Eur J Oral Sci 1996; 104: 229–240
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EUROPEAN JOURNAL OF
ORAL SCIENCES
ISSN 0909-8836

Restorative therapy for erosive lesions

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Lambrechts P, Van Meerbeek B, Perdigão J, Gladys S, Braem M, Vanherle G: Restorative therapy for erosive lesions. Eur J Oral Sci 1996; 104: 229–240.

More needs to be learned about the etiology of erosion lesions before they can be accurately diagnosed, confidently treated and, more importantly, prevented. The treatment is dependent on the location and the degree of erosion. The decision to treat an erosion lesion should be based on careful consideration of the etiology and progression of the condition. Reasons for restoring noncarious enamel/dentin lesions are discussed and various therapeutic measures are provided. Preventive and restorative therapeutic measures for noncarious abrasive/erosive lesions are proposed such as: a change of dietary or behavior patterns; application of desensitization products; intensive fluoride therapy with or without iontophoresis; brushing with desensitizing dentifrices; adhesive penetration with dentin bonding agents; glass ionomers and compomers; resin composites; composite or porcelain veneers; crown and bridge work; occlusal adjustments and nightguard fabrication if the abfraction factor coincides. The clinical durability of restorative therapy and important clinical factors related to the restoration of multifactorial defects are discussed.

Key words: erosion; restoration; adhesion; therapy

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Introduction

Many patients exhibit dental lesions or defects not classified as caries. Conflicting definitions and explanations have been applied to these lesions which can occur on either the lingual, facial and even occlusal aspect of virtually any tooth. Cervico-vestibular or cervico-lingual defects are most common, and some estimates suggest that nearly one-third of the adult population is affected. Their etiology has been attributed to a number of factors (1).

Because of a lack of understanding by the dentist, the terminology attrition, abrasion, erosion, and abfraction is often used interchangeably in the diagnosis of noncarious lesions (2, 3). Confusion exists in the dental community as to what constitutes attrition, abrasion, erosion, or abfraction lesions because in most of the cases, the etiology of tooth lesions is multifactorial. Direct clinical examination, as well as a complete comprehensive review of the patient's clinical and dental history, can distinguish carious lesions, trauma, and the other processes that cause tooth destruction (4, 5). Often, two or more processes of tooth destruction coincide, resulting in diagnostic and treatment dilemmas (2, 6). Accordingly, current research has focused on the causes of noncarious lesions and their varying treatment modalities (7–10).

This article does not only focus on chemical erosive lesions, but establishes reasons for restoring noncarious enamel/dentin lesions and describes the various therapeutic measures available. Additionally, this article describes the clinical durability of restorative therapy and highlights some important clinical factors related to the restoration of multifactorial defects.

Morphological features of erosive-like lesions
Contrasting substrates
Lesions limited to the enamel

In the initial stage of erosive lesions, only the enamel surface is involved. The thinning of the enamel layer occurs at the vestibular, lingual or occlusal surface. Because of the demineralization, the surface is dull due to the change in refractive index and is prone to mechanical wear. At this stage of enamel erosion, with no dentin exposed, the teeth are not hypersensitive (3).

Because of esthetic complaints, a composite or porcelain veneer should be considered as the treatment of choice. It seals the enamel and recontours the tooth.

Lesions into dentin

At a certain stage, dentin becomes exposed. As dentin is a dynamic tissue, a clear characterization of sensitive dentin (open tubules) and nonsensitive or sclerotic dentin (closed tubules) is essential to understand the structural changes of the tooth substrate and to determine the best adhesive and restorative therapy. A clinically correct diagnosis of the dentin condition is essential before restorative therapy is started.

Sensitive dentin

Yoshiyama *et al.* (11) reported in 1989 on the differences between sensitive and insensitive dentin areas on cervical lesions (12–14). Microscopic examination of biopsied dentin lesions with sensitive surfaces demonstrated various levels of dentin tubular patency. Many tubules were open at the surface and demonstrated relatively normal organic membranes within the odontoblastic processes. In cross-section, no calcified deposits were seen in dentin tubules of sensitive lesions.

Many of these hypersensitive dentin lesions are symptomatic and can range from minor sensation to extended painful episodes for the patient. Dentin hypersensitivity is a common reason for patient complaints and treatment need (10, 15). The etiology of this hypersensitivity involving the structure and function of the dentin and pulp can be complex (10, 11, 13, 14, 16–21). Fluid movements in the dentinal tubules (the hydrodynamic theory) are usually caused by stimuli, such as cold air and water and mechanical probing, which rushes painful hypersensitive dentin. Microorganisms in dentinal tubules can also cause irritation and pain (10, 16).

About 30% of the cervical lesions are considered as sensitive at the baseline evaluation. Following the placement of restorations, a clear improvement in sensitivity is obtained (12).

Non-sensitive dentin or sclerotic dentin

Pashley in 1989 (22) refers to dentin as a dynamic substrate subject to continuous age change, and the rate of alteration appears to be directly related to the history of insult of a particular tooth. Dentin alters not only at the pulpal side, but also at the intra-, and peritubular side. Additionally from the oral side, several outer influences determine the maturity of the dentin (13).

First of all, with aging, the odontoblasts of the dental pulp continue to form a barrier of dentin on the inner surface of the tooth. This *secondary dentin* is less organized than primary dentin and is deposited during the whole life of the tooth.

