Odovtos-International Journal of Dental Sciences (Odovtos-Int. J. Dent. Sc.), Online First, 2026.
https://doi.org/10.15517/gjencg98
ISSN: 2215-3411

ODOVTOS
International Journal of Dental Sciences

UNIVERSIDAD DE COSTA RICA
FOd Facultad de Odontología

https://revistas.ucr.ac.cr/index.php/rOdontos

BASIC RESEARCH:

Effect of Different Dentin Desensitizing Agents on Bond Strength and Dentin Morphology in Eroded Cervical Dentin

Efecto de diferentes agentes desensibilizantes dentinarios sobre la resistencia de unión y la morfología de la dentina cervical erosionada

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Received: 17-III-2026 Accepted: 19-VI-2026

ABSTRACT: This study evaluates the effect of different dentin desensitizing agents on the bond strength of a universal adhesive system applied using the self-etch strategy to eroded cervical dentin, as well as their impact on dentin morphology. A total of 100 bovine teeth were sectioned, and standardized dentin specimens were obtained. Erosion was simulated with hydrochloric acid and a daily acid/abrasive challenge using orange juice and abrasive toothpaste for 7 days. Five groups (n=20) were formed according to the desensitizing agent applied: Clinpro White Varnish (sodium fluoride/tricalcium phosphate varnish; 3M), MI Varnish (CPP-ACP/sodium fluoride varnish; GC), Fluor Protector (fluorosilane varnish; Ivoclar), Shield Force Plus (light-cured resin-based desensitizer; Tokuyama), and Desensibilize KF 2% (potassium nitrate/sodium fluoride gel; FGM; active control). Half of the specimens were analyzed via scanning electron microscopy (SEM) to evaluate precipitate formation and the percentage of open dentinal tubules. The remaining samples underwent microtensile bond strength (μTBS) testing with a universal adhesive. Data were analyzed using ANOVA, Kruskal-Wallis, and respective post-hoc tests (α=5%). The active control showed the highest overall bond strength (55.85±2.85 MPa), whereas Clinpro showed the highest bond strength among the tested desensitizing agents (51.80±3.69 MPa). MI Varnish presented the lowest bond strength (36.89±2.03 MPa) ($p<0.05$). Fluor Protector significantly reduced the percentage of open dentinal tubules compared with MI Varnish ($p<0.05$). Despite the higher descriptive prevalence of surface precipitate scores observed with MI Varnish, Fluor Protector, and

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Shield Force Plus, no significant improvement in adhesion was observed. The findings highlight the importance of selecting dentin desensitizing agents that ensure both substrate protection and adequate bonding to eroded dentin.

KEYWORDS: Dentin; Dental adhesives; Tooth erosion; Varnishes; Scanning electron microscopy.

RESUMEN: Este estudio evalúa el efecto de diferentes agentes desensibilizantes dentinarios sobre la resistencia de unión de un sistema adhesivo universal aplicado mediante estrategia autograbante en dentina cervical erosionada, así como su impacto en la morfología dentinaria. Se utilizaron 100 dientes bovinos, de los cuales se obtuvieron muestras estandarizadas de dentina. La erosión se simuló con ácido clorhídrico y un desafío ácido/abrasivo diario con jugo de naranja y pasta dental abrasiva durante 7 días. Se formaron cinco grupos (n=20) según el agente desensibilizante aplicado: Clinpro White Varnish (barniz de fluoruro de sodio/fosfato tricálcico; 3M), MI Varnish (barniz de CPP-ACP/fluoruro de sodio; GC), Fluor Protector (barniz de fluorosilano; Ivoclar), Shield Force Plus (desensibilizante resinoso fotopolimerizable; Tokuyama) y Desensibilize KF 2% (gel de nitrato de potasio/fluoruro de sodio; FGM; control activo). La mitad de las muestras se analizó mediante microscopía electrónica de barrido (MEB) para evaluar la formación de precipitados y el porcentaje de túbulos dentinarios abiertos. Las muestras restantes fueron sometidas a pruebas de microtracción (μTBS) con un adhesivo universal. Los datos se analizaron con ANOVA, Kruskal-Wallis y pruebas post-hoc correspondientes (α=5%). El control activo mostró la mayor resistencia de unión global (55.85±2.85 MPa), mientras que Clinpro presentó la mayor resistencia de unión entre los agentes desensibilizantes evaluados (51.80±3.69 MPa). MI Varnish presentó los valores más bajos de resistencia de unión (36.89±2.03 MPa) ($p<0.05$). Fluor Protector redujo significativamente el porcentaje de túbulos dentinarios abiertos en comparación con MI Varnish ($p<0.05$). A pesar de la mayor prevalencia descriptiva de puntajes de precipitados superficiales observada con MI Varnish, Fluor Protector y Shield Force Plus, no se observó una mejora significativa en la adhesión. Los hallazgos resaltan la importancia de seleccionar agentes desensibilizantes dentinarios que aseguren tanto la protección del sustrato como una adecuada adhesión en dentina erosionada.

