

# Replacing Amalgam Restorations : A Standardized Protocol Based on Analyzing Tissue Physicochemical Modifications

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## ABSTRACT

Almost 60% of operative dentistry is devoted to replacing restorations. When practitioners have to replace an amalgam restoration, they tend to opt for an adhesive restoration, as it is conservative of tooth tissues and mimics the natural appearance of teeth. Based on a literature review, the aim of this article is to determine the best tissue approach when replacing an old amalgam by a new adhesive restoration. After analyzing and understanding tissue alterations due to the amalgam corrosion process, the authors propose an analytical approach to managing the situation. Both tissue orientated and specific mechanical approaches are developed and should be implemented to carry out the optimal clinical procedure and achieve the most conservative and durable treatment.

## INTRODUCTION

A significant part of operative dentistry is devoted to replacing restorations which has become a routine dental procedure. As soon as possible, defective amalgam restoration should be repaired. However, when practitioners have to replace a damaged amalgam restoration, they can opt for an adhesive restoration, as it is conservative of tooth tissues and mimics the natural appearance of teeth.<sup>1</sup>

Still, given the intrinsic advantages of amalgam restorations, that have been shown tolerant and long-lasting, any retreatment should be as successful. After individual risk assessment, clinical analysis should enable adhesive restorations to have the same success rate and achieve biological, functional and esthetic objectives.

Once exposed to the oral environment, this metallic alloy undergoes electrochemical corrosion that alters tooth tissues irreversibly. These tissues are used as the substrate for the replacement adhesive material. Therefore, it is important to examine the advantages -antibacterial properties- and the disadvantages -obstacles to bonding- of the corrosion products found in the tooth-amalgam interface. It is also necessary to observe the effects on both pulp and dentin tissues to promote tissue preservation and optimize bonding conditions.

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The aim of this article is to develop toughness about procedures for replacing amalgam restorations by composite. Our propositions will be based on analyzing and understanding tissue alterations caused by the physical and electrochemical properties of the material.



**Figure 1:** Amalgam restoration that needs replacing

## I. AMALGAM CORROSION AND ITS EFFECTS ON DENTAL TISSUES

Corrosion is an irreversible interfacial reaction of a material with its environment. This results in consumption of the material or dissolution into the material of an environmental component.<sup>2</sup> Amalgam corrosion is mostly due to an electrochemical oxidation, as a metallic alloy made of reactive metals is placed in an electrolytic solution – saliva. Thus, wet corrosion occurs in this environment which contains oxygen and chloride.<sup>3</sup>

Dental amalgam is a combination of mercury silver, tin and copper and sometimes, smaller amounts of zinc, palladium or indium. Thus, this dental alloy undergoes irreversible corrosion<sup>3</sup> which permanently alters tooth tissues. The metals present in amalgams have been shown to exhibit selective ionization of oxidable components so that amalgams gradually change over time when exposed to the oral environment. Therefore, Sn, Zn then Cu undergo oxidation and the noble metals (Hg and Ag) concentrate in the superficial layer of the amalgam.<sup>4</sup> The oxides that are formed are not highly soluble. While some are eliminated, others are retained in the tooth-restoration interface where they cause tissues modifications and exert antibacterial activity.<sup>5</sup> Those « corrosion products » are released within tooth tissues, most of them within the dentine.

**Table 1: Enamel permeability scales**

Enamel	Permeable to ions	Semi permeable to large molecules	Bacteria proof (with intact enamel)
<b>Order of magnitude :</b>	10 <sup>-18</sup> m (attometer-size) (size of ions)	10 <sup>-9</sup> m (nanometer-size) (size of molecules, interprismatic space)	10 <sup>-6</sup> m (micrometer-size) (size of bacteria, enamel prism)

**Table 2: Dentine permeability scales**

Dentin	Permeable to ions	Permeable to molecules	Permeable to bacteria
<b>Order of magnitude :</b>	10 <sup>-18</sup> m (attometer-size) (size of ions)	10 <sup>-9</sup> m (nm) (size of the dentin intertubuli space)	10 <sup>-6</sup> m (micrometer) (size of the dentin tubuli diameter, or of the dentin matrix crystals)