Tertiary or *irritational dentin* is induced by an irritating mechanism in the oral environment, and forms along the pulpal wall adjacent to the irritation. *Reparative dentin* is produced at the lesion site in the pulp chamber in response to more severe insults like caries, operative procedures, and attrition. This reactionary layer of dentin is extremely irregular and may be atubular (23).

Reactive sclerosis occurs in response to slowly progressive or mild irritations like abrasion and chemical erosion.

Cervical abrasive/erosive lesions undergo changes in the oral cavity, and dentinal tubules may become partially or completely obturated by the growth of peritubular dentin or by the precipitation of mineral salts within the tubular orifices (12, 13). Calcification of the dentin tubules has been reported on teeth exhibiting occlusal attrition and advancing cervical lesions (24, 25). The hydroxyapatite crystals occlude the dentinal tubules, thereby sealing the dentin and reducing sensitivity. Yoshiyama *et al.* (11) demonstrated that tubular obliteration was pronounced in naturally desensitized abrasive/erosive lesions with various sizes and shapes of rhombohedral crystalline deposit.

The developing dentin lesion may present clinically as relatively young, small, shallow lesions with opaque, white, light-colored dentin and sharp margins, to large irregular shaped lesions with rounded margins, increasing depth, highly discolored and transparent or sclerotic dentin (26, 27). Especially in older patients, sclerotic dentin imparts a dark yellow or brown color with a glassy, translucent appearance, which results from the obstruction of dentin tubules by calcified deposits with the refractive index of the tubules similar to the intertubular dentin (12, 13, 28, 29). The transparency and discoloration is not restricted to the surface of the lesions but continues to the pulp.

Therapy of noncarious cervical lesions

Several preventive and restorative treatment measures for noncarious abrasive/erosive lesions have been proposed (6, 9, 10, 28, 30–38) such as: a change of dietary or behavior patterns; application of desensitization products; intensive fluoride therapy with or without iontophoresis; brushing with desensitizing dentifrices; adhesive penetration with dentin bonding agents; glass-ionomers and compomers; resin composites; composite or porcelain veneers; crown and bridge work; occlusal adjustments and nightguard fabrication if the abfraction factor coincides (Table 1).

Effective treatment and prevention strategies are needed. More needs to be learned about the etiology of cervical lesions before they can be accurately diagnosed, confidently treated and, more importantly, prevented. No study has been reported that collected data for all the putative risk factors associated with erosion, abrasion and tooth flexure, and paid careful attention to the characterization of lesion morphology (3). The treatment is dependent on the location and the degree of erosion. As soon as dentin is exposed, restorative treatment becomes necessary. In an effort to disclose the influence of dentin variability on adhesion, lesions have to be subjected to various morphologic examinations and characterized before treatment. To document their reaction with current restorative and adhesive systems, data on dentin discoloration, age, sex and dentin sensitivity should be recorded.

There are substantial differences between dentists in the recognition and treatment of noncarious cervical lesions (39). In part, this variation also stems from a lack of knowledge of the etiology of noncarious cervical lesions. The decision to treat a cervical lesion should be based on careful consideration of the etiology and progression of the condition (Table 1) (40).

Desensitization

Application of copal varnishes, potassium oxalate or other desensitization products provide only some temporary pain relief.

Fluorides

Fluoride treatments with or without iontophoresis, provide some pain relief. Iontophoresis treatments using small electronic currents to introduce sodium fluoride and/or corticosteroids into the tubules usually require multiple applications (39–42, 47–49).

Desensitizing dentifrices

Many anti-sensitivity dentifrices form a protective layer (precipitated minerals) on dentin that blocks exposed tubules. Some advise the application of strontium chloride hexahydrate in a dentifrice form (44). However, these desensitizing dentifrices often take 1 to 3 months for required results to be realized

Table 1

Treatment advice and costs related to pathology (the Lussi classification)

Diagnosis	Grade	Treatment	Costs
Facial erosion	0	Preventive measures	*
	1	Preventive measures	*
		or facial recontouring with composites	**
	2	Adhesive resin penetration if sensitive for cold and touch	*
		Recontouring with composites, glass-ionomers or compomers	**
	3	Composite restoration	**
		Glass-ionomer restoration	**
		Compomer restoration	**
		Porcelain veneer	****
		Full crown	****
Lingual erosion	0	Preventive measures	*
	1	Preventive measures	*
		or lingual recontouring with composites	**
	2	Composite restoration	**
		Glass-ionomer restoration	**
		Compomer restoration	**
		Metal shield veneer in the upper front teeth	***
		Full crown	****
Occlusal erosion	0	Preventive measures	*
	1	Composite restoration of eroded occlusal depressions	**
	2	Crown and bridgework	****
Abfraction cofactor	–	Occlusal adjustments together with restorative treatment	**
		Nightguard	**

(9, 10). If the acid challenge persists, the balance is easily reversed and the sensitivity reappears.

Adhesive penetration with dentin bonding agents

One benefit associated with adhesion to tooth structure is the increased resistance to acid or caries attack, if the exposed dentin or root surface is impregnated with monomers of dentin bonding systems (45, 46).

One could advise to condition and prime the sensitive area in order to infiltrate the tubules and intertubular dentin substrate with a semi-filled low viscosity adhesive resin. The principle of wet-bonding combined with a hydrophilic primer is used. If the inorganic filler also releases some fluoride, a complementary beneficial effect can be obtained. This technique does not offer a recontouring of the eroded area, but creates a durable wear resistant coat, combined with filled resin tags of several hundreds of µm length (Figs. 1a, b). Fluid light-cured glass-ionomers can also be used.

