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Effect and Future Trends of Erosive Conditions on Tooth-Colored Restorative Materials: a review

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Abstract: Acidic environment is one of the causes for aggressive destruction of teeth and tooth-colored restorations leading to the dissolution of tooth structure and deterioration in the restorations' properties. Several attempts are found in the literature to resist these erosive conditions rendering the restorations to withstand the harsh chemical and acidic attacks.

Keywords: erosion, wear, tooth-colored restorations, acidic degradation.

Oral cavity is one of the harshest environments of the human body. Hence, teeth & dental restorations are regularly subjected to food & beverages that produce large variations in the oral pH and temperature. Dental restorations must be able to withstand these effects in a comparable or even better way than enamel. Dental erosion is a chemical process characterized by acid dissolution of dental hard tissue not involving acids of bacterial origin. It is also called 'biocorrosion': as it encompasses not only endogenous and exogenous acidic impacts, but also proteolytic degradation of the teeth induced by proteases from the gastric fluid (1).

1. Classification of wear (2):

Wear is the process by which material is displaced or removed by the interfacial forces which are generated as two surfaces rub together. Types of wear that occur in the oral environment are as follows:

a. Erosive wear: degradation of material due to impact of particles travelling with significant velocity.

b. Abrasive wear:

When two surfaces rub together, the harder of the two materials may indent, produce grooves in or cut away material from the other surface. This direct contact wear is known as two-body abrasion and occurs in the mouth whenever there is direct tooth-to-tooth contact. Abrasive wear may also occur when there is an abrasive slurry interposed between two surfaces such that the two solid surfaces are not actually in contact. This is called three-body abrasion, and occurs in the mouth during mastication, with food acting as the abrasive agent. Toothpastes also act as abrasive slurries between the toothbrush and the tooth.

c. Corrosive wear:

Occurs when a chemical reaction between the worn material and corroding medium leads to a loss of material on the worn surface.

d. Fatigue wear:

The repeated loading of teeth produces cyclic stresses that can lead in time to the growth of fatigue cracks. These cracks often form below the surface, and initially grow parallel to it before veering towards the surface or coalescing with other cracks.

2. Etiology of erosion (1):

a. Endogenous sources as stomach acid, gastroesophageal reflux disease (GERD) and eating disorders as bulimia or anorexia.

b. Exogenous sources from dietary habits like acidic beverages or food, lifestyle, occupational hazards (chemical industries) or acidic medications and patients with low salivary flow; xerostomia.

The most frequent type of dental erosions are dietary erosions that could be caused among other things by frequent intake of acidic beverages (e.g. fruit juices, or carbonated soft drinks). Their consumption leads to significant decrease of pH in oral cavity up to 15 minutes. However, these acids act not only on hard dental tissues, but also on all restorations materials found in the mouth (3).

3. Process of tooth erosion:

Early clinical signs of dental erosion are characterized by initial softening of the enamel surface with subsequent and/or progressive loss of volume, with a softened layer (i.e., less surface hardness) remaining at the mineralized tooth surface, loss of enamel texture, a silky glossy appearance and sometimes a dulling of the surface gloss, referred to as the "whipped clay effect", cupping of cusps on the occlusal surfaces and flattening of the occlusal structures. In later stages, occlusal morphology can completely disappear with hollowed out surfaces and restorations "standing proud" above adjacent tooth structures as shown in figure 1-3.

Figs. 1–3: Composite restorations in a patient still suffering from bulimia after intra-oral service of one year only. The restorations showed clear visible signs of marginal disintegration with loss of restoration fragments. Figs. 4 and 5: Occlusal view of upper posterior composite restorations after 5.5 years in service.

4. Consequences of erosive tooth wear

Once in contact with enamel, the acid with hydrogen ion (H3+) or its chelating capacity (from the anions in organic acids) begins to dissolve the hydroxyapatite crystal and release the minerals, figure 6 (1).