**Figure 2:** Corrosion products

In amalgam restorations, corrosion occurs in the occluded oxygen-deficient areas, predicted by the Evans effect (oxygen concentration cells). Because of a mechanism of differential oxygenation,<sup>3</sup> corrosion products will build up along the marginal area, i.e., below the proximal contact point and below the filling. As soon as the amalgam is placed, differential pitting corrosion occurs, as shown by the Evans effect. The resulting metallic oxides -electronegative compounds- are released in the dentine. This galvanic cell is then maintained by the saliva electrolyte at the amalgam-dentine junction.<sup>3</sup>



**Figure 3:** Concentration cell

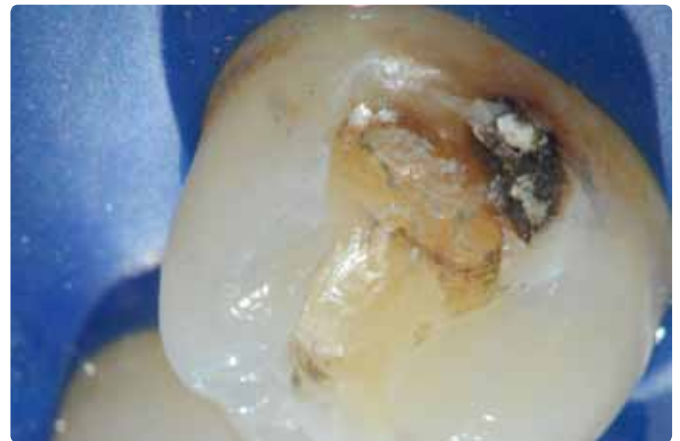
A wide variety of corrosion products has been identified:<sup>6</sup>

- copper and tin oxides
- tin and zinc simple hydroxides and hydroxide complexes
- copper and tin oxy- and hydroxychlorides
- copper chlorides
- silver, copper and mercury sulfides

These ions and molecules are released at the tooth-material interfaces and progress to the restoration margins. Their minuscule size enables them to infiltrate dentin tissues and modify their composition. Due to low solubility, they tend to form precipitates that are able to penetrate the ultrastructure of the dentin.<sup>7</sup> Their transforming and penetrating capacities are determined by the order of magnitude of corrosion products -nanometer level- and their agglomerates -0.1 micrometer.

Thus, while marginal corrosion presents antibacterial advantages, the release of corrosion products in the tissues may have negative consequences for the tooth and for any future treatment.

The biological effects of corrosion on enamel have not been studied extensively. This may be because the non-mineralized spaces between the prisms are only a few nanometers wide and they are filled with proteins and water. This makes it possible for corrosion products to pass through and diffuse into the tissue. These effects are not very significant but they may occur micro-cracks. That is why, in the case of posterior restorations, the quality of the enamel margin has to be assessed. Corrosion products can also remain on the enamel surface after the amalgam has been removed.



**Figure 4:** Amalgam residues on the enamel margin of a premolar

Enamel is a semipermeable barrier, which is almost impermeable due to its highly mineralised nature and structure.. When intact, its permeability to ions and to small neutral molecules is very low.<sup>8</sup> The enamel surface will block the passage of large precipitates which will accumulate at the tooth amalgam interface. There is little corrosion-related histological modification of the tissue. Nevertheless, these aggregates have an effect of surface pollution. The corrosion phenomenon is more severe in the deepest areas of the restoration and occurs mostly in the deep layers of the dentine.<sup>3</sup>

Unlike enamel, dentine is much more permeable, due to its organomineral structure (high organic matter and water content, porous nature and tubular structure. Its fluid-filled tubules enhance the corrosion process, and enable progression of larger oxidation products. Penetration is therefore much faster and deeper than in the enamel tissue.

Clinically, removing an amalgam restoration often reveals a layer of darkish dentine of variable thickness typical of the corrosion process. The deeper the layer or the more deprived of air it is, the darker. Indeed, this deep dentine is both more fluid filled and permeable, and more anaerobic. The spectrophotometric analysis of the layer shows that tin is always present and zinc or copper may be found at the amalgam-dentine interface. Even when the dentin beneath the amalgam is not discoloured, there is metal ion release from the contact

surface area. This can be as deep as a few tenths of a millimetre.<sup>7,9,10</sup> Over the time ions progress with a penetration in order of 1 or 2 mm and results in visible corrosion products.<sup>11</sup>