PALABRAS CLAVE: Dentina; Adhesivos dentales; Erosión dental; Barnices; Microscopía electrónica de barrido.

INTRODUCTION

Erosive tooth wear is characterized by the loss of hard dental tissue due to chemical processes, typically caused by exposure to intrinsic acids—such as those from gastric reflux or vomiting—and extrinsic acids from the diet, without the involvement of bacteria (1,2). The treatment of this condition depends on its severity and includes preventive strategies, such as lifestyle modifications to reduce risk factors and the application of remineralizing agents to the affected tissues (1,2). In cases of significant structural loss, restorative treatments are required to recover both function and aesthetics (3,4).

In this context, dental varnishes and dentin desensitizing agents play a key role in dentistry, protecting eroded dentin and addressing dentin hypersensitivity (5,6). These materials function by occluding dentinal tubules, thereby reducing permeability and creating a protective barrier against erosive challenges (7-9). Clinpro varnish, which contains sodium fluoride and functionalized

tricalcium phosphate, is specifically formulated for the management of white spot lesions and early childhood caries, promoting remineralization through its fluoride content (10,11).

Similarly, MI Varnish, which contains fluoride and CPP-ACP, enhances caries prevention and remineralization (11). CPP-ACP stabilizes calcium and phosphate ions, optimizing their remineralizing action (11). Fluor Protector varnish, which contains silane fluoride, is recognized for its ability to deposit fluoride and form a protective layer on the tooth surface (12).

Finally, Shield Force Plus, a light-cured desensitizer designed to reduce dentin hypersensitivity (13), was included because evidence regarding its behavior on eroded dentin and adhesive procedures remains limited, despite its clinical applications. All these materials were selected based on their market availability and potential to protect eroded dentin and improve adhesion in hypersensitive conditions; thus, we refer to them as dentin desensitizing agents.

The selection of an appropriate treatment must be tailored to the individual needs of each patient. To achieve this, it is essential to understand the characteristics of these materials and their interaction with contemporary adhesive systems. Therefore, the aim of this study was to evaluate the effectiveness of different dentin desensitizing agents on the adhesion of a universal adhesive system to eroded dentin. The null hypothesis tested was that the application of dentin desensitizing agents does not significantly improve the bond strength of the universal adhesive system to eroded dentin.

MATERIALS AND METHODS

This study was approved by the Research Ethics Committee of Universidad Católica de Santa María – UCSM, under registration number 103/2024.

SAMPLE PREPARATION

A total of 100 bovine teeth were selected and sectioned into thirds using low-speed diamond discs (Masterdent, Envigado, Antioquia, Colombia). From the cervical third, samples measuring 10 mm × 10 mm × 5 mm were obtained using a precision cutting machine with irrigation (OCP 100 LC; Odeme Dental Research, Luzerna, SC, Brazil). The buccal surface of each specimen was polished with silicon carbide abrasive papers (#600 and #1200; Norton, São Paulo, SP, Brazil) for 20 seconds to expose cervical dentin and standardize the smear layer formation (14). Figure 1.A illustrates the sample preparation process.