The critical pH at which enamel becomes susceptible to erosion is estimated to be 5.5. Hence, when an acidic material whose pH is at or below this level comes into contact with enamel frequently and for a prolonged period of time, enamel erosion occurs. In prismatic enamel, acid attacks lead to its demineralization. This is due to the dissolution of either the prism cores or the inter-prismatic areas. The eroded prismatic enamel may also have a microscopic honeycomb appearance. This is because the prismatic enamel is dissolved by acid, while the inter-prismatic enamel remains extended above the surface. In aprismatic enamel, the dissolution pattern is more irregular, with various degrees of mineral loss, figure 6 (4).

Dentine is more susceptible to erosion than enamel, and it can be eroded at a relatively high pH (6.0) due to the carbonate content of dentine is greater than that of enamel (6% versus 3%), and the crystals in dentine are much smaller than those of enamel. The latter structure makes more surface area of dentine available for an acid attack (4).

Two actions are responsible for the erosively induced tooth wear observed in the oral cavity (1):

1. Dissolution and loss of dental hard tissue & destabilization of collagen network which is directly induced by the acid attack.

2. Wear of the softened surface by mechanical impacts, such as toothbrushing, tooth-to-tooth contacts.

Recently the term "erosive tooth wear" was coined for this two-step chemical–mechanical process.

In severe situations, as in gastroesophageal reflux disease (GERD), A significant loss of tooth structure, vertical dimension, and/or function, hypersensitivity, esthetically unacceptable defects, and pulp exposure could occur (1).

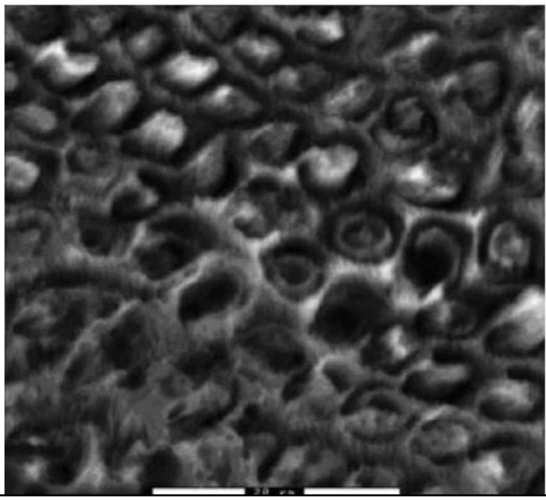

Figure 6. Prismatic structure of the enamel is clearly visible, and different etching patterns can be seen in different regions of the image. Protruding prisms can be seen in the top left of the image, protruding prism boundaries in the middle right and aprismatic enamel can be seen in the bottom left.

5. Role of Saliva:

Saliva is considered an important biological factor influencing dental erosion due to its ability to dilute, neutralizes, buffers acids, form acquired dental pellicle and remineralize eroded dental hard tissues. These protective mechanisms can be potentially reduced in patients with low salivary flow rate and/or low buffering capacity (5).

6. Treatment of teeth with erosions:

In the past, patients were left untreated, or the rehabilitation was performed with extensive crown and bridge work. However, as a result of the improvements in adhesive materials, it has become possible to rehabilitate eroded teeth in a less invasive manner to protect it using direct restorative material (RM) such as composite resins and glass ionomer cement (GIC). These materials are capable of reestablishing the function and esthetics of tooth structure as well as controlling the hypersensitivity. Before restoration of the teeth, abolishment of the causative erosive factors has to be achieved. Thus, nutrition control and/or medical and psychological treatment should be applied, and patients have to be instructed about measures how to prevent erosion using anti-erosive strategies and change of behavior.

Thus, for restoring and protection of the worn dentition, composite restorative materials and ceramic restorations are preferably used. Also, dentin sealants or desensitizers might be applied to protect and seal exposed dentin areas. These procedures might be beneficial at initial stages of hard tissue loss or when final restorations are not yet applicable (6).

