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Comparative Evaluation of Fumaric Acid and Phosphoric Acid in Smear Layer Removal from Coronal Dentin: An *Invitro* Analysis

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KEYWORDS

Fumaric acid, Phosphoric acid, SEM analysis, Smear layer

ABSTRACT:

Background:

Effective smear layer removal is critical for enhancing dentin adhesion and improving the longevity of dental restorations. While phosphoric acid is widely used for etching, its aggressive demineralization may compromise dentin integrity over time. Fumaric acid, a biocompatible organic acid, has shown potential as an alternative etchant due to its smear layer removal properties and milder effect on dentin.

Aim:

To compare the efficacy of 37% phosphoric acid and 0.7% fumaric acid in removing the smear layer from coronal dentin using scanning electron microscopy (SEM).

Methodology:

Twenty-four human mandibular molars extracted for periodontal reasons were prepared by exposing mid-coronal dentin. The samples were randomly divided into two groups (n=12): one treated with 37% phosphoric acid for 10 seconds, and the other with 0.7% fumaric acid for 30 seconds. Following etching, samples were rinsed, kept moist, dehydrated, and subjected to SEM analysis to assess smear layer removal based on percentage of open dentinal tubules. Data were analyzed using an unpaired t-test.

Results:

The mean percentage of open dentinal tubules was 87.92% for the phosphoric acid group and 87.47% for the fumaric acid group. The difference between the two groups was not statistically significant ($p = 0.367$).

Conclusion:

Fumaric acid demonstrated smear layer removal efficacy comparable to that of phosphoric acid, suggesting it may serve as a viable alternative etchant in adhesive dentistry. Given its biocompatibility and conservative action on dentin, further longitudinal studies are recommended to explore its clinical application and long-term effects.

1. Introduction

Dentin adhesion technology has advanced considerably in recent years. Selective enamel etching, performed in combination with total-etch or self-etch adhesive systems, typically employs phosphoric acid in concentrations of 30–40%, resulting in targeted

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dissolution of enamel prisms. This process enlarges interprismatic and intraprismatic spaces, increases surface roughness, enhances surface energy, and improves wettability—creating an optimal substrate for resin monomer penetration and thereby strengthening adhesion [1,2].

During tooth preparation and caries removal with rotary or hand instruments, a smear layer forms on the dentin surface. This layer, composed primarily of crushed hydroxyapatite and thermomechanically denatured collagen, functions as a weakly bound, porous barrier [3]. While it can reduce dentin permeability by up to 86% by sealing tubules and limiting toxin penetration, its unstable attachment may deteriorate over time, contributing to microleakage [4].

Bonding strategies address this weak adhesion either by complete smear layer removal or by incorporating it into the hybrid layer through infiltration with adhesive monomers [5]. Phosphoric acid etching, a common smear layer removal technique, effectively eliminates the smear layer and smear plugs, but may reduce wettability and alter surface polarity [6]. While some studies report no significant effect on initial dentin bond strength [7], others have found improved adhesion after etching [8]. However, phosphoric acid treatment may also reduce long-term bond durability due to collagen network alteration [9].

Fumaric acid (trans isomer of maleic acid, butene-1,4-dioic acid) is a naturally occurring organic acid with anti-inflammatory, anticancer, and growth-modulatory properties [10,11]. It is non-toxic, biodegradable, and biocompatible, making it an attractive option for dental applications. Previous research suggests that fumaric acid is effective in smear layer removal, particularly in the apical third of root canals, when used as a final irrigant [12].Given its properties, fumaric acid may serve as a potential alternative etchant with comparable performance to phosphoric acid.

This in-vitro study aimed to compare the smear layer removal efficacy of 0.7% fumaric acid with that of 37% phosphoric acid on coronal dentin

2. Materials And Methods:

24 human mandibular molar teeth scheduled for extraction for periodontal reasons were collected and used in the study. The extracted teeth were cleaned with pumice to remove any surface deposits and disinfected by immersing them in Chloramine-T solution for two hours. The teeth were examined under magnification to rule out the inclusion of teeth with cracks, fracture lines, root caries, or hypoplastic lesions; any teeth that do not meet the inclusion criteria were discarded. Following disinfection and cleaning, the extracted teeth were stored in saline solution for the duration of the study.