Restorative treatment

Restorative treatment may be necessary if: 1. The structural integrity of the tooth is threatened. 2. The tooth (dentin) is hypersensitive. 3. The defect is esthetically unacceptable to the patient. 4. Pulpal exposure is likely.

The restoration of erosion defects has been a major area of controversy for many years. In the past, such lesions were often disregarded or left untreated. It was normally argued that restoration of such lesions would be temporary and that regardless of the cause of the original lesion, the anomaly would only return. Moreover, conventional cavity preparations that are described in most operative textbooks would involve extensive loss of tooth structure (47).

Research directed towards developing adhesion between restorative materials and mineralized tooth surfaces has been advancing for over 40 yr. The main goal in this process has been to obtain an intimate adaptation with cavity interfaces to resist microleakage and the influx of oral irritants which may lead to post-operative sensitivity, interfacial staining, and recurrent caries (12).

While pertinent success has been achieved with respect to enamel surfaces, adhesion to cementum and dentin substrates has been more challenging. Conditioning of enamel with acidic solutions, such as phosphoric acid (37%), predictably creates microporosities into which resinous materials can penetrate, thereby achieving mechanical retention and sealing (48–50). Initially, similar strategies employed for dentin surfaces have been discouraged due to inadequate adhesive bond strengths (51) and concerns for pulpal injury (52, 53).

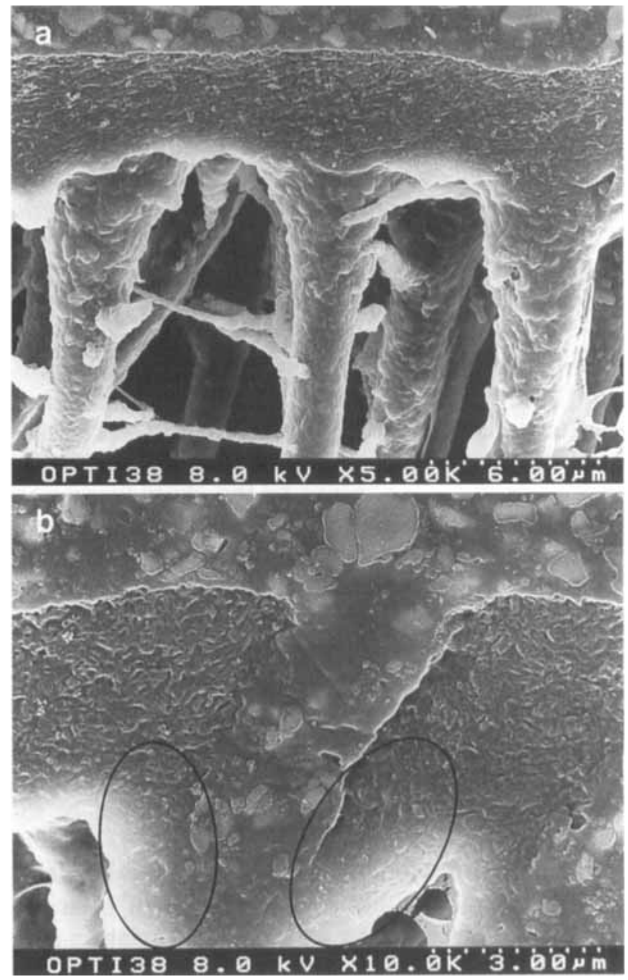

Fig. 1a. Resin-dentin interface after *in vitro* treatment with OptiBond (Kerr Co.). The specimen shows resin tags, and a 4-µm-thick resin-dentin interdiffusion zone. The filled-fluid resin is filled with radiopaque particles, which penetrate the tubules.
Fig. 1b. Closer view of particle-filled resin tags. The fluoride-containing particles penetrate deep into the tubule. Note the lateral triangular peritubular resin-dentin interdiffusion zone (ovals).

In order to increase the surface area for microretention on enamel, it is important to place a long bevel along the enamel margin using a flame-shaped diamond. This enamel surfacing procedure or beveling is quite substantial. The bevel visually decreases the boundary between the restoration and tooth structure. Additionally, it amplifies the bond to the underlying enamel. If the restoration is extended onto unetched enamel surfaces, this will result in discolored margins because the overlying unbonded composite gradually lifts from the surface. Finally, many of the modern dentin all-etch bonding agents use a phosphoric or other organic acid etching agent with only a 10% concentration to condition enamel and dentin simultaneously.

Matured enamel in older patients and uncut enamel surfaces commonly require a much higher acid concentration (approximately 30–37%) for effective etching. Failure to bevel and properly acid etch the enamel margin can result in a boundary line between the restoration and adjacent enamel (47).

Currently, several different restorative techniques are recommended for the abrasion/erosion lesion:

Glass-ionomers and compomers

Defective regions can be restored with glass-ionomers only. They are especially effective for treating noncarious cervical lesions because of their potential to release fluoride ions into the underlying dentin to prevent decay (15, 30–32). This consideration is important in treating older patients who often experience reduced salivary flow, which makes them more susceptible to caries. Glass-ionomers are also appropriate in patients who have an elevated caries index.