Definitive treatment protocol (additive):

Once the etiology has been established and risk factors controlled, restorative management can be considered. When there is no compromise to the existing tooth structure, resin sealants, or bonding agents can be applied over the dentin. This may not only reduce sensitivity for a limited time period but may also slow down the progression of ETW. Restorations should be conservative and additive in nature, especially in mild and moderate lesions. Additive procedures can involve both direct resin composite and indirect ceramic partial coverage restorations. In advanced lesions where loss of occlusal vertical dimension may have occurred, more aggressive therapy to restore esthetics and function may be indicated. This includes full coverage crowns as part of an extensive oral rehabilitation. Regular monitoring and evaluation of ETW management should be done during recall visits (6).

Resin composite restorations, glass ionomer cement and ceramic restorations are usually used as treatment options to rehabilitate patients with erosion:

- Minimal Loss of Vertical Dimension <0.5 mm: surface Sealant or direct flowable Resin Composite. The sealing procedures must be repeated periodically; fortunately, to ensure stability of the new sealant.
- Loss of Vertical Dimension <2 mm: Direct Reconstruction with Composite Materials or glass ionomer restoration.
- Loss of Vertical Dimension >2 mm: Rehabilitation with indirect Ceramic Veneers and Overlays.
- Loss of Vertical Dimension >4 mm: Rehabilitation with indirect Ceramic restorations as crowns and bridges (7).

Although restorative materials are less susceptible to erosion compared to enamel, the erosive attack can induce, at least to some extent, the degradation of the matrix and fillers of restorative materials.

7. Effect of erosive conditions on different tooth-colored restorative materials

a. Effect of erosion on composite restorative materials:

Using composite for direct restorations allows for a minimally invasive treatment, only replacing the dental hard tissue lost under the erosive conditions. Additionally, using direct restorations might be regarded as an expectative approach allowing to render the patient familiar with the new vertical dimension. Composition of composite materials has a certain effect on the erosion of the surface of composites. Mechanism of erosion is the hydrolysis of ester radicals present in dimethacrylate monomers, i.e. BisGMA, UDMA and TEGDMA.

Organic acids dissolve Bis-GMA polymers more easily causing leaching of the diluent agents such as TEGDMA. The softening and hydrolysis of the resin matrix could promote displacement of the filler particles, contributing to the formation of a rough surface and protrusion of fillers as a result of matrix degradation.

Under persisting acidic and erosive conditions using dietary acids, hybrid and nano-hybrid composite restorative materials have been shown to be resistant to acidic attacks compared to glass-ionomer restoratives. However, the erosive challenges degrade the resin matrix or the silane coupling agent, resulting in the loss of filler particles. There is a linear relationship between wear resistance by acids and the filler volume (8).

Biodegradation phenomenon is a complex process that may lead the composite polymer matrix to collapse, causing several problems such as filler-polymer matrix debonding, release of residual monomers, wear and erosion caused by food, chewing and bacterial activity. This process may deteriorate the mechanical properties of the material and reduce the clinical life of composite resin restorations. Furthermore, surface disintegration of composite resins may increase wear and plaque retention, thus decreasing the longevity of the restoration, and potentially increasing the risk of secondary caries.

Effect of erosive conditions on microhardness and surface roughness of resin composite restorations(9):

- Nanocomposites are the most stable under erosive conditions with higher wear resistance and microhardness values. This is due to nano-sized regular particles, which allow the incorporation of a large volume of inorganic fillers.
- Surface roughness values of nanocomposites after erosive challenges are lower than hybrid composites due to homogeneous composition and their particles are less prominent on the surface.
- Resin materials that have larger filler particles presented greater surface micromorphology changes when submitted to acidulated phosphate fluoride (APF) gel, i.e., Fluoride ions causes depolymerization reaction of the coupling agent so that weakening the interface between the filler and matrix, resulting in the release of the filler particles, causing the filler particles to project out thereby increasing surface roughness.
- APF typical dissociation reaction in the solution results in H+ & F ions that forms hydrofluoric acid (HF) a known glass etchant which dissolves glass particles , dissolves composite filler particles and fluorosilicate glass particles that contribute to decrease in surface hardness. Organic esters in the methylmethacrylate matrix undergo hydrolytic cleavage of the ester group in low pH.
- Fluoride ion has been implicated in depolymerization reaction of the matrix filler interface. Possible mechanisms may explain the interaction pathway of fluoride which are hydrolysis of the organosilicon ester group and disorganization of the siloxane network formed from the condensation of intramolecular silanol group which stabilizes the interface (10).

