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Buonocore Memorial Lecture

Dental Erosion

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SUMMARY

There is some evidence that dental erosion is steadily spreading. To diagnose erosion, dental professionals have to rely on clinical appearance, as there is no device available to detect it. Adequate preventive measures can only be initiated if the different risk factors and potential interactions between them are known. When substance loss, caused by erosive tooth wear, reaches a certain degree, oral rehabilitation becomes necessary. Prior to the most recent decade, the severely eroded dentition could only be rehabilitated by the provision of extensive crown and bridgework or removable dentures. As a result of the improvements in composite restorative materials and in adhesive techniques, it has become possible to rehabilitate eroded dentitions in a less invasive manner.

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INTRODUCTION

Erosive tooth wear is becoming an increasingly important factor when considering the long-term health of the dentition. There is some evidence that the occurrence of this condition is steadily increasing. Dental erosion is a multifactorial condition: The interplay of chemical, biological and behavioral factors is crucial and helps to explain why some individuals exhibit more erosion than others. The erosive potential of erosive agents, including acidic drinks or foodstuffs, depends on chemical factors (for example, pH, mineral content and on its calcium-chelation properties). Biological factors, such as saliva, acquired pellicle, tooth structure and positioning in relation to soft tissues and tongue, are related to the pathogenesis of dental erosion. Furthermore, behavioral factors, including eating and drinking habits, regular exercise with dehydration and a decrease in salivary flow, excessive oral hygiene and an unhealthy lifestyle (chronic alcoholism), are predisposing factors for dental erosion.

It is important to diagnose early the tooth wear process in children and adults. Dental professionals have to rely on clinical appearance to diagnose erosion.

This is of particular importance in the early stages of erosive tooth wear. Adequate preventive (and restorative) measures can only be initiated if the different risk factors and potential interactions between them are known. Subsequently, an individually tailored preventive program can be suggested.

PREVALENCE

National dental surveys are not routinely undertaken and, when they are conducted, they seldom include assessments of tooth wear, specifically erosion. Erosion was first included in the UK childrens' dental health survey in 1993 and is now repeated periodically. The prevalence of erosion was seen to have increased from the time of the children's dental health survey in 1993 to the study of 4- to 18-year olds in 1996/97.[1] There was a trend towards a higher prevalence of erosion in children between the ages of 3.5 and 4.5 years and in those who consumed carbonated drinks on most days, compared with toddlers who consumed these drinks less often.

Jaeggi and others[2] assessed a sample of 417 Swiss Army recruits (ranging in age from 19 to 25 years). Clinical examination showed dental erosion on all tooth surfaces, with the most pronounced defects found on the occlusal aspects. Eighty-two percent of the screened recruits had erosive lesions within enamel on these tooth surfaces. Occlusal lesions with the involvement of dentin were found in 128 recruits (30.7%). Facial defects occurred in 60 cases (14.4% enamel erosion) and two cases (0.5% dentinal erosion). Palatal erosions were scarce, with only three individuals affected.[2] Lussi and others[3] examined the frequency and severity of erosion on all tooth surfaces of 391 randomly selected individuals from two age groups: 26-30 years and 46-50 years. Erosions confined to enamel were found on facial surfaces in 11.9% of the younger and 9.6% of the older subjects; whereas, more pronounced erosive defects (erosion with the involvement of dentin) were found in 7.7% of the younger and 13.2% of the older age group. Occlusally, erosions confined to enamel were found in 35.6% of the younger and 40.1% of the older individuals. At least one severe erosive lesion (erosion with the involvement of dentin) was observed in 29.9% of the younger and 42.6% of the older sample. Therefore, 3.2 teeth per person in the younger group and 3.9 teeth per person in the older group showed these advanced lesions. Statistical analyses revealed a significant impact resulting from the consumption of erosive drinks and foodstuffs on facial and occlusal erosions. On the palatal surfaces in 3.6% of the younger and 6.1% of the older individuals who were examined, slight erosive defects were found (erosion was confined to enamel). Severe palatal erosions (erosion with the involvement of dentin) were scarce and highly associated with chronic vomiting.[3] To determine progression of the erosive defects, 55 individuals were re-examined six years later.[4] All the individuals were meticulously informed about the risk of erosive tooth wear during their first examination. No change in their habits could be found six years later. A distinct progression of erosion on the occlusal and facial surfaces was found. The occurrence of occlusal erosions with the involvement of dentin rose from 3% to 8% (26-30 years old at the first examination) and from 8% to 26% (46-50 years old at the first examination). The increase in facial erosions was smaller, but again, it was more marked for the older group. In this longitudinal study, the subjective evaluation of dentin hypersensitivity remained unchanged despite the marked increase in erosive and wedge-shaped defects.