Because the first generation glass-ionomers were opaque and rough, many clinicians veneered the glass-ionomer surface with a microfill resin. The present-day glass-ionomers are superior to their predecessors in terms of color match, wear resistance, and polishability. The retention rate for glass-ionomer cement restorations is between 90 to 100% retained restorations after three years. Powel *et al.* (54) found that 97.3% of these restorations were retained after 3 yr. This compares well with previously reported clinical results (55, 56).

The glass-ionomer cement restorations have a slightly rougher surface texture than composite resin restorations. The glass-ionomer restorations are better retained than composite restorations applied with dentin bonding agent only. In a laboratory setting, investigators found less microleakage with glass-ionomer restorations when compared to nonretentive composite restorations (57). One possible explanation is that the glass-ionomer restorations undergo less stress and gap formation, resulting from polymerization shrinkage and from thermal expansion and contraction (58, 59).

Recently, several new visible light cured glass-ionomers have been introduced which are hybrids between the conventional glass-ionomers and the resin composites. At the moment, a real confusion exists about the correct terminology of these so-called "compomers" and their limits of use. They bond as efficiently to dentin as the new adhesive resin systems, but they still have a low cohesive strength which results in inferior shear bond strength values to dentin. These new materials are not indicated for posterior restorations, because their wear resistance is too low and their fatigue resistance is insufficient. They are probably indicated in situations that require a moderate strength and esthetics, and when ease in use is requested.

Resin composites applied with a dentin bonding agent

New dentin adhesives became available to bond to exposed dentin. Common to these modern agents has been the incorporation of a conditioning and/or priming step and the use of resin formulas with increasing hydrophilicity. Two or more steps are typical with new generation dentin adhesives.

Conditioning step: Normal cut dentin is covered with a smear layer which is firmly bonded to the underlying dentin. The action of conditioners on unaffected ground model dentin surfaces in the laboratory phase has been documented by Perdigão (60, 61). After conditioning, the smear plugs are removed from the tubule apertures, the intertubular microporosity increases and the outer peritubular collagen fibers are exposed (Figs. 2, 4a,b). Such a conditioned surface is extremely receptive to the development of micromechanical retention of polymeric materials and accounts for the high bond strengths observed in laboratory investigations.

Priming step: After a superficial portion of the hydroxyapatite or inorganic phase has been removed (Fig. 2), the resin primer is impregnated into the dentinal surface. The use of the hydrophilic primer solution affords an improved wetting by the subsequently applied adhesive agent (12).

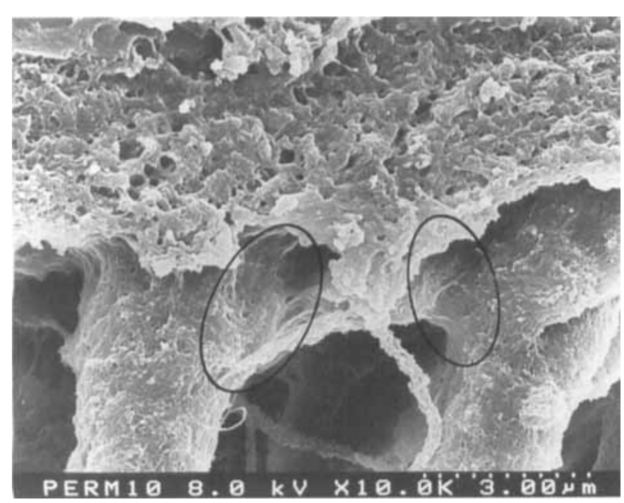

Fig. 2. Dentin etched with 37% phosphoric acid liquid. Lateral view of the transition between demineralized dentin and unaffected dentin. A layer of residual material covers the surface. A triangular-shaped pattern of peritubular demineralization is also shown. The direction of the outer peritubular fibers is mostly circular, while the intertubular fibers are randomly oriented.

Adhesive resin penetration step: The mechanisms of adhesion between current adhesive systems and normal unaffected model dentin have been highlighted by VAN MEERBEEK *et al.* (62, 63) and by PERDIGÃO (60). A micromechanical retention is created from the infiltration of the monomers into a surface zone of demineralized dentin, generating the so-called hybrid layer or resin interdiffusion zone (Fig. 3). The monomers polymerize, forming a complex interlocking network with the dentin matrix, together with a penetrating resinous tag network (Figs. 1a,b, 3).

Resin composite step: Resin composite material shrinks during polymerization. As the overall shrinkage depends on the quantity of material placed at a given time, one should remember that the greater the volume, the greater the extent of curing shrinkage. It is strongly advocated that the composite resin be placed in increments, with each portion followed by light curing. The greater the extent of shrinkage, the higher the level of shear stresses at the dentin/resin interface. If all the necessary restorative material is inserted in one stage and cured, a significant reduction in the adhesion potential is caused. It is recommended that three to four segments of material be used for most lesions, with the first segment mainly on dentin. The number of increments depends on the volume of space undergoing restoration, with larger lesions demanding more incremental applications of the material. Each portion should be cured for at least 20 s. The final placement, however should be light cured for at least one full minute to increase the surface wear resistance (47).