To simulate intrinsic erosion, the specimens were immersed in 5 mL of 0.6% hydrochloric acid (pH 2.3) for 5 minutes (15). They were then rinsed with distilled water for 15 seconds and stored in artificial saliva at 37 °C until use. The artificial saliva was composed of KCl, $CaCl_2$, $MgCl_2$, NaCl, KH_2PO_4, carboxymethylcellulose, and sorbitol in distilled water (F & E, Arequipa, Peru).

The sample size was justified using G*Power software (version 3.1.9.7; Heinrich Heine University, Düsseldorf, Germany) for one-way ANOVA, considering five experimental groups, an alpha level of 0.05, a statistical power of 80%, and an expected effect size of 0.52 based on previous microtensile bond strength data obtained under

comparable experimental conditions. The calculation indicated a minimum total sample size of 50 specimens, corresponding to 10 specimens per group. Therefore, 10 specimens per group were used for each test. For μTBS analysis, the tooth/specimen was considered the experimental unit. The sticks obtained from the same specimen were treated as technical subsamples, and the mean μTBS value of each specimen was used for statistical analysis.

EROSIVE PROTOCOL AND EXPERIMENTAL GROUPS

To simulate erosive tooth wear, the specimens underwent a daily acid/abrasive challenge for seven days. The acid challenge consisted of immersion in commercial orange juice (Gloria, Huachipa, Lima, Peru) with a pH of 3.80 ± 0.04 for 5 minutes, mimicking the effects of regular orange juice consumption. Subsequently, the abrasive challenge was carried out by applying an abrasive toothpaste (Luminous White; Colgate-Palmolive, Mexico) using a Robson brush, operating at 4.5 N·cm torque and 600 rpm (Ai-motor; Woodpecker, Guilin, Guangxi, China) for 5 seconds on the eroded cervical dentin (15). Afterward, specimens were rinsed with 10 mL of distilled water and stored in artificial saliva at 37°C throughout the experiment.

Dentin desensitizing agents were applied at two time points: at the beginning of the experiment and after seven days of acid/abrasive challenge. The specimens were randomly assigned to five groups (n=20) according to the dentin desensitizing agent used: CP (Clinpro™ White Varnish TCP), MV (MI Varnish Recaldent™ CPP-ACP), FP (Fluor Protector), SF (Shield Force Plus), and DK (Desensibilize KF 2%, active control). DK was selected as an active clinical comparator because it is a fluoride- and potassium nitrate-based desensitizing gel commonly used for the management of dentin hypersensitivity. Since the present study was designed to compare clinically applicable desensitizing/protective strategies before adhesive procedures on eroded cervical dentin, an active control was considered more clinically representative than leaving hypersensitive eroded dentin untreated. Table 1 presents the chemical composition and application protocols for each dentin desensitizing agent.

Each experimental group included 20 specimens (n=20), subdivided as follows: 10 specimens for dentin morphology analysis using scanning electron microscopy (SEM) and 10 specimens for microtensile bond strength (μTBS) testing with the universal adhesive system.

Table 1. Dentin desensitizing agents, composition, and application protocol used.

Dentin desensitizing agents		Composition	Application protocol
CP	Clinpro™ White Varnish TC (3M, USA, #9229556)	5% Sodium fluoride (NaF) Tricalcium phosphate (TCP) Resins and excipients Sweeteners and flavoring agents	Apply a thin layer using a microbrush or disposable applicator.
MV	MI Varnish Recaldent™ CPP-ACP (GC, Japan, #2203081)	Amorphous calcium phosphate (ACP) Casein phosphopeptide (CPP) Sodium fluoride (5% NaF, 22,600 ppm F^-) Resins and solvents	Apply a thin layer of varnish using a microbrush or disposable applicator.
FP	Fluor Protector (Ivoclar Vivadent, Liechtenstein, #Z04RMD)	Fluorosilane (9 mg) Ethyl acetate Isopentyl propionate Polyurethane-based varnish	Apply a thin layer using a disposable applicator or brush.
SF	Shield Force Plus (Tokuyama, Japan, #086MM1)	3D-SR monomer Fillers Solvents and photoinitiators	Apply a thin layer on the dental surface, leave for 30 s, and light-cure.
DK	Desensibilize KF 2% (FGM, Brazil, #030223)	Sodium fluoride (2%) Potassium nitrate Gel-based vehicle	Apply the gel evenly and leave for 10 min.