DIAGNOSIS

Diagnosing early forms of erosion is difficult, as erosion is accompanied by few signs, and fewer, if any, symptoms. There is no device available in a routine dental examination for the specific detection of dental erosion and its progression. Therefore, clinical appearance is the most important feature for dental professionals when diagnosing this condition. This is of particular importance in the early stage of dental erosion.[5] The teeth should be dried thoroughly and well illuminated to note minor surface changes. The appearance of smooth, silky-glazed, sometimes dull enamel with the absence of perikymata and intact enamel along the gingival margin are typical signs. It has been hypothesized that the preserved enamel band along the oral and facial gingival margin may be due to some plaque remnants, which might act as a diffusion barrier for acids. This phenomenon may also be due to an acid neutralizing effect of the sulcular fluid.[6] The initial features of erosion on occlusal and incisal surfaces are the same as described above. Further progression of occlusal erosion leads to rounding of the cusps and restorations rising above the level of the adjacent tooth surfaces. In severe cases, the whole occlusal morphology disappears. Figures 1 through 4 show typical patterns of the dental erosion process.

It is sometimes challenging to distinguish between the influences of erosion, attrition and abrasion during a clinical examination. Attrition-affected areas are often flat, have glossy areas with distinct margins and corresponding features at the antagonistic teeth. Facial erosion should be distinguished from wedge-shaped defects that are located at or apical to the enamel-cementum junction. The coronal part of wedge-shaped defects ideally has a sharp margin and cuts at a right angle into the enamel surface; whereas, the apical part bottoms out to the root surface. Thereby, the depth of the defect exceeds its width.

Figure 1. *Facial erosion: Enamel with a smooth tooth surface and the absence of perikymata is clearly visible as well as undulating borders of the lesion and the involvement of dentin. Both teeth have intact enamel along the gingival margin.*

Figure 2. *Palatal erosion with the involvement of dentin. The process seems to be in an inactive status (discoloration of the surface).*
NOTE: All of the teeth have intact enamel along the gingival margin.

Figure 3. *Occlusal erosion with the involvement of dentin. Amalgam restorations are rising above the level of adjacent tooth surfaces.*

Figure 4. *Palatal and occlusal erosion with the involvement of dentin. Note the grooves on the occlusal surface.*

Table 1: *Criteria for Grading Erosive Wear (Bartlett & others[7])*

Score	
0	No erosive tooth wear
1	Initial loss of surface texture
2*	Distinct defect, hard tissue loss <50% of the surface area
3*	Hard tissue loss ≥50% of the surface area

**In scores 2 and 3, dentin is often involved.*

The Basic Erosive Wear Examination (BEWE) provides a simple scoring system that can be used with the diagnostic criteria of all current indices.[7] The most severely affected surface in a sextant is recorded with a four-level score (Table 1), and the cumulative score is classified in complexity levels guiding the management of the condition (Table 2). The maximum score per subject is 18. The management of the condition includes identification and elimination of the main etiological factor(s), prevention and monitoring, as well as symptomatic and operative intervention, where appropriate. The BEWE further aims to increase awareness of clinicians and general dental practitioners regarding tooth erosion and it aims to provide a guide for its management.

RISK FACTORS

There are many factors involved in the erosive tooth-wear process. Figure 5 shows the different predisposing factors and etiologies of the erosive condition. Biological, behavioral and chemical factors interact with the tooth surface, which, over time, may either wear it away or protect it. The interplay of all these factors is crucial and helps to explain why some individuals exhibit more erosion than others, even if they are exposed to exactly the same acid challenges in their diets. Other factors listed in the outer circle of Figure 5 will further influence the whole process of erosion development or defense.[5] It is useful to consult a checklist in order to unveil risk factors (Table 3).

Table 2: *Complexity Levels as a Guide to Clinical Management (Bartlett & others[7])*

Susceptibility Level	Cumulative Score of All Sextants	Management
None	less than or equal to 2	• Routine maintenance and observation. • Repeat at three-year intervals.
Low	between 3 and 8	• Oral hygiene and dietary assessment, and advice. Identify the main etiological factor(s) and develop strategies to eliminate respective impacts, routine maintenance and observation. • Repeat at two-year intervals.
Medium	between 9 and 13	As above + • Consider fluoridation measures or other strategies to increase the resistance of tooth surfaces. • Ideally, avoid placement of the restorations and monitor erosive wear with study casts, photographs or silicone impressions. • Repeat at 6-12 month intervals.
High	14 and over	As above + • Especially in cases of severe progression, consider special care that may involve restorations. • Repeat at six-month intervals.