Several materials can be used to esthetically re-establish abrasive/erosive lesions. However, the color-matching potential is only one of the factors to conceive. One must also reflect on certain physical and mechanical characteristics. Other than wear resistance and color stability, an important characteristic could be the modulus of elasticity or stiffness of the material. This is essential because when a tooth is hyperoccluded, the masticatory forces are transmitted preferentially to this tooth. The masticatory stresses are transferred through the cusp and are concentrated at the fulcrum of the vestibulo-, or linguo-cervical region. Under such a condition, the resultant stress is one of two types –

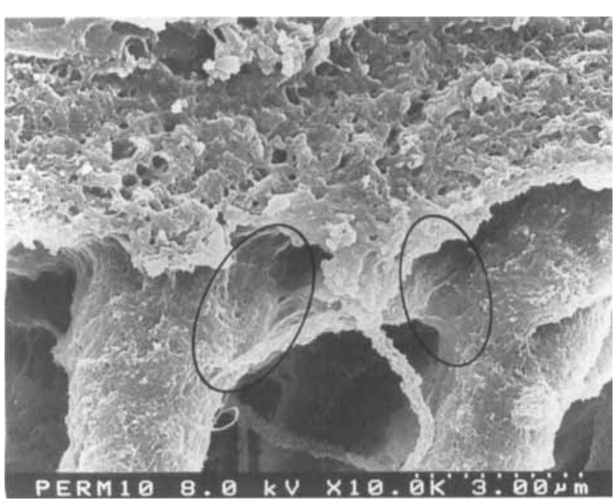

Fig. 3. Resin-dentin interface after *in vitro* treatment with Permagen (Ultradent Co.) associated with 10% phosphoric acid. Specimen is demineralized with HCl and deproteinized with NaOCl. A 3 µm-thick reticular resin-dentin interdiffusion zone is observed with a triangular transition towards the resin tags.

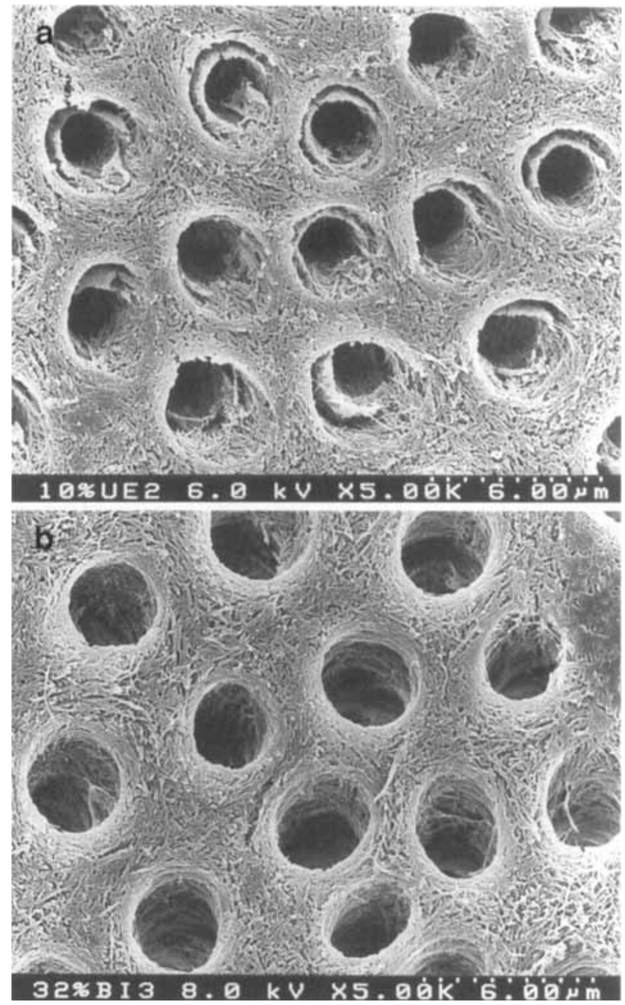

Fig. 4a. Dentin etched with Ultra-Etch 10% (Ultradent Co.) phosphoric acid. Top view showing cross-sectioned tubules. Note the intense intertubular microporosity available for adhesive resin penetration. A cuff of mineralized peritubular dentin is visible in all the tubules. An area of exposed outer peritubular collagen is observed in the area between the peritubular cuff and the dentin surface.

Fig. 4b. Dentin etched with Uni-Etch 32% (Bisco Co.) phosphoric acid. Top view showing cross-sectioned tubules. Note the intertubular microporosity and exposed outer peritubular collagen fibers. The subsurface collagen fibers are visible through the pores. All peritubular dentin cuffs are demineralized.

either compressive or tensile – depending on the direction and the vector of the forces. It is recommended, therefore, that composite resins with a low modulus of elasticity be used. With this type of resin, much of the transferred energy is absorbed by the restoration rather than transmitted to the dentin-restoration interface. Consequently, the bond between the restoration and the dentinal surface is considerably less challenged. The elastic modulus of the microfilled composites is much lower than that of hybrid or conventional composite resins. The reduced elastic modulus is related to a lower level of filler loading. On the basis of these findings, it is apparent that the material of choice for restoring lesions in the cervical area are microfilled composite resins (47). In the occlusal area, hybrid composites are more indicated because of their wear resistance.

Restoring affected teeth improves patient oral hygiene maintenance, reduces thermal sensitivity, prohibits pulpal involvement, dentifrice abrasion, acid erosion, and food impaction, discomfort for the tongue and cheeks and, primarily, ameliorates esthetics and strengthens the teeth (6). Composite resin restorations offer a more permanent or long-lasting solution because of the acid-etch technique and the micromechanical and (chemical) adhesion to the tooth structure through dentinal bonding systems (8).

