when applied with fluoride vehicles<sup>74</sup>. Besides, it melts and solidifies the dental surface, creating a smoother new surface<sup>52,74</sup>. The melted enamel surface can show a crystal growth that can reduce the interprismatic spaces and consequently, the diffusion of acids during an acid challenge<sup>22</sup>. All these chemical and morphological changes of the dental surface might lead to a decreased susceptibility to erosive demineralisation.

However, there are few studies available testing the effect of the laser application on the prevention of erosive demineralisation and most of them are related to carious and not erosive demineralisation. Tsai et al.<sup>90</sup> compared the effectiveness of laser treatment (pulsed CO<sub>2</sub> and pulsed Nd:YAG – 83.33 J/cm<sup>2</sup>) 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 study<sup>19</sup>. 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 agent<sup>19</sup>.

Regarding dentin, Naylor et al.<sup>73</sup> 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.<sup>66</sup> 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.

#### *2.4.3 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/degradation<sup>80</sup>. The activation of MMPs seems to play a part 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 caries<sup>23</sup>. MMPs related to the degradation of collagen present in dentin are MMPs 2, 8, and 9<sup>89</sup>. Besides, the phosphorylated proteins released during the dentin matrix demineralisation could interact with TIMP-inhibited host MMPs within the lesion and reactivate them, thus enhancing the degrading activity. Despite a 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.<sup>89</sup> 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 demineralised dentin matrix is assumed to hamper ionic diffusion into and out of the demineralising area. Therefore, a destruction of the collagen layer by host MMPs of dentin is expected to increase the progression of dental caries in human teeth<sup>89</sup>.

Due to the connection 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 erosion<sup>13</sup>. Green tea polyphenols, especially epigallocatechin gallate (EGCG), were found to have distinct inhibitory activities against MMPs<sup>23</sup>. Recently, one study about the

preventive effect of green tea on dentin wear was performed, showing that the rinse with green tea reduced dentin erosion and abrasion *in situ*<sup>49</sup>.

Other potential MMP inhibitors are chlorhexidine (CHX), an antibacterial agent, which was found to inhibit the activity of MMPs 2, 8 and 9<sup>34</sup>, as well as natural products such as avocado, soya bean and oleic acid<sup>23</sup>. CHX presents beneficial effects on the preservation of dentin bond strength *in vivo*, as an MMP inhibitor<sup>21</sup>, when applied between the acid attack and the bonding. 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 researches for the prevention of dental erosion.

### 3 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 can not 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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## Legends

Figure 1 - Clinical appearance of tooth wear in enamel: Enamel erosion in a 36 year old female patient caused by the frequent consumption of Coke. Erosion can be distinguished from a wedge-shaped defect, which shows a sharp margin of the coronal part.

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

Figure 3 - Diagram proposed by Lussi (2006) modified.

Figure 4 – The erosive demineralisation of dental enamel ( $\text{pH} < 4.5$ ).

Figure 5 – The erosive demineralisation of dentin (longitudinal and cross sectional view).



**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



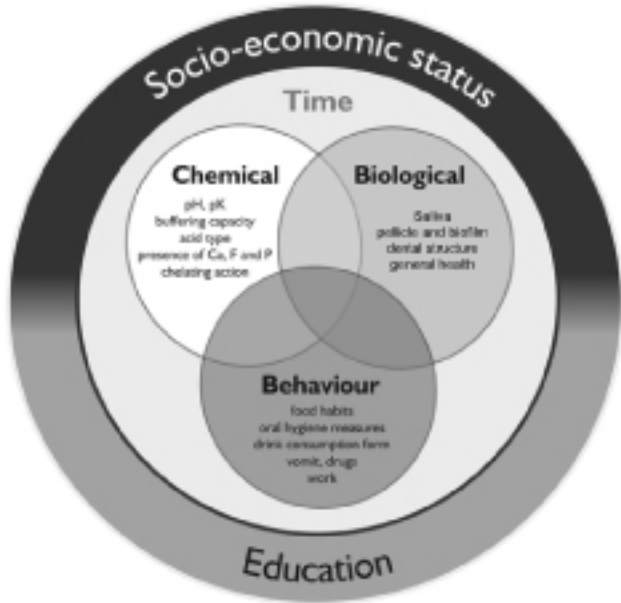
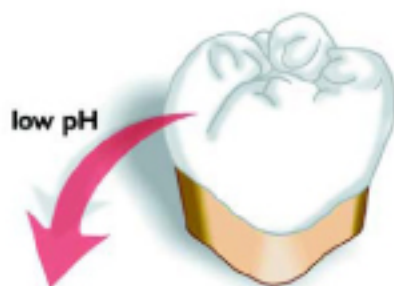


FIGURE 3- Diagram proposed by Lussi (2006), modified



## Dental enamel

Erosive challenge (pH < 4.5)