A slow-speed Isomet saw was used to remove the coronal occlusal third of each tooth crown, exposing the mid-coronal dentin. Then, silicon carbide paper was used to polish using water irrigation for one minute, creating a uniformly smooth dentin surface. 24 tooth segments were divided into two groups at random into phosphoric acid and fumaric acid group.

Using the dilution equation, pure ingredients were added to distilled water to create 0.7% fumaric acid (w/v) solutions.

(m1v1 = m2v2)

1.75 grams of 99% fumaric acid were dissolved in 250 millilitres of distilled water to yield 0.7% fumaric acid.

The prepared dentin surfaces (n=12) per group were conditioned with 37% phosphoric acid for 10 seconds and 0.7% of fumaric acid for 30 seconds and thoroughly washed with water but kept moist by removing the excess of water from the dentin surface using cotton pellets. Then the samples were subjected to SEM for smear layer removal evaluation.

3. Scanning Electron Microscopic Analysis:

After dehydrating, the samples have been mounted on aluminium metal stubs, gold sputtering was done, and examined under a field emission SEM (ULTRA 55, Field Emission SEM [Karl Zeiss] with EDS, GERMANY) to determine the removal of smear layer.

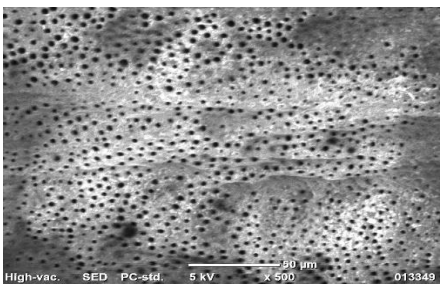

Figure1: SEM Image of open dentinal tubules for 37 % Phosphoric acid group

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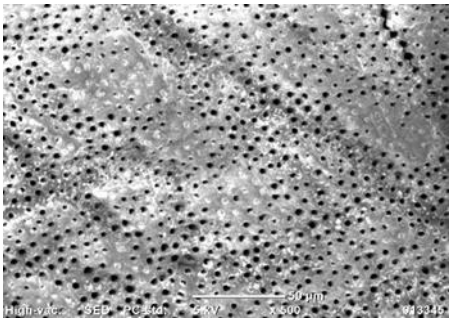

Figure 2: SEM Image of open dentinal tubules for Fumaric acid group

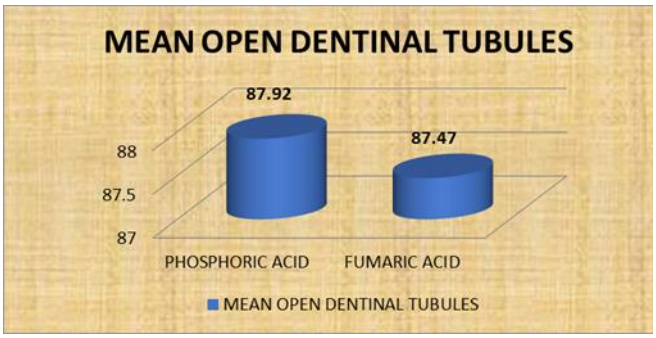

Figure:3 Comparison of percentage of open dentinal tubules

5. Results:

GROUP	MEAN	SD	MEAN DIFFERENCE	p-value
PHOSPHORIC ACID	87.92	1.23	0.45	0.367 NS
FUMARIC ACID	87.47	1.18		

Table1: Intergroup comparison between Phosphoric acid and Fumaric acid group

The phosphoric acid group achieved a mean smear layer removal score of 87.92 ± 1.23, while the fumaric acid group recorded a mean score of 87.47 ± 1.18. The mean difference between the groups was 0.45, which was not statistically significant (p = 0.367). These findings indicate that both acids demonstrated comparable smear layer removal efficiency.

6. Discussion:

This study represents a novel investigation in the field of dentistry, focusing on the comparison of phosphoric acid and fumaric acid for smear layer removal. While further longitudinal studies are necessary to establish definitive clinical recommendations, short-term findings provide valuable insight into the comparative efficacy of these etchants. The removal of the smear layer is critical because a thick or persistent smear layer can hinder adhesive penetration, reduce bond strength, and contribute to restoration failure. Eliminating the smear layer enhances the infiltration of resin monomers into the demineralized dentin matrix, allowing for improved micromechanical retention and more durable resin–dentin bonds [9].