Table 3: *Checklist in Order to Unveil Etiological Factors for Erosions (in part from Lussi & others;[56] Lussi & Hellwig[93])*

- Take case history (medical and dental).
- Diagnose the severity and site-specific distribution.
- Record the dietary intake over four days and estimate the erosive potential.

  Question the patient for specific factors that they may not be aware of:

Diet:	Herbal teas, acidic candies, alcohol, sports drinks, effervescent Vitamin C tablets, etc.
Gastric symptoms:	Vomiting, acid taste in the mouth and gastric pain (especially when awakening), stomach ache, any sign of anorexia nervosa.
Drugs:	Alcohol, tranquilizer, anti-emetics, antihistamines, lemonade tablets. (Change of acidic or saliva-reducing drugs is possible in consultation with the patient's physician).

- Determine the flow rate and buffering capacity of saliva.
- Reveal the oral hygiene habits, abrasivity of toothpaste and technique.
- Question the patient for occupational exposure to acidic environments.
- Question the patient for X-ray therapy of the head and neck area.
- Assess further progression with silicone impressions, study models and/or photographs.

Biological Factors

Biological factors, such as saliva, acquired pellicle, tooth structure and positioning in relation to soft tissues and the tongue, are related to dental erosion development. A very important biological parameter is saliva. Several salivary protective mechanisms come into play during an erosive challenge: dilution and clearance of an erosive agent from the mouth, neutralization and the buffering of acids, which slow down the rate of enamel dissolution through the common ion effect by salivary calcium and phosphate and involvement in the formation of the pellicle.[8] The acquired pellicle is an organic film free of bacteria that covers oral hard and soft tissues. It is composed of mucins, glycoproteins and proteins, including several enzymes.[9] The acquired pellicle may protect against erosion by acting as a diffusion barrier or a perm-selective membrane, preventing direct contact between the acids and tooth surface, thus reducing the dissolution rate of dental hard tissue.

Practical experience with patients suffering from salivary flow impairment demonstrates the importance of saliva. Studies have shown that erosion may be associated with low salivary flow or/and low buffering capacity.[4,10-11] Dry mouth condition is usually related to aging,[12-14] even though some other studies have not found this correlation.[15-16] It is well established that patients taking medication can also present decreased saliva output,[17] as well as those who have received radiation therapy for neck and head cancer.[18] Tests of the stimulated and unstimulated flow rate and buffer capacity of saliva may provide some information about the susceptibility of an individual to dental erosion. However, it has to be kept in mind that these parameters are only two of a multifactorial condition. Sialometric evaluations should be carried at a fixed