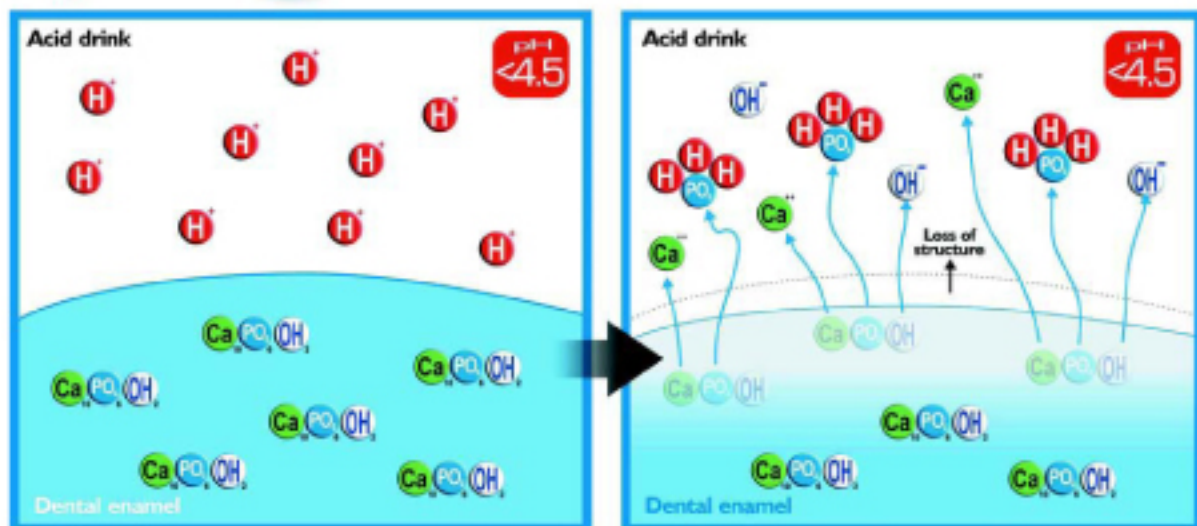
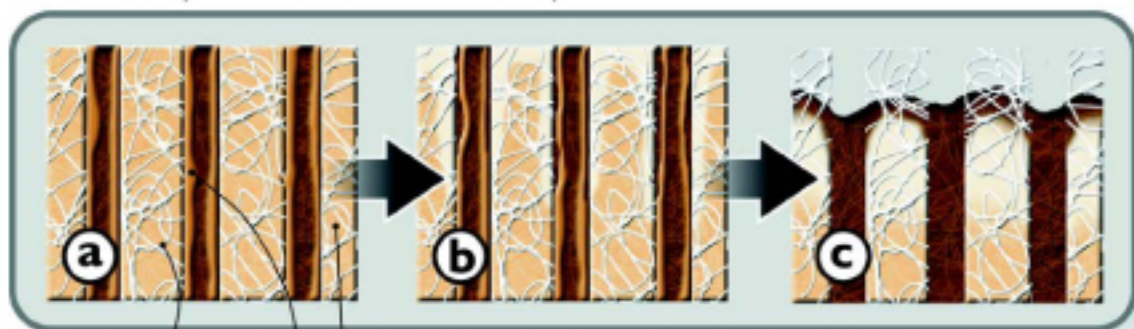
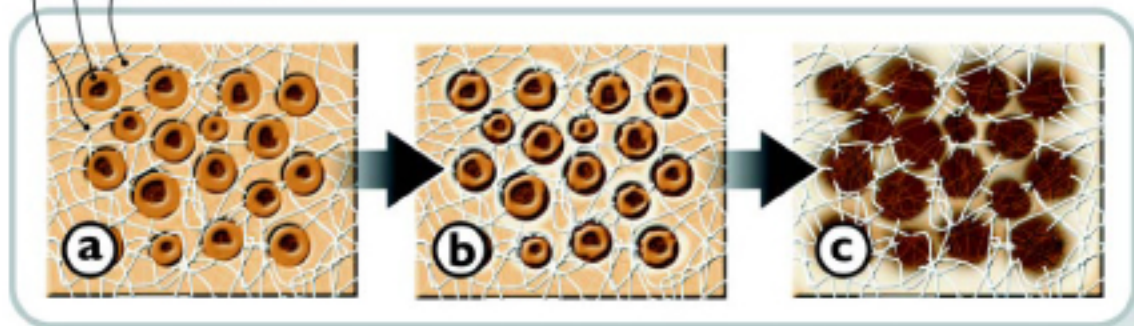


FIGURE 6- Erosive demineralization of dental enamel (pH < 4.5)

## Dentin (LONGITUDINAL VIEW)



collagen  
peritubular dentin  
intertubular dentin



## Dentin (CROSS SECTIONAL VIEW)

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)

**Table 1.** Anamnestic factors indicating an increased risk for dental erosion

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

**Table 2.** Preventive measures for patients with increased risk for erosion

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