To date, strategies for dentin adhesives have been based upon an understanding of normal or "model" dentin composition and microstructure. Whether directed towards chemical bonding (either ionic to mineralized phases, or covalent to organic constituents), or mechanical bonding (i.e., tubular and intertubular penetration by resin), development efforts have not taken the structural changes into account that accompany dentin surfaces in the oral cavity during aging. Several dentin types may be encountered during adhesive bonding procedures depending upon clinical conditions or depth of lesions. To what extent these chemical and ultrastructural differences may influence the clinical performance of current dentin adhesives is presently unknown (12). Sclerotic dentin may be less receptive to current dentin adhesives. Mjör (23) suggested in 1987 that the extreme variation in dentin structure and composition, as encountered clinically, may account for the unpredictable behavior of dentin adhesive agents.

The observation of the natural abrasive/erosive lesions prior to treatment reveals variable dentin surfaces ranging from exposed dentinal tubules with sensitive dentin, to gradually obturated orifices with insensitive dentin. The more sclerotic or discolored the dentin surface, the less apparent are tubular openings (12). When non-sclerotic, shallow, opaque surfaces are conditioned, surface alterations are similar to unaffected dentin.

The highly sclerotic dentin specimens are much less affected by the conditioner. The openings of tubules are filled with precipitates exemplary of those described by Yoshiyama *et al.* (11). In addition, the volume of peritubular dentin increases with advanced sclerosis. This finding is consistent with previous reports on age changes in dentin (23,24,64). With increasing levels of sclerosis, the conditioner solution is less effective regarding developing tubular patency. Minimal surface alteration is observed on specimens with highly discolored sclerotic dentin. Such dentin is clearly resistant to alteration by the conditioner solution. In the central area of deep, sclerotic lesions, the application of the conditioner results in a surface with residual calcified odontoblasts protruding from the tubules. The ability to condition natural cervical abrasion/erosion lesions is related to the amount of sclerotic dentin present. The older, highly discolored lesions are much less affected following the use of the conditioner. The observed age changes in dentin morphology, i.e., increase in peritubular dentin and obturation of tubular orifices, may constrain the evolvement of satisfactory mechanical retention. In addition, changes in aged dentin chemistry, such as the elevated mineral content of sclerotic dentin, may control the action of conditioning solutions (65). The use of more aggressive etching agents or longer etching times may be required to produce retentive features in highly sclerotic dentin. Previous studies on the pulpal compatibility associated with more offensive etching agents may doubt such strategies. However, the highly sclerotic dentin may serve as an effective barrier to such agents and prevent pulpal injury (66).

The tag development in sclerotic lesions is less reliable. The resulting cross-sectional restored specimens demonstrate little or no resinous tag penetration into the tubular openings. On the contrary, mineral tubular casts protrude into the adhesive resin layer (Fig. 5a) (67) The microstructure of the interface varies depending on the direction of the dentin tubules relative to the interface. From the deepest dentin part of the wedge- or saucer-shaped lesions to the outer dentino-enamel junction, the tubule direction changes from an oblique direction to one parallel with the interface of the eroded surface. In the latter areas, dentin tubules are embedded in the interface, and only a limited hybridization to the tubular walls is allowed (Fig. 5b) (67).

Emphasis has been placed on the penetration of resin composite into the dentin tubules to acquire mechanical adhesion with current adhesive systems

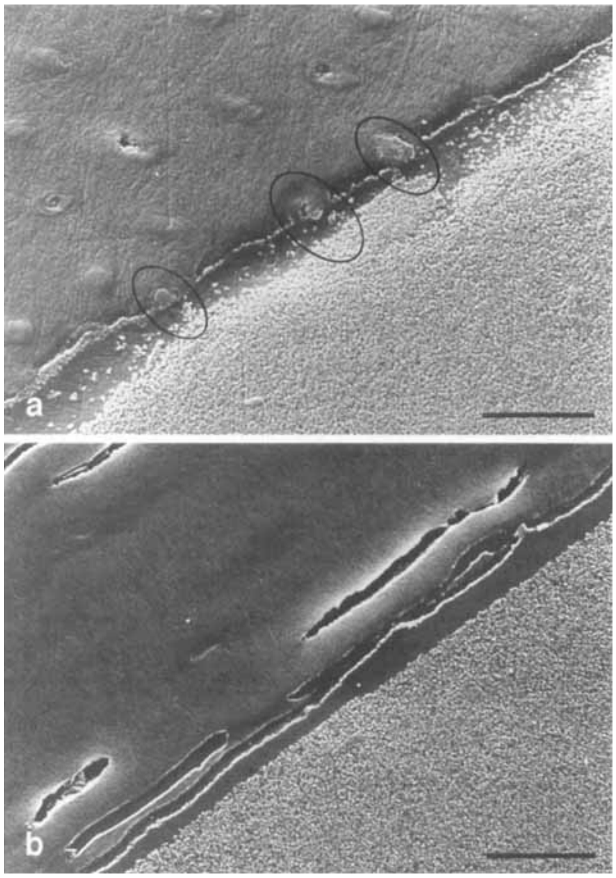

Fig. 5a. Photomicrograph illustrating the resin-sclerotic dentin interdiffusion zone obtained with Clearfil Liner Bond System (Kuraray Co.), when the dentin tubules run semi-parallel with the interface. The tubules appear obstructed by peritubular dentin apposition and do not contain resin tags. (Bar is 10 μm). *Fig. 5b.* Photomicrograph illustrating the resin-sclerotic dentin interdiffusion zone obtained with Clearfil Liner Bond System (Kuraray Co.), when the dentin tubules run parallel with the interface. A superficially localized dentin tubule was penetrated by resin and embedded in the interface, while a deeper localized tubule remained patent. (Bar is 10 μm).