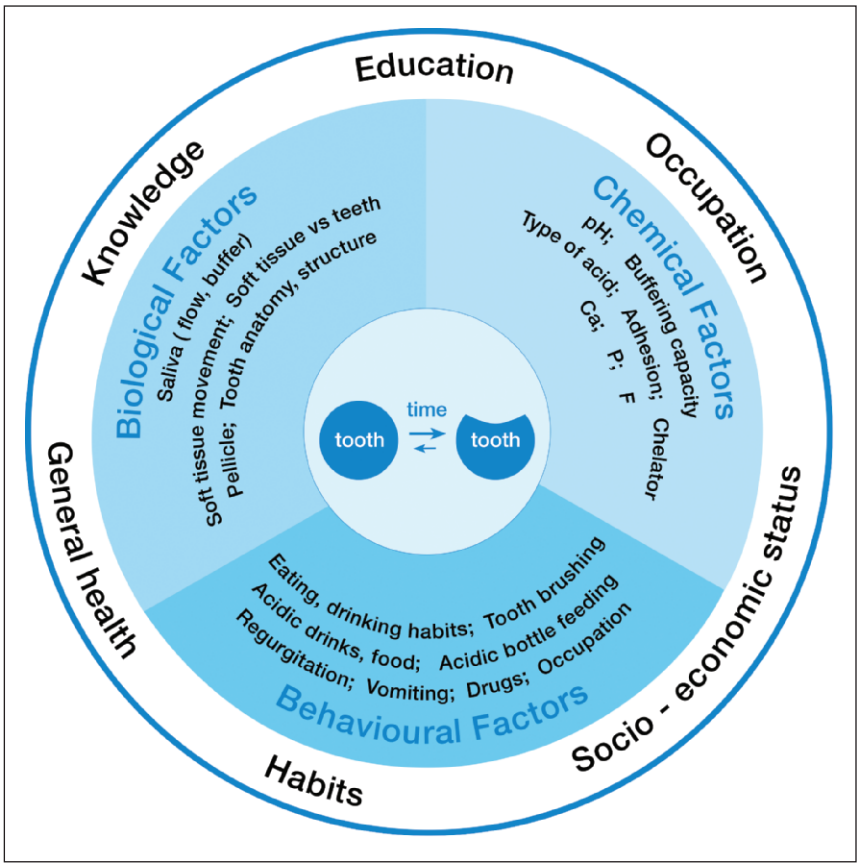

Figure 5. *Interactions of the different factors for the development of erosive tooth wear.*

time-point or in a limited time interval in the morning, avoiding intra-individual variations due to the circadian cycle. Studies have shown that sour foodstuffs have a strong influence on the anticipatory salivary flow,[19-20] which can be significantly increased when compared to the normal unstimulated flow rate.[21] Hypersalivation also occurs in advance of vomiting as a response from the "vomiting center"of the brain,[22] as seen in individuals suffering from anorexia and bulimia nervosa, rumination or chronic alcoholism. It is suggested that this could minimize the erosion caused by acids of gastric origin. On the other hand, patients with symptoms of gastro-esophageal reflux disease (GERD) should not expect the salivary output to increase before gastric juice regurgitation, because this is an involuntary response not coordinated by the autonomic nervous system.[23] Therefore, there may be insufficient time for saliva to act before erosion occurs. The influence of saliva on the remineralization/re-hardening of erosive damaged dental hard tissue is a controversial issue. It seems that, *in vitro*, some re-hardening could be expected if a supersaturated solution or saliva with no protein added is used; whereas, *in situ* or *in vivo*, this is only the case to a very small extent and needs several hours, if not days.[24]

Millward and others[25] monitored pH at the surface of teeth of healthy volunteers after drinking 1% citric acid. These authors observed that the pH recovered to above pH 5.5 within two minutes from a site adjacent to the palatal surface of the upper central incisor and within four-to-five minutes from another palatal surface of the upper first molar. Other observations have revealed a longer clearance time on the upper incisors for patients with active erosions and normal saliva values compared to patients with no erosion (Lussi unpublished). These differences could be due to the anatomy of the teeth and soft tissues, which may influence the retention and clearance patterns of erosive agents. Also, soft tissue movements of the tongue and buccal mucosa and the swallowing pattern can influence the clearance rate. The importance of the tongue in modifying the tooth-wear process has long been the subject of speculation. Holst and Lange[26] considered mechanical abrasion caused by the tongue to be a contributing factor in erosion caused by vomiting. Observations from animal studies also provide support for this claim, insofar as beverages produced erosion mainly on the lingual surfaces of rat molars, therefore, in areas where the tongue is in contact with the teeth.[17]

Chemical Factors

Several *in vitro* and *in situ* studies have shown that the erosive potential of an acidic drink or foodstuff is not exclusively dependent on its pH value but is also strongly influenced by its mineral content, its titratable acidity ("the buffering capacity") and by the calcium-chelation properties. The pH value, calcium, phosphate and fluoride content of a drink or foodstuff determines the degree of saturation with respect to the tooth mineral, which is the driving force for dissolution. Solutions oversaturated with respect to dental hard tissue will not dissolve it. A low degree of under saturation leads to very initial surface demineralization, which is followed by a local rise in pH and increased mineral content in the liquid surface layer adjacent to the tooth surface. This layer will then become saturated with respect to enamel (or dentin) and will not demineralize further.

Acids, such as citric acid, exist in water as a mixture of hydrogen ions, acid anions (for example, citrate) and undissociated acid molecules, with the amounts of each determined by the acid dissociation constant and the pH of the solution. The hydrogen ion directly

attacks the crystal surface. Over and above the effect of the hydrogen ion, the citrate anion may complex with calcium when the pH is high enough. Consequently, acids, such as citric acid, have double actions and may be very damaging to the tooth surface.[28] Up to 32% of the calcium in saliva can be complexed by citrate at concentrations common in fruit juices, thus reducing the supersaturation of saliva and increasing the driving force for dissolution with respect to tooth minerals.[29]

The dissolution with water of drinks containing organic acids with high buffering capacity will hardly reduce the pH but will reduce the titratable acidity. This is of some importance, as the greater the buffering capacity of the drink, the longer it will take for saliva to neutralize the acid. But dilution will also reduce the concentrations of Ca and P (if present) that have a protective effect.