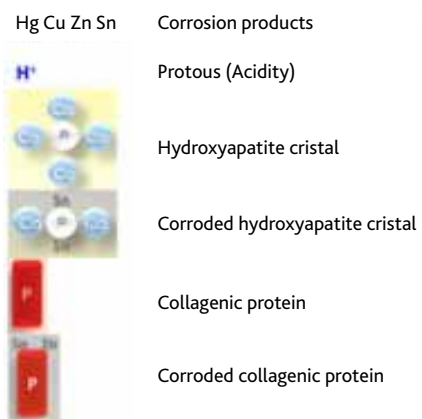
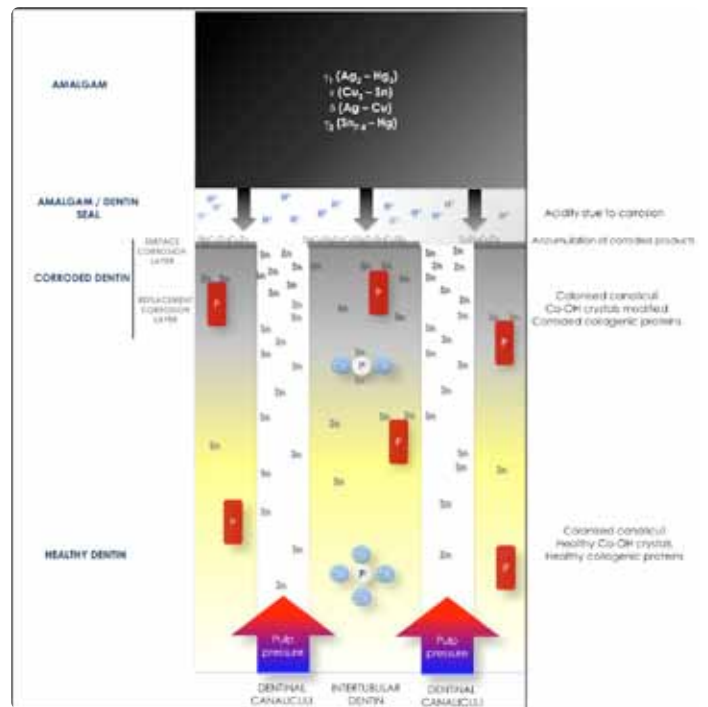
The intrinsic corrosion of the material and the release of electronegative compounds, aggravated by the differential oxygenation process, entail a more acidic environment and a rise in protons and chloride. The acidity may induce dentinal demineralization. Lower pH levels then break down hydroxyapatite crystals and calcium is replaced by tin and zinc.<sup>9</sup> The process is fast and it occurs within 30 to 60 days of amalgam placement. The depth of the structural modification depth corresponds to the dentine demineralization depth. Thus, darkish dentine is eventually composed almost only of crystals made of phosphate and tin or zinc compounds.<sup>6</sup>



**Figure 5:** Corroded layer of dentine after amalgam removal

In short, the acidity from the amalgam-tooth interface demineralizes the dentine surface and releases collagenic proteins. The corrosion products bind to them and accumulate to form the surface corrosion layer, i.e., the darkish coloration which is clinically visible when removing the amalgam. The metallic oxides then extend into the dentine. The calcium ions are replaced by tin and zinc ions to form the replacement corrosion layer. The layer exists even in the case of non discoloured dentin.<sup>7</sup> Deeper in the tissues, corrosion products are released mostly within the dentinal tubules along an age-related concentration gradient, with concentrations getting lower as the further away the zone is from the restorative material.<sup>11,12,13,14</sup>

However, it is necessary to distinguish between the dentine of vital and non-vital teeth since they have very different permeabilities.



**Figure 6:** Overview of the release of corrosion products within the dentin of a vital tooth.

It is important to remember that dentine in contact with the material undergoes both structural and physicochemical modifications. Today, these processes need to be taken into account when placing adhesive restorations that will meet the treatment objectives both biologically and in terms of restoration longevity.

## II. DISCUSSION

### A. PROBLEM ANALYSIS

Amalgam corrosion entails modifications in tooth tissues which may negatively impact replacement treatments and possible future restorations. That is why one should examine the various aspects of the clinical situation during subsequent tissue preparation.

