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Original Article

Evaluating the Effectiveness of Silver Nanoparticle-Modified Dental Fillings on Enhancing Hard Tissue Durability

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ABSTRACT

This research investigates how the use of an etching gel containing silver nanoparticles (Ag NPs) affects the structural integrity and bonding strength at the “dentin-filling” and “enamel-filling” interfaces in permanent teeth with poor caries resistance in hard tissues. Teeth samples were taken from individuals aged 18 to 60 years, who underwent extractions for medical purposes. Adhesive systems from the IV and V generations were used for sealing, and both fluid and packable composites were selected as the filling materials. For metallographic analysis, the samples were cut perpendicular to the tooth axis, mechanically polished, and treated with concentrated orthophosphoric acid. Microscopic examinations were performed using both light and scanning electron microscopes. The findings show that the etching gel does not reduce the cohesive strength of the interfaces, even with the inclusion of silver nanoparticles.

Keywords: Etching gel, Cavity, Silver, Dental filling

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Introduction

The breakdown of the adhesive bond at the “dentin-filling” and “enamel-filling” junctions is a primary contributor to the formation of secondary caries, a problem that remains a significant challenge in dentistry [1-3]. A potential solution to mitigate this issue is remineralizing therapy, which helps maintain the bioorganic structure in dentin that has been affected by demineralization [4, 5]. Consequently, the addition of silver nanoparticles (Ag NPs) to dental materials shows promise in combating secondary caries due to their potent antibacterial effects [6-8].

In healthcare, Ag NPs have a broad range of applications, including wound healing, surface sterilization, and coatings for implants [9-12]. The ongoing development of Ag NPs production methods is essential due to the imperfections of current technologies, with a focus on enhancing the stability and bioactivity of the products [13, 14]. However, the exact way in which Ag NPs affect the adhesive bonds in “dentin-filling” and “enamel-filling” remains unclear, particularly whether silver-based substances weaken the cohesive strength of these boundaries. When applied, silver can penetrate the bioorganic matrix of demineralized dentin, contributing to its remineralization [15-18]. The etching process used in cavity preparation is key to ensuring the effective delivery of silver to both dentin and enamel [19-21].

This study aims to assess how an etching gel containing Ag NPs impacts the cohesive strength at the "dentin-filling" and "enamel-filling" interfaces in permanent teeth with low resistance to caries. The main focus of this research is to analyze the influence of an etching gel with silver nanoparticles on the strength properties of the "dentin-filling" and "enamel-filling" boundaries in permanent teeth from individuals with weakened caries resistance.

Materials and Methods

This study involved 46 teeth, including premolars and molars, extracted for medical reasons from patients aged between 40 and 60 years, all showing class I and II carious cavities [22]. The teeth were split into two groups, each containing 23 specimens. The first group, serving as the control, underwent the traditional treatment procedure, where the cavities were etched for fifteen seconds with a 36 percent H3PO4 solution [23]. In the second group, the teeth were treated for fifteen seconds with Etchmaster Ag™ gel, which includes 36% H3PO4 and a filler with ten ppm of Ag NPs [12]. Both groups had their cavities filled with "Aeliteflo™" fluid composite and "Aelite All-Purpose Body™" and "Aelite Aesthetic Enamel™" packable composites, using adhesive systems of the IV generation "All-Bond 3™" and V generation "Sealbond Ultima™". After the bonding process, both groups had their tooth and filling surfaces treated with the same gels used in each respective group, along with Fortify™ sealant.

For metallographic analysis, the teeth were cut into 1 mm thick slices from the middle part of the crown, perpendicular to the tooth's main axis **(Figure 1)**. These slices were then polished mechanically, and the damaged surface was etched with concentrated H3PO4 for two to five minutes. The enamel near the filling interfaces and microstructure of the dentin was observed using a metallographic microscope at ×500 magnification. Higher magnification imaging was done using a scanning electron microscope (JSM-6390LV) [24]. To measure silver content in the teeth, an LSX-500 laser ablation unit (Cetac) was used [12].