Chelating and acidic agents are commonly employed for smear layer removal, either completely or partially, depending on the clinical protocol. Among these, phosphoric acid is one of the most widely used etchants in adhesive dentistry. Clinical protocols typically employ phosphoric acid concentrations between 30% and 40%, which can completely demineralize dentin and rinse away the smear layer. This property makes it highly compatible with etch-and-rinse adhesive systems, as it facilitates resin infiltration by exposing the collagen network and creating micro-retentive features [10].

However, the aggressive nature of phosphoric acid etching has been associated with some long-term disadvantages. Etch-and-rinse adhesives, while producing strong initial bonds, have been shown to result in a more pronounced deterioration of the resin–dentin interface over time compared to self-etch systems [11]. This degradation is thought to result from the exposure of a greater number of collagen fibrils due to extensive demineralization. Once unprotected, these collagen fibrils are susceptible to enzymatic degradation by matrix metalloproteinases (MMPs), endogenous enzymes that contribute to the breakdown of the organic dentin matrix [12]. Over time, such enzymatic activity can compromise the integrity of the hybrid layer and lead to reduced bond durability.

To overcome these drawbacks, alternative etchants with milder demineralizing effects have been explored. Fumaric acid, a naturally occurring dicarboxylic acid, has been investigated for its ability to effectively remove the smear layer while minimizing damage to dentin structure. In the present study, fumaric acid demonstrated smear layer removal comparable to that of phosphoric acid. This performance may be attributed to its unique

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molecular configuration, in which two carboxylic groups are positioned opposite each other in three-dimensional space, potentially enhancing its chelating and smear layer removal capabilities [13].

Unlike phosphoric acid, which can cause excessive dentin demineralization, fumaric acid appears to exert a milder effect, preserving more of the dentin substrate while still effectively opening dentinal tubules. This preservation of tooth structure is advantageous in adhesive dentistry, as excessive demineralization can result in unsupported collagen networks that are difficult to fully infiltrate with resin, leading to nanoleakage and reduced bond longevity.

In the current study, samples treated with both acids were evaluated using scanning electron microscopy (SEM) to assess smear layer removal and dentinal tubule exposure. Statistical analysis using the independent t-test revealed no significant difference between the two groups in terms of open dentinal tubule count or smear layer removal scores. These results indicate that fumaric acid can be as effective as phosphoric acid in smear layer removal under the tested conditions, suggesting its potential as a viable clinical alternative.

Previous literature supports these findings. Jaiswal et al. [13] compared fumaric acid to other common endodontic irrigants and found that a 1-minute application of 0.7% fumaric acid, followed by 3% sodium hypochlorite, achieved superior smear layer removal compared to 7% maleic acid and 17% EDTA. This superior performance was evident in SEM images, which showed more uniformly open dentinal tubules and cleaner intertubular surfaces. The authors attributed this effect to fumaric acid's ability to chelate calcium ions efficiently while minimizing dentin erosion.

Similarly, Sariçam et al. [14] reported that fumaric acid demonstrated a smear layer removal and dentinal tubule penetration ability comparable to EDTA and chitosan solutions. Moreover, they found that fumaric acid exerted less detrimental impact on dentin microhardness compared to stronger acids, indicating that it could preserve dentin integrity while still achieving effective cleaning. This preservation of microhardness is clinically relevant, as maintaining dentin's mechanical properties is important for resisting masticatory forces and supporting long-term restoration survival.

The implications of these findings are significant. While phosphoric acid remains the gold standard for etching in etch-and-rinse adhesive systems, its aggressive nature and the potential for collagen degradation over time present limitations, particularly in situations where bond durability is critical. Fumaric acid, by offering comparable smear layer removal with a less aggressive action, may reduce the risk of over-etching and collagen exposure, potentially enhancing the stability of the resin–dentin interface over time. Furthermore, its milder demineralization profile may make it suitable for minimally invasive adhesive dentistry, where the preservation of tooth structure is a primary goal.

7. Limitations:

The evaluation period was short, limiting the ability to assess long-term effects such as bond strength stability, nanoleakage, and interface degradation.

8. Conclusion:

Fumaric acid exhibited smear layer removal effectiveness comparable to that of phosphoric acid, indicating its potential use as an alternative etchant. Currently, there is no published research specifically evaluating fumaric acid's smear layer removal capacity on coronal dentin, highlighting the need for future longitudinal studies to assess its long-term performance.

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