SEM ANALYSIS OF DENTIN

After treatment, 10 specimens per group (n=10) were stored in artificial saliva for 24 hours and then dehydrated in colloidal silica for seven days. Subsequently, they were mounted on metallic stubs and sputter-coated with a layer of gold under vacuum conditions (120 s, single cycle).

Specimens were analyzed using a scanning electron microscope (EVO 10 MA; Carl Zeiss, Oberkochen, Germany) operating at 20 kV. Four areas of each dentin surface were initially examined to assess homogeneity, and the most representative region was selected to capture images at 500× magnification to analyze surface precipitates. All images were acquired by a single operator and evaluated by two calibrated examiners (k=0.82), who classified the level of residue precipitation using the following scale:

- Score 0: No precipitates.
- Score 1: Minimal precipitates, with most dentinal tubules open.
- Score 2: Mild precipitates, with more than 50% of the dentin surface free of residues.
- Score 3: Moderate precipitates, with less than 50% of the surface free of residues.
- Score 4: Heavy precipitates, with tubules completely obstructed.

In addition, ImageJ software was used to quantify the percentage of open dentinal tubules at 1000× magnification (16). For each standardized SEM field, the total number of visible dentinal tubules and the number of open dentinal tubules were recorded. The percentage of open dentinal tubules was calculated as follows: open dentinal tubules / total visible dentinal tubules × 100. Figure 1.B shows the specimen distribution for SEM analysis.

MICROTENSILE BOND STRENGTH (μTBS) TEST

The universal adhesive system Scotchbond Universal (3M ESPE, St. Louis, MN, USA) was applied to 10 specimens per group (n=10) following the manufacturer's self-etch strategy. The adhesive was light-cured with an LED curing unit (Valo; Ultradent, Salt Lake, UT, USA) at 1200 mW/cm² for 20 seconds.

Immediately after adhesive application, a 4-mm-high composite resin block (Filtek Z350; 3M ESPE, St. Louis, MN, USA) was built in four 1-mm increments, each light-cured for 20 seconds. Specimens were stored in distilled water at 37 °C for 24 hours, then sectioned longitudinally in both mesiodistal and buccolingual directions across the adhesive interface to obtain resin-adhesive-dentin sticks measuring approximately 1 mm × 1 mm. Ten sticks with a cross-sectional area of 1.0 ± 0.2 mm² were selected from each specimen, excluding peripheral regions to avoid enamel remnants. The exact width of each stick was measured with a digital caliper (Digimatic Caliper; Truper, MEX, Mexico). A total of 100 sticks per group were obtained. These were stored in distilled water at 37 °C for 30 days, with weekly water changes.

The sticks were fixed to a JIG using cyanoacrylate gel adhesive (Superglue Gel; Tesa, Offenburg, Germany) for microtensile testing in a universal testing machine (OM150; Odeme Dental Research, Luzerna, SC, Brazil), using a 1 kN load cell and a crosshead speed of 0.5 mm/min. Each stick was positioned with the resin-tooth interface centered and perpendicular to the tensile force (15). Figure 1.B shows the specimen distribution for the μTBS test.

After failure at the adhesive interface, bond strength values were calculated by dividing the maximum force (N) by the bonded area (mm²). The mean μTBS value was calculated for each specimen from its corresponding sticks, and these specimen-level means were used for group-level statistical analysis. Additionally, two independent examiners evaluated the adhesive interface to classify failure modes using a stereomicroscope at 10× magnification. In case of disagreement, magnification was increased to 30× for more accurate classification (15). The failure modes were categorized as follows: Adhesive (failure at the resin–dentin interface); Cohesive in dentin (failure within the dentin); Cohesive in resin (failure within the resin); and Mixed (combination of adhesive and cohesive failures)

DATA ANALYSIS

Statistical analysis was performed using Jamovi software (version 2.3.18.0, Melbourne, Australia). Data normality was assessed using the Shapiro-Wilk test, and homogeneity of variances was assessed using Levene's test. The percentage of open dentinal tubules and bond strength data were analyzed using one-way ANOVA for independent samples and Tukey's post-hoc test when parametric assumptions were met. Precipitate scores on dentin surfaces were analyzed using the Kruskal-Wallis test followed by Dunn's post-hoc test. All analyses were conducted at a 5% significance level.