Results and Discussion

The optical images captured at ×20 magnification revealed clear differences in color between the filling, enamel, and dentin, with their relative positions in the tooth crown reflecting the characteristics of the filling placement **(Figure 1)**.

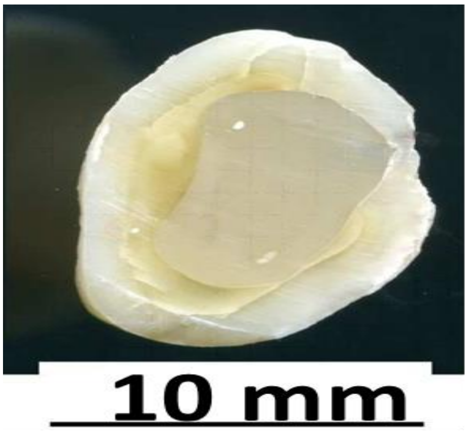
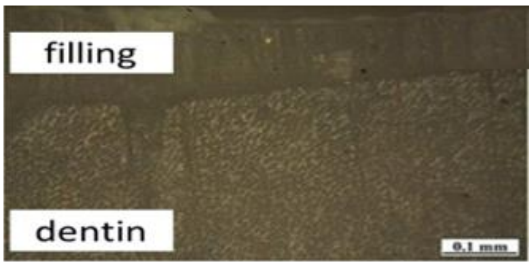


Figure 1. A sample cut from the crown of a tooth (×20)

The interfaces between the tooth's hard tissues and the filling appeared as thin, uniform lines, free from pores or cracks. No noticeable differences were observed between the control groups. At higher magnification of ×500, observations confirmed that the "dentin-filling" **(Figure 2)** and "enamel-filling" interfaces remained intact, presenting smooth lines with no visible defects. A slight etching at the boundaries, which was undetectable at ×20 magnification, was attributed to the surface preparation method, which involved etching with concentrated orthophosphoric acid [25-28]. Similarly, no significant differences were found between the "dentin-filling" and "enamel-filling" boundaries in either group, whether in the control or the observation samples.



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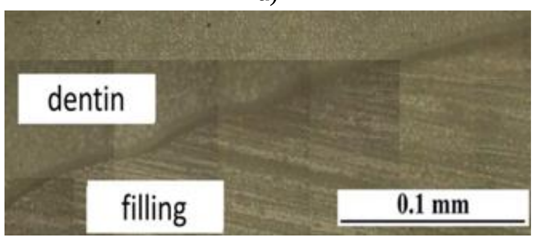

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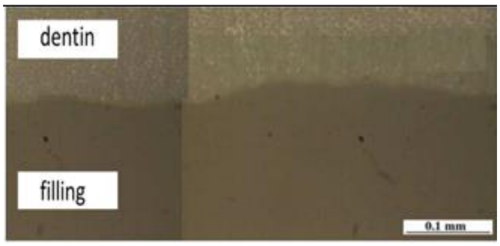

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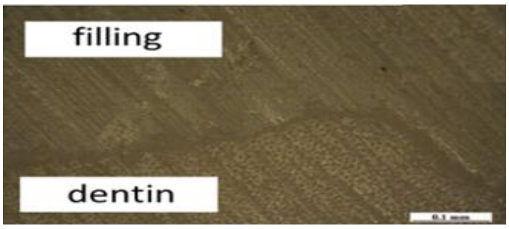