Effect of erosive conditions on adhesive bonding strength and microleakage of resin composite restorations (11) :

• Composite specimens subjected to erosive attacks showed microleakage and decreased bond strength of etch- and-rinse and self-etching adhesives.

•The effects on bonding are more pronounced on enamel than on dentin because erosion primarily affects the inorganic part of the tooth and bonding to enamel is mainly achieved by a micromechanical interlocking of resin into microporosities of the acid-etched surface. However, in case of GERD, the gastric protease (pepsin) leads to organic matrix degradation and progression of erosive lesions in dentin.

Influence of fluoride releasing restorations in inhibiting erosion of adjacent enamel(12):

Inability of the fluoride-containing restorative materials to prevent erosion in the vicinity of the restorations. Due to the low levels of fluoride released by the materials and/or the high aggressiveness of the erosion when compared to caries.

Influence of topical fluoride varnishes in inhibiting erosion of adjacent enamel(13):

However, topical fluoride varnishes with high concentrations are shown to be effective in increasing enamel microhardness thus reducing erosion, since varnishes creates a calcium fluoride (CaF_2) layer acting as a physical barrier hampering the contact of the acid with the underlying enamel or to act as a mineral reservoir which is attacked by the erosive challenge. Thereafter, released calcium and fluoride might increase the saturation level with respect to dental hard tissue in the liquid adjacent to the surface, thus promoting remineralization.

The protective effect of fluoride varnishes is mainly related to the mechanical rather than to the chemical protection and the anti-erosive effect of conventional fluorides requires a very intensive fluoridation regime.

-Recent trends to overcome erosions using resin composites

1. CAD/CAM designed ultrathin composite occlusal veneers yielded a decreased risk of failure as compared to lithium disilicate ultrathin occlusal veneers. The use of ultrathin occlusal veneers might be regarded as a conservative approach to treat erosive lesions, with the aim to save as much dental hard tissue as possible.

2. CAD/CAM composite restorations (hybrid ceramics or nano-composite compositions) behave similarly or even better than human enamel with respect to two-body wear and toothbrushing wear.

3. Incorporation of bioactive components into composite resins may be an advantageous alternative for restorations in patients frequently exposed to erosive challenges, due to the release of ions that could play a relevant role in the erosive tooth wear process by promoting tooth remineralization E.g., dicalcium phosphate dihydrate particles(14).

4. Application of Surface penetrating sealants are unfilled/nanofilled low-viscosity resins polymerized on surface of resin composite to preserve or improve its properties. It is applied to fill the cracks, decrease the porosity, increase the wear resistance, and maintain the marginal integrity of restorations (15).

5. Giomer's technology was developed to enhance material properties, providing wear resistance associated to fluoride release. Surface Pre-Reacted Glass-ionomer (S-PRG) fillers (fluoro-boro-aluminosilicate glass and a polyacrylic

acid solution) release multiple ions including F− Sr2+, Na+, BO33- , Al3+, and SiO3 which results in the buffering action and prevents enamel demineralization around the material (16).

b. Effect of erosion on glass ionomer restorations:

Compared to resin composite, glass ionomer cement is more unstable and experiences a decrease in hardness values and an increase in surface loss under erosive conditions. This is due to the dissolution of the silicate-glass hydro-gel network peripheral to the glass particles. Conventional glass ionomer (GI) restoration shows lowest micro-hardness and highest surface degradation compared to resin modified glass ionomer (RMGI). Moreover, conventional GI does not provide enough protection against erosion for the surrounding enamel and dentin because it shows more marginal than bulk degradation. Therefore, it is preferable to use them in a closed sandwich restoration rather than leave them exposed directly to this environment. Then if any leakage of acid occurs, some protection against demineralization may be provided to the adjacent tooth structure by the GIC (17).