(13). However, as reported by WANG & NAKABAYASHI (68), optimal mechanical adhesion may also require penetration of resin composite into intertubular dentin. Strong phosphoric acid concentrations have been investigated for conditioning highly sclerotic dentin. Tubular orifices can be opened with these agents, and extensive tag development into dentin tubules has been noted. However, the intertubular dentin changes, commonly reported from etching unaffected dentin with phosphoric acid, have not been seen with sclerotic dentin. Similar findings have previously been recorded by GWINNETT & JENDRESEN (69) in their comparison of natural erosive lesions and unaffected dentin treated with phosphoric acid. The resistance of intertubular dentin to conditioning solutions is ascribed to sclerotic dentin. Intertubular dentin of sclerotic dentin is hypermineralized compared to normal dentin (70–72). The hypermineralization appears to emanate in the organic, or collagen component of dentin. Therefore, the sclerotic lesion may have a surface without any collagen.

Composite restorations with a dentin bonding agent result in restorations that are clinically acceptable for color match, marginal staining, surface texture, and caries development when evaluated after 3 yr (54, 73, 74). The study of POWEL *et al.* (54) found retention rates of 75.7%. One explanation for this low retention rate may be that the age of the patients was older, mean 70 yr of age, and the treated dentin was sclerotic. Adhesive success is less in the more aged erosion subjects. The influence of these age changes in dentin relative to adhesive behavior is not fully understood. As the dentin lesion becomes more sclerotic and calcified, it would stand to reason that dentin adhesives which are focused at establishing mechanical retention into tubular orifices, would be less successful (75, 76). Secondary to aging and wear, the dentinal tubules in sclerotic dentin are obturated by intraluminal crystals (11). As this sclerotic dentin is resistant to the conditioner solution, and almost not affected by the primer, resinous tag penetration into the tubules is not created (13) (Fig. 5a,b). Lost restorations, and those displaying marginal staining, are confined to lesions with increased transparency and greater discoloration. The restorations placed in opaque and white, shallow lesions show better retention rates.

Further research into not only the microstructure, but also chemical changes that are particular in aged dentin surfaces, is justified. Such information would help in the progress of new adhesive strategies and provide valuable clinical direction for the use of current and future adhesive agents.

Resin composites applied with a glass-ionomer liner and a dentin bonding agent

Some laboratory studies have concluded that a "sandwich" technique, the layering of composite over a glass-ionomer cement liner, reduces microleakage when compared to glass-ionomer restorations or composite resin restorations, especially when the gingival margin of cervical restorations is examined (30, 77).

Other studies have found that glass-ionomer cement restorations, dentin bonding systems, and glass-ionomer liners used with dentin bonding systems all result in similar microleakage patterns (78, 79).

Composite resin restorations with a dentin bonding agent and a glass-ionomer liner seem to be better retained than the composite resin restorations applied with only a dentin bonding agent (54). A laboratory study came to a related outcome, that glass-ionomer-lined composites showed less leakage than unlined composites (80). A possible clarification for this finding is that the liner transmits some flexion to the whole restoration. KEMP-SCHOLTE & DAVIDSON (81) found in an *in vitro* study that an intermediate layer reduced the inflexibility of the total restoration, allowing it to compensate for stress that exceeded the bond strength. An increase in flexibility is attributed to the "movability" of the clusters of molecules in the early set of the glass-ionomer cement liner, which compensated for polymerization shrinkage of the composite resin. Further stress relief can also be obtained by water sorption of the lining materials. This hypothesis is further strengthened by the fact that microfilled composite resins, with their increased flexibility, are better retained than macrofilled composite resins (82, 83).

Another theory why composite restorations combined with a glass-ionomer cement liner performed better is that the glass-ionomer cements may benefit from the extra calcium ions found in sclerosed dentin. According to MITRA (84), in the third step of the setting reaction for Vitrebond, positive ions (Ca^{2+}, Al^{3+}, AlF^{2+}, etc) react with the negatively charged polycarboxylate polymer to form a cross-linked network. Glass-ionomers rely less on the demineralization of the dentin surface, a step that is essential to the dentin bonding agent (85).

Composite or porcelain veneers

Especially if the labial surfaces are involved, one can chose for a direct or indirect composite veneer or even porcelain veneers. Both, however, rely on the principles of enamel and dentin bonding as described above. The advantages of porcelain veneers are their esthetics and durability. Also, if the incisal margins are eroded, porcelain veneers are able to cover the lost tooth structure. A disadvantage is the amount of sound tooth tissue which has to be removed in order to attain sufficient porcelain thickness for strength. Financially, porcelain veneers are expensive, and many patients cannot afford this type of treatment. There are no long-term studies that substantiate the use of porcelain veneers on a routine basis to treat eroded tooth surfaces.

At the upper palatal side, porcelain veneers are contraindicated because of the destructive wear observed on the enamel of the antagonists. Therefore, metal shields or, more esthetical, direct composite veneers are advocated. The main problem, however, is the lack of vertical space, because of eventual supereruption of the lower antagonists.