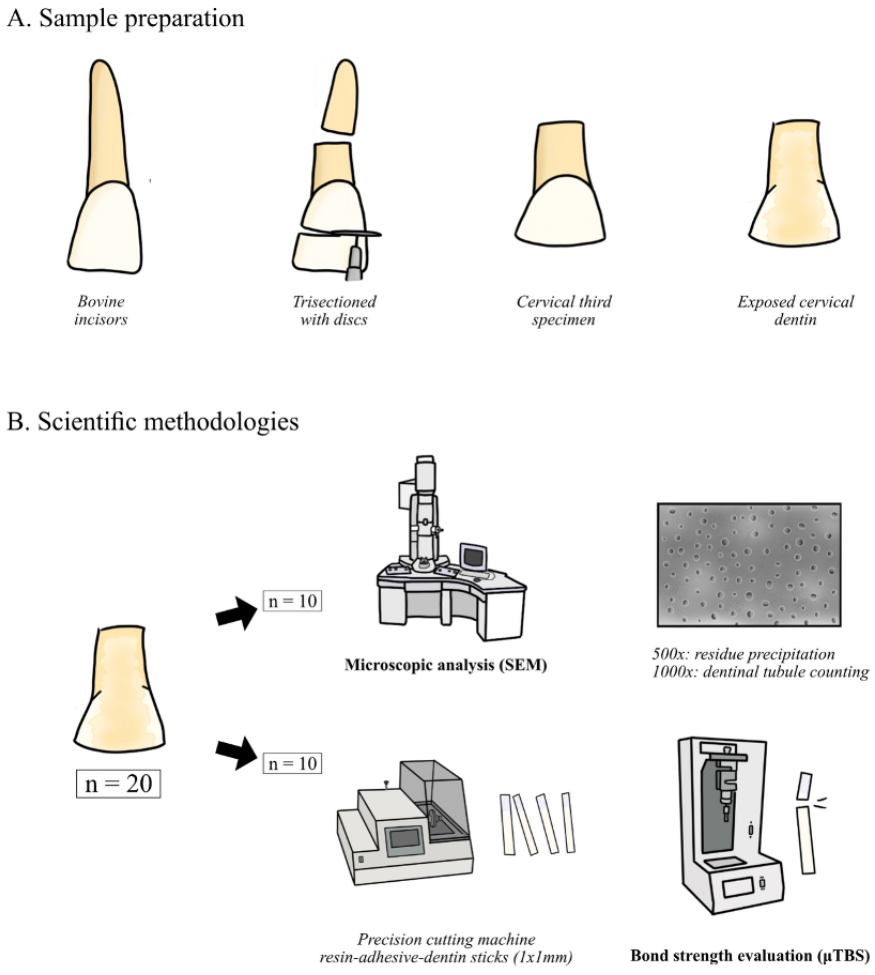


Figure 1. Methodological diagram. A: sample preparation; B: scientific methodologies.

RESULTS

The Shapiro-Wilk and Levene tests confirmed normal distribution and homogeneity of variances for the percentage of open dentinal tubules ($p=0.426$ and $p=0.405$, respectively) and bond strength data ($p=0.784$ and $p=0.798$, respectively). Therefore, one-way ANOVA and Tukey's post-hoc test were considered appropriate for these outcomes. The percentage of open dentinal tubules differed significantly among groups ($p<0.001$).