The calcium and phosphate content of a foodstuff or beverage are important factors for the erosive potential, as they influence the concentration gradient within the local environment of the tooth surface. The addition of calcium (and phosphate) salts to erosive drinks has shown promising results. The addition of calcium to a low pH black currant juice drink has been shown to reduce the erosive effect of the drink.[30] When Ca was added to a sports drink, a reduction in the erosive potential was found.[31] Today, several Ca-enriched orange juices and sports drinks, which barely soften the enamel surface, are on the market. Yogurt is another example of a food with a low pH (~ 4.0), yet it has barely any erosive effect due to its high calcium and phosphate content, which makes it supersaturated with respect to apatite. It has to be kept in mind that adding minerals to sports drinks does not fully prevent enamel dissolution. However, the progression of enamel dissolution can be retarded, which has some implications for the patient and the clinician.

Theoretically, fluoride has some protective effects in a drink with a pH higher than that indicated by the saturation-curve of fluorapatite at the given Ca and PO4 concentrations. Lussi and others[32-33] and Mahoney and others[34] found an inverse correlation of the erosive potential of different beverages with their fluoride content. At the concentration present in beverages, it is unlikely that fluoride alone has any great beneficial effect on erosion, because of how high the challenge is in those beverages. However, it is possible that, under conditions in which the other erosive factors are not excessive, fluoride in solution may exert some protective effect. It appears that topical fluoride application can limit the tooth wear process when it is incorporated into and deposited onto the enamel during treatment.

Both adhesiveness and displacement of the liquid are additional factors to be considered in the erosive process. There appears to be differences in the ability of beverages to adhere to enamel based on their thermodynamic properties, for example, the thermodynamic work of adhesion.[35]

In summary, the two very-often cited parameters, pH and titratable acidity, do not readily explain the extent of the erosive potential of food and drink. Mineral content is also an important parameter, as is the ability of any of the components to complex calcium and remove it from the mineral surface.

Behavioral Factors

During and after an erosive challenge, behavioral factors play a role in modifying the extent of tooth wear. The manner in which dietary acids are introduced into the mouth will affect which teeth are contacted by the erosive challenge and, possibly, the clearance pattern. As lifestyles have changed throughout the decades, the total amount and frequency of consumption of acidic foods and drinks has also changed. Soft drink consumption in the USA increased by 300% in 20 years[36] and serving sizes increased from 185 g in the 1950s to 340 g in the 1960s and to 570 g in the late 1990s. Somewhere around 1995, between 56% and 85% of American school children consumed at least one soft drink daily, with the highest amounts ingested by adolescent males. Of this group, 20% consumed four or more servings daily.[37] Studies in children and adults have shown that this number of servings per day is associated with the presence and progression of erosion when other risk factors, such as swishing drinks, is present.[4,38] High erosion was associated with a method of drinking whereby the drink was kept in the mouth for a longer period.[39] Multiple regression analysis showed that the consumption of erosive drinks and foodstuffs was associated with the development of facial and occlusal erosions.[3]

Considerable risk of erosion was found with the frequent consumption of citrus fruits (more than twice a day) as well as ingesting soft drinks daily.[10] On the other hand, other studies were not able to find an association between dental erosion and behavioral factors[2,40] or they found only a weak association.[1] One can only speculate about the reasons. One possible explanation is the mode of questioning the individuals (oral vs written questionnaire), the statistics employed (multivariate vs univariate) and the population group under study (selected vs randomly).

Excessive consumption of acidic candies, combined with a low salivary buffering capacity or hyposalivation, may aggravate erosive lesions.[41-43] The high intake of herbal teas, widely perceived as a healthy drink, may have an erosive potential exceeding that of orange juice.[44]

A healthier lifestyle, paradoxically, can lead to dental health problems in the form of dental erosion, as it often involves regular exercise and what is considered to be healthy diets, with more fruits and vegetables. A lactovegetarian diet, which includes the consumption of acidic foods, has been associated with a higher prevalence of dental erosion.[40] The benefits of exercise are well proven; however, exercise increases the loss of body fluids and may lead to dehydration and decreased salivary flow. A few case reports and studies have reported an association between sports activities and erosive tooth wear. The cause could be direct acid exposure or strenuous exercise, which may increase gastroesophageal reflux. Risk groups are swimmers exercising in water that has a low pH and athletes who frequently consume erosive sports drinks. Sports drinks are often erosive[31,45-47] and, if consumed during strenuous activity when the person is in a state of some dehydration, the possible destructive effects may be enhanced even further. Health-conscious individuals also tend to have better-than-average oral hygiene. While good oral hygiene is of proven value in the prevention of periodontal disease and dental caries, frequent tooth brushing with abrasive oral hygiene products may enhance erosive tooth wear.