Crown and bridgework

Extensive defects which occur e.g. with perimylolysis often require extensive crown and bridgework as the vertical dimension has to be repaired at the same time (37, 38). Especially the correction of the vertical height needs thorough occlusion analysis. Both arches should be treated simultaneously if the occlusal surface is made of porcelain. Otherwise, the antagonistic remaining dentition wears away due to attrition by the harder porcelain (86). Gold overlays, partial crowns and full crowns are preferred for antagonistic occlusal reconstruction. The durability is 15 to 20 yr and offers a long lasting solution.

The extensive crown and bridgework may lead to overtreatment. Also the financial implications are often too high for these medically compromised patients.

Risk factors

Recently, investigators have also determined that factors unique to the oral environment, other than the restorative materials and technique, may significantly influence the clinical performance and retention of restorations. The dentin substrate, shape of the lesion and axial depth, arch: maxillary or mandibular, tooth position: anterior or posterior, oral hygiene, occlusion and occlusal stresses, presence of eccentric and/or centric occlusal contacts and/or wear facets, and the presence of tooth mobility, salivary flow or composition, nutrition and patient age are a few factors that should be considered (13, 54, 83, 87, 88). Especially the occlusal stress and dentin substrate are of importance.

Occlusion and occlusal stresses

Before any therapeutic measure can be decided, an analytical classification of the lesions based on a uni-, or multifactorial etiology should be made. Only recently, abfraction by stress corrosion and mechanical microfracture has been recognized in the multifactorial concept of tooth destruction. For the development of noncarious dental lesions, the etiology should be considered as a triad of abrasion, erosion, and abfraction, in which one or other factor dominates, while the others contribute (2–7, 26, 28, 89–92).The persistence of the stress factor after restorative therapy is usually underestimated.

Occlusal forces increase microleakage and gap formation at the cemental margin (93, 94). HEYMANN *et al.* (83) also found occlusal factors to be associated with decreased retention of restorations. If in heavy occlusion, a tooth undergoes elevated flexure, and this stress may contribute to adhesion loss between the dentin and the restoration.

The detailed *in vivo* investigations by HEYMANN *et al.* (83) have offered unprecedented support of the tooth flexure theory that was basically proposed a decade ago. In a series of clinical studies involving fairly large sample sizes, they determined that restoration retention in cervical regions depends on several factors, including the type of restorative material. Their work has given credence to the hypothesis that microfilled composite resins tend to "flex" with the tooth under stress rather than debond (47).

Maybe the most significant advice in the restoration of an abrasion/erosion/abfraction lesion is the correction of potential hyperocclusion of the tooth in question "before" starting the actual restorative procedure. The level of contact should be equalized to that of the adjacent teeth, checking the occlusal contacts in centric relation using articulation paper or ribbon. Occlusal adjustments and night-guard fabrication is recommended if the abfraction factor coincides. Treatment of lesions will be ineffective in the long term, unless the etiologic factors are eliminated (90, 95).

While routine mechanical preparation may not be required, as it was before the development of the new adhesives, some modifications of the surface are advisable. During mastication, the restored defect will build up strong shear stresses along the restoration-preparation interface. Research by several authors indicated that facial V-shaped cervical lesions (less than 135 degrees) retain restorations better than shallow, U-shaped cervical lesions (13, 31). They concluded that the U-shaped cervical lesions do not have adequate retention features to resist "deflection of the restoration" during occlusal loading. Mechanical retention may be required for these lesions (13). One should consider to establish a well-defined cervical groove along the cervical margin of the defect. This configuration can be generated by a conic burr. This procedure provides some extra mechanical retention of the restoration.

Older teeth have thin enamel as the result of years of wear. Increased flexure because of microfractures is also found in older teeth, thereby increasing the possibility of restoration loss in geriatric patients. However, whenever periodontal disease occurs with attendant mobility, teeth do not display flexure to the same degree because mobility dissipates stress concentration (6).

Dentine structure and composition. Smear layer

MJÖR in 1987 (23) suggested that the extraordinary divergence in dentin structure and composition may explicate the variable clinical comportment of dentin adhesives. Laboratory studies are normally conducted on ground teeth that contain ideal dentin, such as that in recently extracted third molar teeth or in bovine teeth (Figs. 2, 4a,b). Such unaffected teeth, as suggested by GWINNETT & JENDRESEN (69) are not representative of dentin present in teeth to be restored clinically, namely dentin affected by advancing caries or other pathologic erosive conditions.

The standard dentin substrate for clinical trials is the cervical abrasion/erosion lesion. Cervical lesions in dentin can vary greatly and are seldom, if ever, typical of ground dentin produced on unaffected teeth. Contrasting these two substrates, the natural cervical abrasion is normally without a smear layer because no grinding of the tooth is performed. Secondly, the dentin of the cervical abrasion has been exposed to the oral environment for years during maturation by several processes. The clinical appearance, the histologic, morphologic and compositional variation in those dentin surfaces that the dentist must treat depend on age, disease conditions, depth of erosion/abrasion and habits of the patient. The more sclerosis dentin presents, the less effective is dentin conditioning and resin adaptation (Fig. 5a,b). Greatest failure occurs in more sclerotic lesions. The clinical treatment must be specifically adapted to sensitive or non-sensitive lesions. In order to produce sufficiently retentive features for sclerotic lesions, one should eventually extend the application time of the etching agents, or use more aggressive ones, or simply remove sclerotic dentin during cavity preparation. Adhesive systems that recommend a total-etch pretreatment for both enamel and dentin with relatively aggressive acids seem to offer a reliable prospect of bonding equally well to various dentin substrates (67).

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