Release of ions such as fluoride, sodium, phosphate and silicate have also been found to increase at lower pH values due to the presence of higher amounts of H+ ions and these attack the cement matrix, causing release of ions and consequently dissolution (18). This may be accompanied by an increase in the pH of the acid solution, because of the glass ionomer buffering effect is likely to be beneficial in protecting the teeth from the occurrence and evolution of dental erosion(19).

RMGI is less susceptible to acidic degradation compared to conventional GIC, due to the presence of reinforcing and higher acid resistance resin matrix. Therefore, RMGI provides protection against erosion for the surrounding enamel and dentin and can be considered material of choice among fluoride releasing materials for restoring erosive lesions in patients at higher risk for erosion in contrast to the conventional GI (14).

However, the increase in the surface roughness of RMGI is due to the matrix dissolution peripheral to the glass particles, which could be the result of dissolution of the siliceous hydrogel layer (20).

c. Effect of erosion on dental ceramics surface roughness and hardness:

Although dental ceramics are chemically inert, their chemical stability is influenced by the elemental composition, microstructure, and chemical character of the erosive agent, and changes in oral temperature and exposure time.

It is important to understand the two phases present in a ceramic, i.e., a crystalline phase and a glass phase. When a low pH solution (acidic in nature) comes in contact with ceramic, it attacks the glass phase, causing its breakdown and release of crystals into solution, which affects the kinetics of ion release and ultimately leads to dissolution and a roughened ceramic surface.

In an acidic environment, there is anion exchange between the protons present in erosive solutions and network modifiers (Ca, Zn, Li) in ceramic bulk.

The risk of acidic environment lies in its chelating effect that can cau se degradation, ionic dissolution and leaching out of alkaline lithium and aluminum ions, which are less stable in the glassy phase than in the crystalline phases, and results in the dissolution of the ceramic silicate network leading to crack propagation, roughening, plaque accumulation, discoloration, and weakening of ceramic structure (21) (22).

Strong acids such as HCl from gastric regurgitate (GERD) can etch the surface of glass-based ceramics, resulting in increased surface roughness and a decrease in the hardness values of the ceramic restorations. Local hydrolysis in ceramic cracks is accelerated in acidic pH, as GERD, leading to crack propagation and, hence, ceramic corrosion. The subsequent increase in surface roughness can increase the accumulation of bacterial plaque on the ceramic restorations (23).

Strong acidic compounds, such as hydrofluoric acid and acidulated phosphate fluorides (APFs) are able to etch the surface of both glass and feldspathic based ceramic materials. This detrimental effect of APF gels is already existent after a 4 min exposure of metal-ceramic and all-ceramic glass-based materials. APF gels are used for either fluoridation regimes but may also be used for pre-treatment of glass-based ceramics in repairing protocols. In the case of hydrofluoric acid, its etching property is used in the pre-treatment of glass-based and feldspathic ceramic restorations before adhesive luting to dental hard tissues(1).

When dental ceramic restorations are exposed to erosive beverages they produce surface degradation, subsequently leading to crack propagation within the ceramic structure. This phenomenon is a result of leaching out of the alkali ions, which tend to be less stable in the glass phase in comparison to the crystalline phase. As a consequence of such degradation, the exposed ceramic surface will eventually be roughened, thereby promoting greater plaque accumulation, discoloration, and weakening of ceramic structure as well as resulting in the wearing of antagonist natural teeth and restorations (24).

Zirconia is the most resistant material against acid attack. This may be due to their polycrystalline microstructure that provides strength and fracture resistance. Additionally, the absence of a glass phase makes the polycrystalline ceramics more resistant to acid attack.

Lithium disilicate has a different microstructure than zirconia that render it more prone to acid attacks. It contains approximately 70% of the volume of needle-like crystals in a glassy matrix, making it more prone to corrosive acid compared to zirconia. Acids might cause a disruption to the silica phase of lithium disilicate through leaching out of alkaline ions such as Al, Si, and Zr (25).