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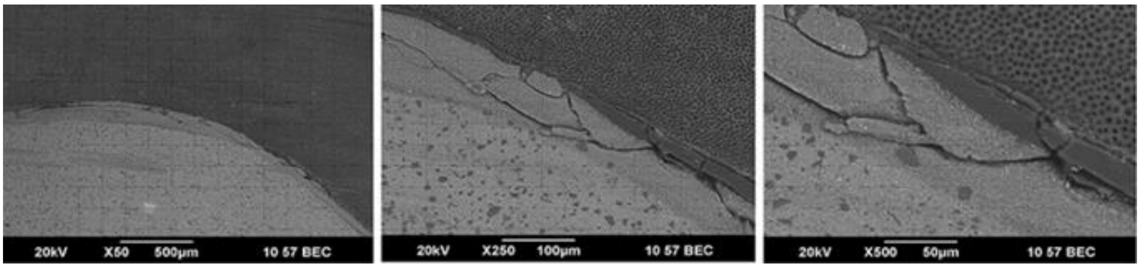
Figure 2. The “dentin-filling” boundary after etching gel treatment (optical microscope); a) With Ag NPs, using an adhesive system from the IV generation, b) With Ag NPs, using an adhesive system from the V generation, c) Without Ag NPs, using an adhesive system from the IV generation, d) Without Ag NPs, using an adhesive system from the V generation.

The findings from the electron microscopy align with the previously mentioned observations. The interfaces of the “dentin-filling” **(Figure 3)** and “enamel-filling” **(Figure 4)** were free from continuity defects, showing uniform etching across their entire length. The presence of a few microcracks at the boundaries is likely due to mechanical stress applied during the tooth-cutting process and the mechanical polishing of the sample surface [29-31]. Additionally, factors like acid etching and dehydration during storage could contribute to the formation of these cracks, possibly leading to sample deformation and weakening of the adhesive bond [32-35]. However, it is important to note that these cracks do not extend into the surface layer of the dentin or enamel. Despite enduring substantial mechanical forces, none of the samples from the structural studies showed failure at the boundaries [36-38]. Notably, electron microscopy revealed no significant differences in the boundaries between samples from the observation and control group.



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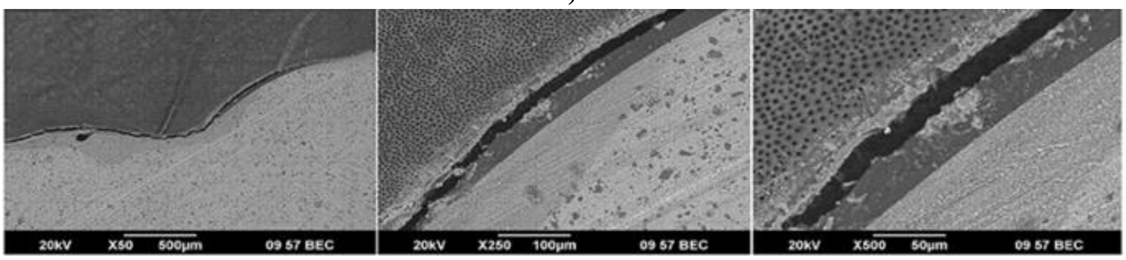

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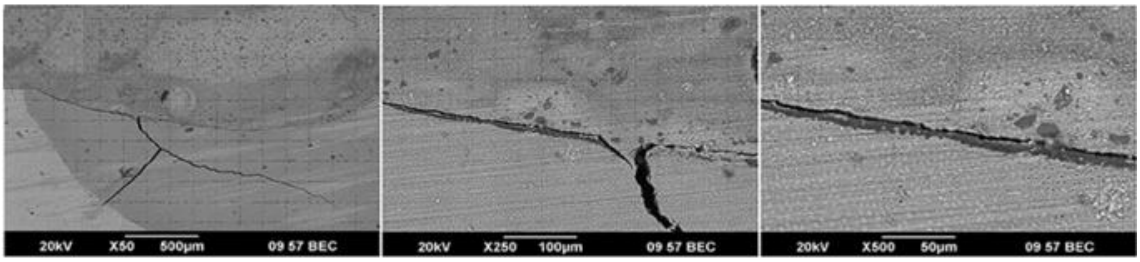