So far, there is no evidence of biological toxicity of the corroded dentine layer -surface and replacement layers- to the dentine-pulp complex. On the contrary, it seems corrosion products can counter dentine permeability by blocking the tubules with aggregates.<sup>15</sup> This gives some indirect pulp protection by rendering the tissue less permeable. Combined with the bacteriostatic and bactericidal properties of the corrosion products, it reduces the risk of secondary caries formation.

The mechanical resistance levels of the corroded tissue -replacement layer- are almost unchanged by the effects of corrosion on dentine. However, specific retentive designs are used for amalgam cavities (undercuts, secondary retention form). In clinical situations which involve extensive tissue loss, adding retentive features may further weaken a low-resistance wall and promote cracks at the amelodentinal junction.<sup>16</sup>

Clinically, similar cracks are often present in large amalgam-filled teeth. Based on scientific papers, a significant difference in crack prevalence has been shown between amalgam restorations and composite restorations<sup>17</sup> and between amalgam restorations and healthy teeth.<sup>18</sup>

The Opdam study examined a sample of 1949 teeth over twelve years and noted a 5.9% incidence fractures in amalgam restorations, as opposed to a 1.3% incidence of fractures in composite restorations and more importantly 4.5% cracks in amalgam restorations as opposed to 0.1% in composite restorations.

Several hypothesis account for this phenomenon :

- The physical properties of amalgams and dental tissues differ greatly (modulus of elasticity (Amalgam (41 GPa) - Tooth (20 GPa)). Coefficient of thermal expansion (Amalgam (22–28 ppm/\_C) - Tooth (8–11 ppm/\_C)).) Thus, stress distribution is poor.
- Amalgams undergo slow gamma-1 to beta-1 phase transformation which leads to expansion and consequently fracturing and crack formation of tooth tissues<sup>19</sup>
- The physico-chemical characteristics of corroded dentine and its modified modulus of elasticity are less prone to absorb stress.
- The lack of cohesion between dentine and amalgam increases stress distribution.
- The undercut design of a cavity promotes stress concentration at the bottom which makes it more likely to crack.

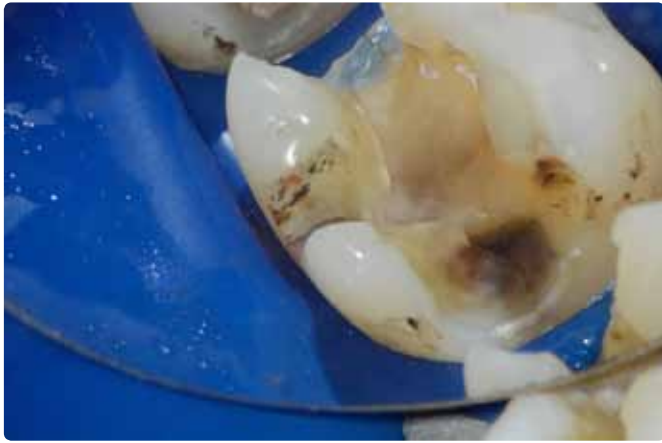
- The effects of amalgam creep

Thus, microcracks occur as a consequence of masticating forces on weakened cusps, together with the different physical and chemical properties of amalgams and dental tissues. Due to repeated occlusal forces, fatigue cracks may appear and extend over time associated with pulpal or mechanical consequences.

The darkish color of the layer of corroded dentine precludes aesthetic integration of restorations in the visible zone. The corrosion products cause pigmentation, known as metallic pigmentation (as opposed to organic chromophores from protein degradation in a non-vital tooth).<sup>6</sup> Bleaching treatments have no effect on metallic discolouration. For aesthetic purposes, it should be necessary to remove all the stained tissues mechanically or cover it in case of pulp proximity.

The quality of adhesive restorations depends to a great extent on the quality and permanence of the restoration to tooth bond. Many studies have compared bond strength values on corroded dentine, compared to healthy dentine.<sup>20</sup> The results show that the strength of the bond to corroded dentine is much lower than to sound dentine, whichever bonding protocol is used (self-etch or etch and rinse systems). In addition, most failures obtained during tests are adhesive, i.e., which occur at the composite-dentine junction, and not cohesive fractures, i.e., within the material.<sup>7,20</sup>

Corroded dentine has a normal tubular structure. The penetration of metallic ions modifies its permeability and accounts for the reduced shear bond strengths. Three hypotheses have been developed to account for the reduced adhesive performance.<sup>21,22</sup>



**Figure 7:** Distal crack underneath amalgam restoration

The first hypothesis suggests that the corrosion products released by the restoration in the dentinal fluids cause plasma proteins to precipitate. This lowers dentine permeability and interferes with adhesive infiltration during bonding.