At the other end of the spectrum, an unhealthy lifestyle may also be associated with dental erosion.[48] Wine has properties, such as low pH and a low content of P and Ca, which results in erosive potential. Alcoholics may be at particular risk for dental erosion and tooth wear. Robb and Smith[49] reported significantly more tooth wear in 37 alcoholic patients than in age- and sex-matched controls. Tooth wear was most pronounced in males and those individuals with frequent alcohol consumption. Although a direct impact of alcohol cannot be ruled out, one has to keep in mind that alcoholics often have regurgitation.

Professional wine tasting is very common all over the world. In some countries (for example, Sweden and Finland), wine tasters are employed by their state to support their state-owned wine shops. Full-time Swedish wine tasters test on average 20-50 different wines per week. Wiktorsson[50] investigated the prevalence and severity of tooth erosion in 19 qualified wine tasters in relation to the number of years spent wine tasting, the salivary flow rate and buffer capacity. The salivary flow rate and buffer capacity of unstimulated and stimulated saliva were measured. Data on occupational background and dental and medical histories were collected. Fourteen subjects had tooth erosion mainly on the labio-cervical surfaces of maxillary incisors and canines. The severity of the erosion tended to increase with years of occupational exposure. Caries activity in all subjects was low. It was concluded that full-time wine tasting is an occupation associated with an increased risk of tooth erosion.

Although no detrimental effects were described on a population level, it has to be pointed out that, for some patients, factors, such as sports drinks, consumption and occupation, can serve as a cofactor in the development of or in the increase of dental erosion when other factors are present. It is unlikely that one or two isolated factors (for example, sports drinks or dehydration) will be responsible for a multifactorial condition, such as erosion.

RISK ASSESSMENT AND PREVENTION

The early clinical differentiation of the various defects found under the umbrella of tooth wear (abrasion, attrition, erosion) is important to adequately prevent each of these dental hard tissue defects.[4] The preventive measures for lesions predominantly caused by abrasion, such as wedge-shaped defects, have to be different from the prevention of erosion. It is important to evaluate the different etiological factors in order to identify persons at risk from erosion. The early detection of such risk patients is a prerequisite to initiating adequate preventive measures. A modern preventive strategy suggests the training of dentists in early detection and monitoring of the erosive tooth wear process. Only with these capabilities can dentists comply with their responsibilities of providing adequate care for patients. Often, patients themselves do not seek treatment until the condition is at an advanced stage, when the teeth become hypersensitive or when the esthetics are affected. This is particularly true for patients who suffer from anorexia nervosa or bulimia. Dentin hypersensitivity is one possible sign of erosive tooth wear.

When dental erosion is detected by a dentist or when there are indications of an increased risk, a detailed patient assessment should be undertaken. All of the causes have to be taken into account. Table 3 provides a checklist. A very important part of the patient assessment is taking a case history. However, chairside interviews are generally not sufficient to determine dietary habits that may lead to erosion, because patients may be unaware of their acid ingestion. It is therefore advisable to have such patients record their complete dietary intake for four consecutive days. The time of day and quantity of all ingested foods and beverages, including dietary supplements, should be recorded. Both weekdays and weekends should be included, as dietary habits during weekends may differ considerably from those on weekdays. This dietary and behavioral record should be sent to the dentist prior to the next appointment. The dentist can determine the erosive potential of the different acidic food items and drinks, assess the frequency of ingestion during main meals and snacks, then estimate the daily acid challenge. Erosion-protecting foods should also be considered.

Acid-eroded enamel is more susceptible to abrasion and attrition than intact enamel. The thickness of the softened enamel removed following different abrasive procedures varies in different studies, depending on the experimental conditions.[51-57]

As previously discussed, various processes may cause degradation of the tooth substance. When giving instructions related to prevention, all of the causative components must be taken into consideration. Other behaviors, which either stimulate salivary flow (such as chewing gum) or directly help neutralize acids (such as rinsing with sodium bicarbonate), may counter the destructive effects of dietary acids.[58-59] Furthermore, chewing gum after a meal helps to reduce postprandial esophageal acid exposure.[60] It was also suggested that chewing gum might be a treatment option for some patients with symptomatic reflux.[61-62]

A further strategy to prevent enamel and dentin from acid-induced tissue loss is to make the tooth surface more resistant against acid impacts.