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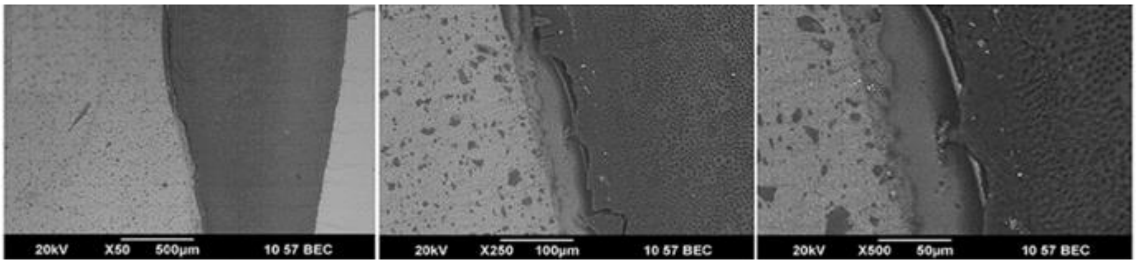

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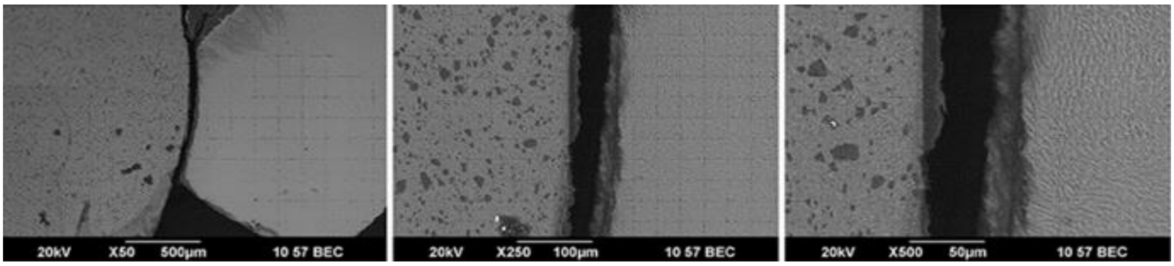
Figure 3. The “dentin-filling” boundary following etching gel treatment (scanning electron microscope); a) With Ag NPs, using an IV generation adhesive system, b) With Ag NPs, using a V generation adhesive system, c) Without Ag NPs, using an IV generation adhesive system, and d) Without Ag NPs, using a V generation adhesive system.



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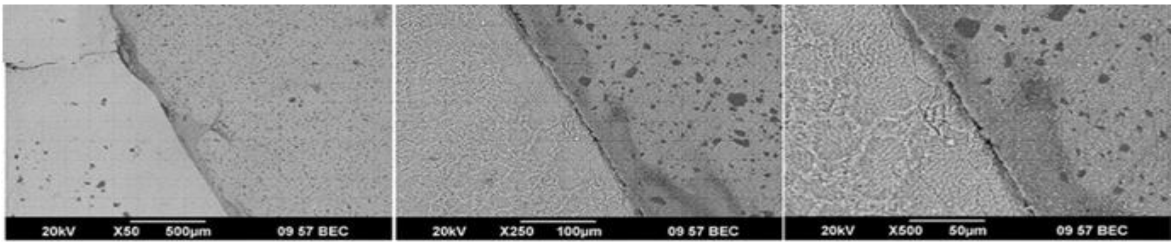

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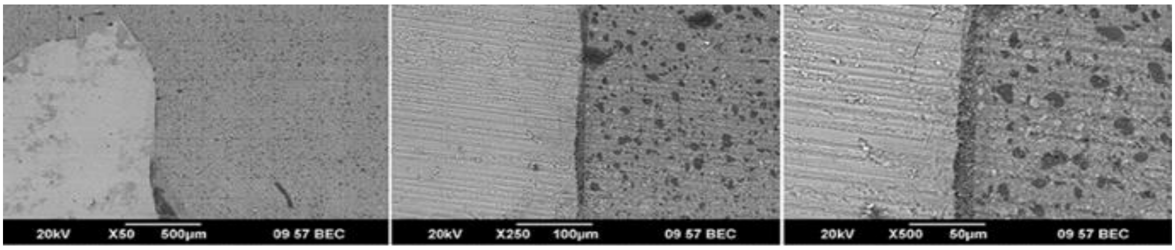