Figure 7. Emax occlusal overlay with 0.5-0.6mm thickness for restoring vertical dimension lost due to erosion using e-max press ingots.

Figure 8. Anterior porcelain palatal veneers restoring eroded incisal edges.

Example of acid attacks effect on microstructure of restorative materials (26):

Scanning electronic micrographs visualize the conventional GIC group that the acid episodes caused cracks in the microstructure of this material, which increased in number and size with the following episodes, figures 9. Similar images were obtained for RMGIC, however, this material showed a smaller amount of cracks, which were only more evident after one month of immersion, figures 10.

The direct resins showed similar results regarding to degradation, which was proved by the images showing, as time went by, a degradation of the polymeric matrix with consequent increasing of roughness and decreasing of microhardness (Figure 11). The images of the ceramic showed that this material, although suffering a degradation as the immersion time went by, underwent a smaller degradation than the other materials. It can be seen in the images the maintenance of the surface during the first two readings, and the presence of bubbles and grooves on the surface of the material, suggesting a slight degradation, figures 12.

SEM images of all materials tested at the different phases of evaluation of the samples (initial, 7 days and 30 days), at x 10,000 magnification, figures 9,10,11 and 12:

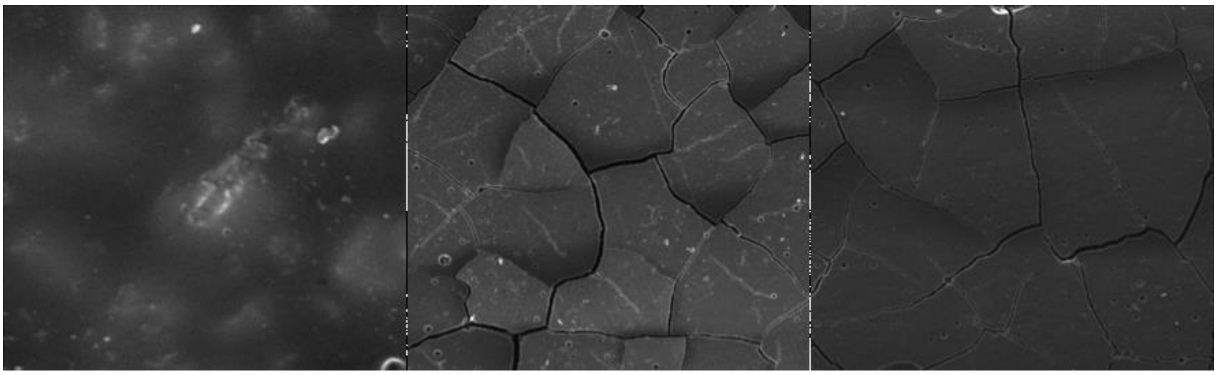

Figure 9. Photomicrography; Glass Ionomer Cement (Vidrion): a) initial reading; b) second reading; c) third reading.