Table 2 shows that Fluor Protector exhibited the lowest percentage of open dentinal tubules, indicating greater tubule occlusion than CP, MV and SF ($p<0.05$), while no significant difference was observed between FP and the active control (DK) ($p>0.05$). MI Varnish showed the highest percentage of open dentinal tubules and differed significantly from FP and DK ($p<0.05$). The qualitative analysis showed a higher descriptive prevalence of moderate/heavy precipitate scores in samples treated with MI Varnish, Fluor Protector, and Shield Force Plus; however, no statistically

significant differences in precipitate scores were found among groups ($p>0.05$). The distribution of precipitate scores for each group is presented in Figure 3.

These findings suggest that some agents produced different levels of tubule occlusion, whereas the qualitative distribution of precipitate scores did not differ significantly among groups. Figure 2 presents representative images of the dentin surface at 500× magnification, showing the presence of precipitates, and at 1000×, illustrating the degree of dentinal tubule obliteration for each evaluated agent.

Table 3 shows that Clinpro was the only desensitizing agent with bond strength values comparable to the active control ($p>0.05$). When compared to Fluor Protector and Shield Force Plus, no statistically significant differences were found ($p>0.05$). On the other hand, MI Varnish showed the lowest bond strength among all evaluated groups ($p<0.05$), except in comparison with Shield Force Plus, with which it also did not differ significantly ($p>0.05$).

These results suggest that although Clinpro performed similarly to the active control, MI Varnish was associated with lower bond strength. Figure 4 shows that mixed failure was the predominant type across all groups, indicating that failure was not restricted exclusively to the adhesive interface. However, these findings should not be interpreted as evidence of direct bonding between the desensitizing agents and dentin, since the μTBS test evaluated the bonding performance of the universal adhesive system after previous dentin treatment.

Table 2. Percentage of open dentinal tubules within standardized SEM fields after application of dentin desensitizing agents.

Agents	CP	MV	FP	SF	DK
Mean (%)	59.67^{bc}	83.94^{c}	30.67^{a}	64.17^{bc}	49.78^{ab}
SD	11.18	13.95	6.66	7.51	9.34
95% CI	52.74-66.60	75.30-92.59	26.54-34.79	59.51-68.82	43.99-55.56

Different lowercase letters within the same row indicate statistically significant differences ($p < 0.05$). SD, standard deviation; CI, confidence interval. CP, Clinpro; MV, MI Varnish; FP, Fluor Protector; SF, Shield Force Plus; DK, Desensibilize KF 2% (active control).