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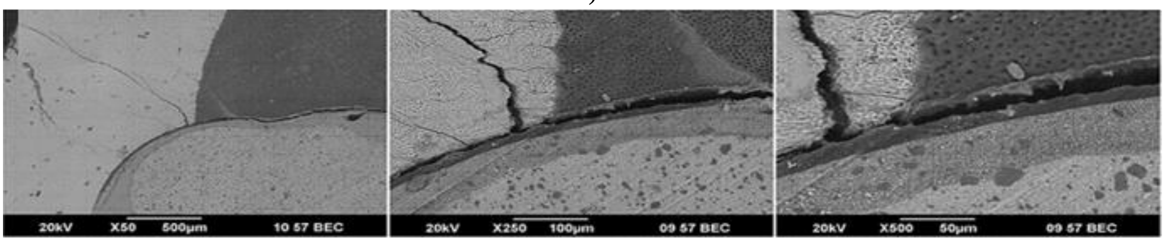

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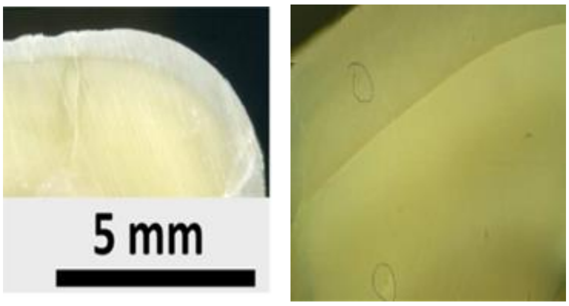
Figure 4. The “enamel-filling” boundary after etching gel treatment (scanning electron microscope)*; a) With Ag NPs, using an IV generation adhesive system, b) With Ag NPs, using a V generation adhesive system, c) Without Ag NPs, using an IV generation adhesive system, and d) Without Ag NPs, using a V generation adhesive system.

The analysis of the elemental composition of dentin and enamel in the control group samples performed approximately 1.25 mm away from the filling interface, revealed that a 50 µm thick layer of hard tissue contained around 10 ppm of silver **(Figure 5)**. In contrast, no silver was detected in the samples from the observation group.



a) b)

Figure 5. Dentin-enamel junction treated with etching gel containing Ag NPs; a) After cutting (showing no cracks or pores at the boundary), and b) After analyzing the elemental composition in dentin and enamel (laser ablation sites are marked).

The examination of the cohesive strength at the "dentin-filling" and "enamel-filling" interfaces using physical materials science techniques provided two important insights:

The cohesive strength at these boundaries was strong enough to resist the mechanical forces applied during sample cutting and polishing, Also the impact of aggressive treatments like concentrated orthophosphoric acid, regardless of the etching gel contained Ag NPs.

When the etching gel containing Ag NPs was used, a layer of hard tissue, located about 1.25 millimeters from the boundaries of the prepared cavities, became enriched with Ag NPs. These levels of silver were found to be sufficient to produce bactericidal and fungicidal effects [39, 40].

Conclusion

The results of this study indicate that the presence of up to 10 ppm of Ag NPs in enamel and dentin does not impact the restoration's strength. As such, the primary role of silver in the etching gel appears to be its preventive effect on pathology.

However, it is essential to remember that, in clinical practice, the bond strength between the filling and the tooth's hard tissues can be influenced by various factors. These include the condition of the enamel and dentin, the specific properties of the filling material, and the chemical composition of both the etching gel and the adhesive system. The study used samples from teeth extracted for medical purposes, which closely mimics natural conditions. Given the results, it can be noticed that Ag NPs in the etching gel serve mainly as a preventive agent against pathology without affecting the restoration's strength properties.

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Conflict of Interest: None

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Ethics Statement: None

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