The second one suggests that the metallic elements from the amalgam corrosion products are found at the surface of the collagen fibers. They can affect resin monomer polymerization by inhibiting the initial oxidizing-reducing reaction. Thus, no corroded collagen fiber can react with the resin monomers to ensure optimal polymerization. Furthermore, the mechanism that initiates polymerization seems to depend on the amount of metallic particles. Excessive zinc delays the polymerization reaction of a resin monomer.

The third hypothesis is that the heavy metals (Hg) that may have been released by the corrosion phenomenon, would reduce the acid solubility of the corroded dentin, thus interfering with the bonding protocol as early as etching.

Whatever hypotheses are valid, bonding failures due to corroded dentine modifications has been confirmed.<sup>20</sup> Therefore, it is necessary to conduct a systematic clinical analysis of both the cavity preparation and the selection of materials whenever placing direct or indirect bonded restorations.<sup>15,21,22</sup> The recommended protocols are mentioned below.

Depth and penetration kinetics of corrosion products within dentine vary with time. It has been shown that the corrosion layer -surface layer and replacement layer- could be as thick as 1 or 2 mm on teeth that have been restored with amalgam for many years.<sup>11</sup> Very small amounts of tin and zinc ions are present in all of the coronal dentine and then of the radicular dentine. This shows that the amount of corrosion products continuously increases over time, from the moment when the corroded material stays in contact with the dentin surface.<sup>11</sup> From the first day, corrosion products rapidly progress through the dentin (25 to 100  $\mu\text{m}$ ) then progress seems to slow very gradually over time but never really stops. Only when the amalgam is removed, does it slow down and stop.

## B. SPECIFIC CLINICAL ANALYSIS

Today, when an amalgam needs replacing, practitioner can use direct or indirect adhesive restorations -composite or ceramic restorations.

In case of treatment of a vital tooth, we suggest a specific analysis of the clinical situation to implement the most appropriate therapeutic protocol to minimize the risks of adverse effects and maximize the success rate of the new restorations.

Observing the tooth in the arch to assess its visibility when smiling is the first element in the decision-making process. This allows one to estimate the needs for tissue preparation and for removal of the discolored replacement layer of the corroded dentine.

Observing the restoration that is to be removed prior to starting the procedure gives indications on the damage of the underlying tissues ; how old the amalgam is, how well preserved the material surface is, how advanced its marginal deterioration rate is ; all these give a predictive approach of the state of tissues when removing the amalgam. A bitewing X-ray is useful to estimate the depth of the restoration and its proximity to the dental pulp cavity.

Observing the tissues that have been removed requires a different analysis depending on substance loss. We suggest to consider two types of situations : on the one hand, little coronal substance damage, on the other hand, extensive tissue damage (pulp proximity, weak residual walls).

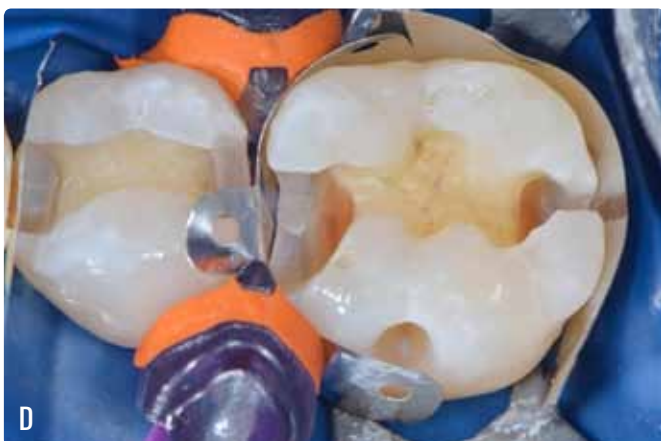
Based on these observations, we suggest guidances for dentine preparation in different clinical situations

## C. IMPACT ON CLINICAL PROCEDURES:

### i. Little substance damage

This is the most favorable situation as loss of enamel and dentine is minimal and the dentine along the axial and pulpal walls is sufficiently thick. To optimize bonding efficacy, it would be appropriate to remove all the corroded dentine. Then, we could proceed in the elimination of the stained tissue or, if it is not discoloured, a thin surface layer of approximately 0.5 mm, to obtain a dentine surface adapted to hybridization. In these instances, this microsurgery will have no impact either on the mechanical resistance of the tooth, or on its pulpal health (clinical case).