In this context, the application of dentin adhesives has been discussed, but clinical results have shown that these coatings are lost after several months in use.[63] Another strategy for strengthening tooth surfaces is the application of fluorides. The topical fluoride application results in the precipitation of CaF_2-like precipitates, which are the thicker, more concentrated and acidic in preparation.[64] Respective mineral salts, however, are readily soluble in acids; therefore, an intensive fluoridation with frequent applications or concentrated preparations has often been recommended. Recent work, however, has demonstrated that the fluoride compound could play a key role in efficacy[65] and, in particular, fluoride preparations containing polyvalent metal cations are in the focus of research, with the tin ion showing the most promising results.[66]

For individuals at high risk for erosive tooth wear and for those with active erosion, it is suggested that tooth brushing should be postponed after the consumption of erosive foodstuffs or beverages in order to minimize enamel loss. Another (more efficient) possibility is to gently apply fluoride prior to the erosive attack. This has to be achieved by carefully using a low-abrasive toothpaste[67] in order to not disturb the protecting pellicle. For individuals prone to caries, the risk of enhancing the progression of carious lesions by postponing tooth brushing may be too great following the rapid decrease in plaque pH after ingesting sugar-containing foods or beverages. A measure that is beneficial for both erosion and caries is rinsing with fluoride solutions, thereby, enhancing remineralization and stimulating salivary secretion.[68] Table 4 gives recommendations for patients at high risk for dental erosion.

Therapy

When substance loss caused by erosive tooth wear reaches a certain degree, oral rehabilitation becomes necessary. There are different reasons for the need for treatment. (1) The structural integrity of the tooth is threatened. (2) The exposed dentin is hypersensitive. (3) The erosive defect is esthetically unacceptable to the patient. (4) Pulpal exposure is likely to occur. Even with advanced erosive destruction, minimally invasive restorative intervention, such as sealing or covering with composite material, should be the therapy of choice. When a restoration is inevitable, the preparations have to follow the principles of minimally invasive treatment in all cases. In no case may early diagnosis of erosive tooth wear be an excuse for an extensive restoration. Instead, preventive measures must be initiated. Several conditions, when followed properly, will enhance the lifespan of the restorations. It has been shown that resin bond strengths to non-carious sclerotic cervical dentin are lower than bonding to normal dentin. This is thought to be a result of tubule occlusion by mineral salts, thus preventing resin tag formation.[69] In such cases, it is advisable to etch scle-

Table 4: *Recommendations for Patients at High Risk for Dental Erosion (modified from Lussi & others;[56] Zero & Lussi;[68] Lussi & Hellwig[93])*

• Reduce acid exposure by reducing the frequency and contact time of acids (main meals only).
• Do not hold or swish acidic drinks in your mouth. Avoid sipping these drinks.
• Consider using modified acid beverages with no or reduced erosive potential.
• Avoid toothbrushing immediately after an erosive challenge (vomiting, acidic diet). Instead, use a fluoride-containing mouth rinse, a sodium bicarbonate (baking soda) solution, milk or food, such as cheese or sugar-free yoghurt. If none of the above is possible, rinse with water.
• Use a soft toothbrush and low-abrasion fluoride-containing toothpaste. High-abrasive toothpastes may remove the pellicle.
• Gently apply periodically concentrated topical fluoride (slightly acidic formulations are preferable, as they form CaF_2 at a higher rate). Use (tin-containing) fluoride mouthrinses.
• After acid intake, stimulate saliva flow with chewing gum or lozenges.
• Use chewing gum to reduce postprandial reflux.
• Refer patients or advise them to seek appropriate medical attention (gastroenterologist and/or a psychologist) when intrinsic causes of erosion are involved.

rotic dentin for a few seconds more than usual and pretreat the surface with a steel bur.

Future treatment regimes have been made possible by the development of sophisticated preparation techniques, improved adhesive systems and restorative materials that will result in the therapy of more small-sized lesions having a greater lifespan. One has to keep in mind that the chemical degradation of tooth substance and restorative materials as a result of acids may continue, even if preventive measures are initiated. Due to their hydrophilic nature, resin-modified glass-ionomer cements showed significantly higher water sorption values compared to composite cements.[70-71] The effect of a carbonated beverage on the wear of human enamel opposed by dental ceramics is also of importance. Human enamel against ceramic specimens was tested in a wear machine in a cycling model with intermittent immersion in a cola beverage. It was concluded that exposure to the beverage accelerated the enamel wear and decreased wear resistance of the ceramics.[72]

Taking into account several investigations,[73-78] the following conclusion can be made: Under acidic conditions, all dental restorative materials show a degradation over time (surface roughness, decrease of surface hardness, substance loss). However, it seems that ceramic and composite materials show good durability.