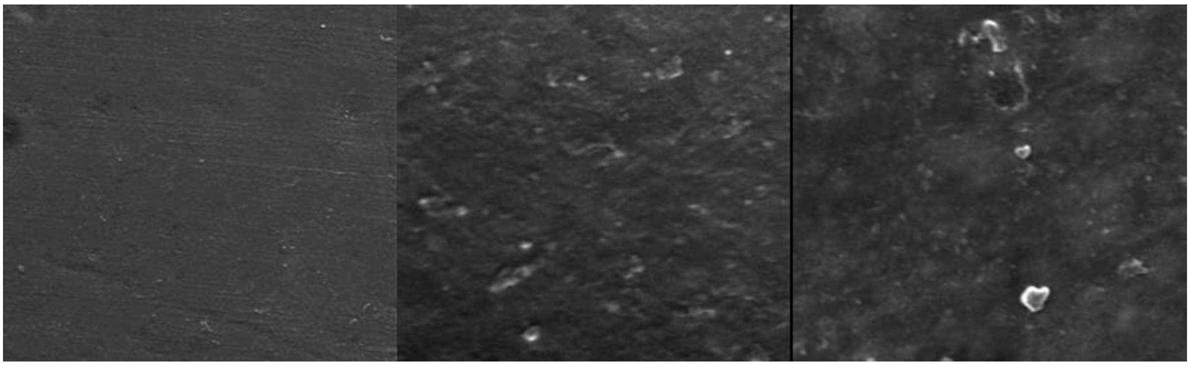

Figure 10. Photomicrography - Direct Resin (Z350): a) initial reading; b) second reading; c)third reading.

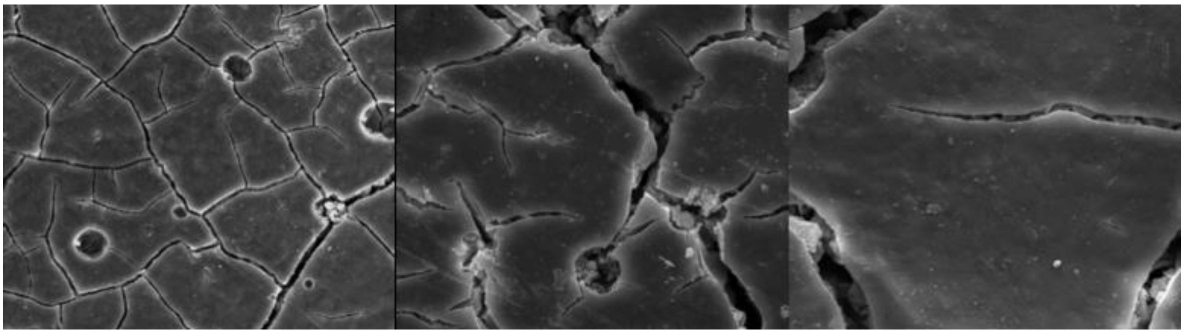

Figure 11. Photomicrography - Resin-modified Glass Ionomer Cement (Vitremer): a) initial reading; b) second reading; c) third reading.

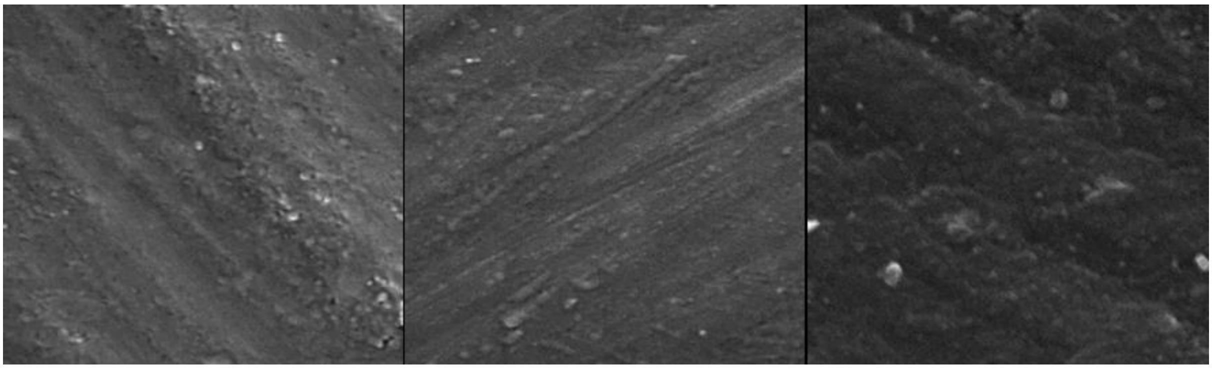

Figure 12. Photomicrography Ceramic (Empress II): a) initial reading b) second reading; c) third reading.

Conclusion:

Under acidic conditions all restorative materials show degradation over time (surface roughness, decrease of surface hardness, substance loss). However, ceramic materials and resin composites present much better durability than conventional glass-ionomer cements and resin-modified glass-ionomer cements and that the latter materials should not be used in erosion patients.

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