However, the reactionary dentine layer, that is often observed in case of old restorations, should be left untouched to maintain the natural protection of the pulp due to the reduced dentine permeability of this tissue. The bonding protocol will thus be carried out optimally.<sup>15</sup>



**Figure 8:** Clinical case with little substance damage

Removing the corroded dentine layer from a small restoration is absolutely necessary to restore optimal bonding strength. This procedure is to be performed with an excavator, a round tungsten or diamond bur or by means of air abrasion or ultrasonic abrasion. This protocol that is well-adapted to the replacement of small-sized restorations is conducive to optimal esthetic integration and ensures the best adhesive seal.<sup>21</sup>

## ii. Extensive substance damage

When damage is deep and extensive, analysis needs to be more thorough and is based on two different levels of observation – the histological characteristics and the mechanical parameters.

### 1. Tissue approach

Preparing the cavity after removing the amalgam is similar to managing deep extensive caries - a centripetal, differentiated protocol for tissue elimination has to be followed. The objective is to ensure the peripheral seal of the restoration as well as to limit pulpal involvement. The first step is to adjust enamel contours to achieve a healthy peripheral dentinal surface, particularly at the enamel-dentin junction, to obtain the best marginal fit and optimal bonding strength values (in the range of 30 to 55 MPa).<sup>20</sup>

The second step consists in carefully removing the corroded dentine from the whole cavity floor, except at juxtapulpal walls. Given corroded dentine bonding strength values are lower by about 20 MPa,<sup>20</sup> it is important to retain only a small surface. This approach may be likened to that used to treat deep carious lesions.<sup>23</sup>

This approach strikes a good balance as it makes it possible to use the peripheral dentine surface for bonding and leaves bioactive self-sealing corrosion products next to the pulp. It provides pulp and dentine protection. Hence, bonding protocols can be implemented on these surfaces directly, with no dentine substitutes.

If a dentine substitute is necessary (sandwich technique), using a glass ionomer cement seems to be the best solution to obtain adequate bonding strength. Theoretically, its capacity to form a chemical bond with metal oxides makes it appropriate.<sup>24,25</sup>



**Figure 9:** Clinical case showing extensive damage of coronal tooth tissue

## 2. Mechanical approach

Like all the extensive substance damage the biomechanical analysis is standardized before restoration. The criteria used are as follows :

- Extent of substance damage
- Number of remaining walls
- Deflection of walls (shape, deformation potential, height-to-thickness ratio)
- Occluso-functional analysis

Replacement treatments after amalgam restoration need to be conducted carefully. Analysis is required to estimate if a wall with unknown mechanical characteristics does not combine the effects of the corrosion process and/or the time-related stress: the presence of corroded dentine and/or enamel-dentin cracks. These additional clinical observations require perfect observing conditions, i.e., operating field, dry surface, optical aids with bright lighting to be able to identify the negative parameters.

Once the negative clinical parameters have been noted, a suitable therapeutic approach should be adopted. Generally speaking, it is advantageous to cover the walls that still contain some corroded dentin to limit the risks of fractures or postoperative sensitivity due to possible structural deformation.

To treat existing cracks, it is necessary to track their paths. The final decision may range from occlusal equilibration combined with an adhesive procedure, to elimination of the weakened part, covering it with the restoration.<sup>26</sup>

## CONCLUSION

Given the high number of amalgam restorations which require replacement, any retreatment may aggravate the situation and the second restoration may not be as durable as expected. Therefore, this procedure requires.

Despite the lack of scientific evidence and clinical limitation in the ability of tissues control, it seems reasonable to have the most appropriate approach.

In the current state of our knowledge and with our clinical expertise, we develop thinking based on an understanding of the modifications and consequences caused by amalgam corrosion and we propose an analytical protocol.

The clinical decision depends on tissue damage and the therapeutic procedure should enable to provide the most conservative and the most durable treatment.

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