Treatment Strategies

Initial restorative treatments should be conservative and use adhesive materials.[79] Modern therapeutic concepts insist that minimal amounts of healthy tooth substance should be sacrificed. Reconstructive restorative treatments should be adapted to the tooth, not vice versa. However, when teeth wear, the alveolar bone and associated tissues adapt to some degree to change with alveolar compensation.[80] Despite losing crown height, teeth maintain their occlusal contact; this may lead to problems with respect to their reconstruction, because there is not enough space for the restorative material. To prevent an invasive, full-mouth rehabilitation, it can be beneficial to gain interocclusal space with orthodontic measures, especially if groups of teeth (for example, all the teeth in the anterior region) are involved in erosive tooth wear. The orthodontic treatment can be achieved with fixed or removable appliances, such as the Dahl appliance.[80] Following orthodontic treatment, the eroded teeth can then be reconstructed.[81] Prior to the most recent decade, the severely eroded dentition could only be rehabilitated by the provision of extensive crown and bridge work or, in more severe cases, by means of removable overdentures.[82-84] As a result of the improvements in composite restorative materials and adhesive techniques, it has become possible to rehabilitate eroded dentitions in a less invasive manner. In recent years, the wear resistance of posterior composite fillings has been enhanced.[85] Therefore, the use of modern, direct restorative materials can provide excellent longevity, even in load-bearing situations.[86-87] Several case reports demonstrate the successful rehabilitation of (erosive) worn dentitions using adhesive techniques.[81,88-91] The restorative treatment plan should be adapted to the degree of tooth substance loss (for example, loss of vertical dimension).

- *Loss of vertical dimension <0.5 mm: Sealing or direct composite restoration.*

  The treatment of erosive tooth wear should be performed at an early stage in order to prevent the development of functional and esthetic problems. The most minimally invasive measure is sealing of the affected tooth surface. Applying dentin adhesives to exposed dentin in patients with erosive tooth wear is a practical measure that delays further damage. Adhesive systems may protect dentin from further acid actions and, for a limited period of time, brushing abrasion. The coating should be repeated every six-to-nine months.[63] Clinical experience shows an obvious decrease in the hypersensitivity of erosively-damaged teeth after sealing.

  Occlusal erosions typically show grooves on the occlusal aspects and edges of the restorations rising above the level of adjacent tooth surfaces. These grooves demonstrate a prolonged time of a depressed pH value after an acid attack (unpublished observation), which leads to further progression of the erosive process at this site. In such cases, minimally invasive composite fillings are able to protect the affected region. Conventional glass-ionomer cements are not recommended as permanent restorations, because of their disintegration in acidic conditions.[92]

- *Loss of vertical dimension >0.5 mm: Direct reconstruction with composite materials or rehabilitation with ceramic veneers, overlays and crowns.*

  As long as there is only a loss of 1 to 2 mm of interocclusal space, the teeth can be easily reconstructed directly with resin composite materials. Patients usually tolerate such a small increase in vertical dimension without any problem. The teeth are rebuilt "freehand" according to their original anatomy. This restorative measure can also be used for the reconstruction of localized facial or palatal surface defects. The advantage of direct composite restorations is that they are adaptable to the defect and the repair is straightforward. The situation is more problematic if occlusal and vestibular erosions merge, the original tooth shape becomes hardly recognizable and the loss of vertical dimension is greater. In these

cases, a direct composite build-up, using a vacuum-formed matrix template, is convenient. The quality over a mean observation period of three years seems to be good.[91]

In general, less invasive reconstruction procedures, such as direct adhesive methods, are preferable to indirect methods. However, if the upper front teeth are severely eroded and need to be reconstructed, porcelain veneers may sometimes be applied. If the defects (on posterior teeth) show an extension over two or more tooth surfaces and the vertical tooth substance loss is greater than 2 mm, then reconstruction with full ceramic overlays or crowns is indicated.

The treatment methods demonstrate that esthetically pleasing, yet conservative reconstructions are possible. However, such treatment is expensive. Therefore, it is important to combine active treatment with preventive measures and organize patient recall at regular intervals to ensure long-term success.

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