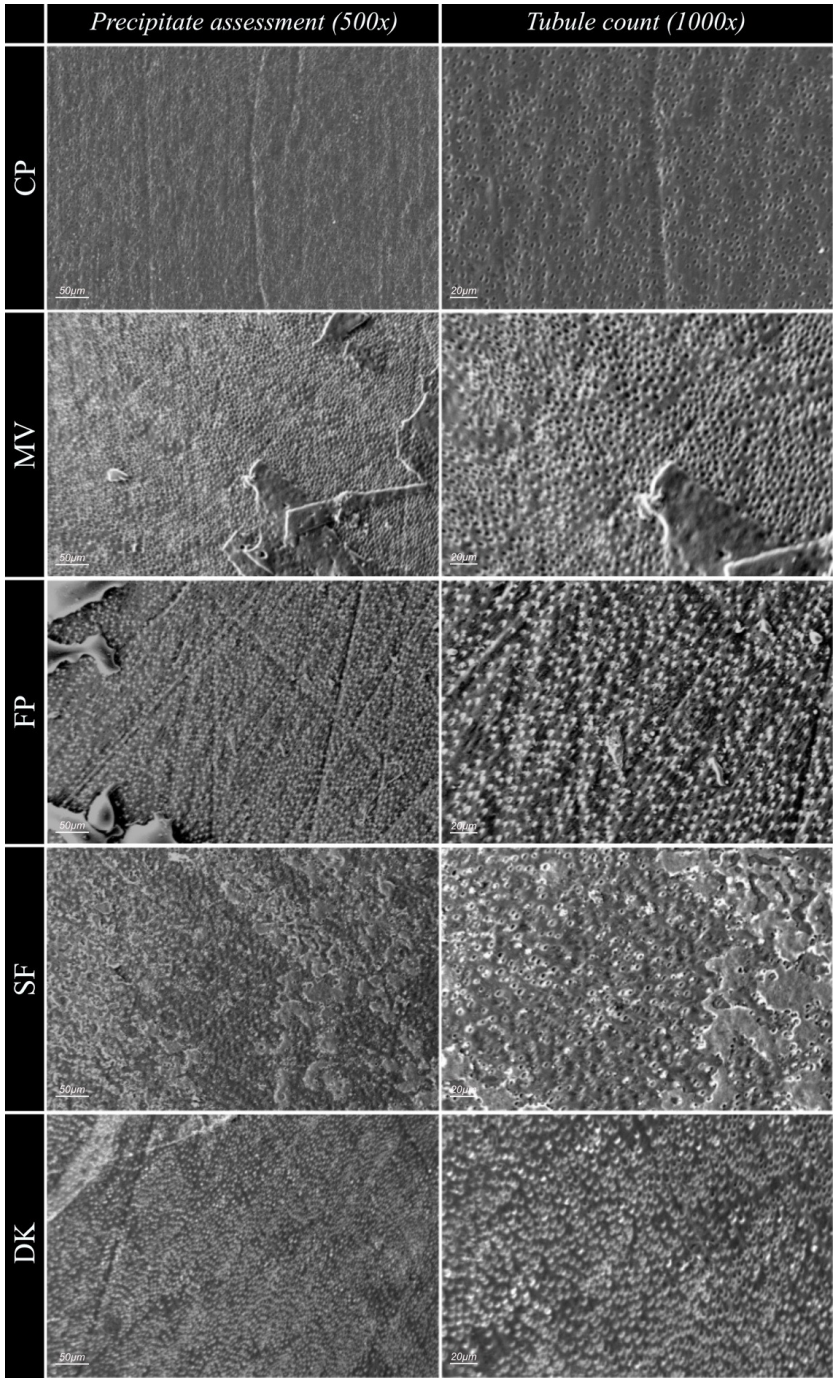


Figure 2. Representative SEM images of the dentin surface according to the applied dentin desensitizing agents at 500× and 1000× magnification. CP, Clinpro; MV, MI Varnish; FP, Fluor Protector; SF, Shield Force Plus; DK, Desensibilize KF 2% (active control). Scale bars: 50 µm and 20 µm.

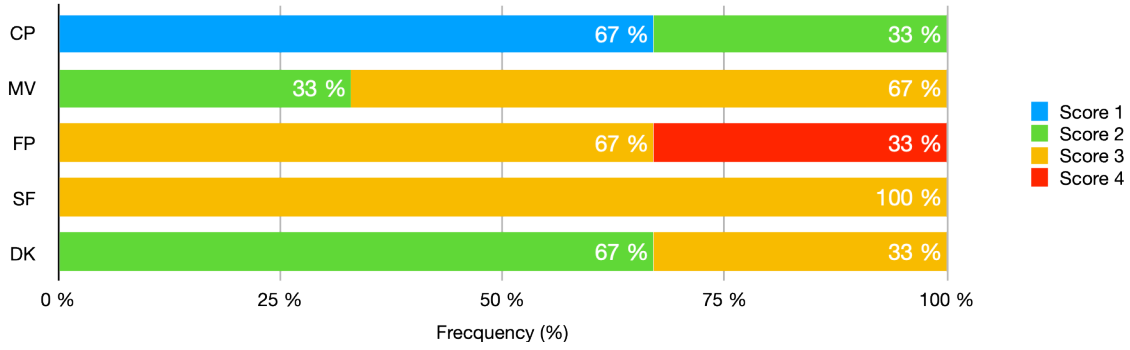


Figure 3. Frequency distribution of precipitate scores after application of dentin desensitizing agents. CP, Clinpro; MV, MI Varnish; FP, Fluor Protector; SF, Shield Force Plus; DK, Desensibilize KF 2% (active control). Score 0: no precipitates; Score 1: minimal precipitates; Score 2: mild precipitates; Score 3: moderate precipitates; Score 4: heavy precipitates. Score 0 was not observed in any group.

Table 3. Bond strength of the universal adhesive system to eroded dentin treated with the evaluated dentin desensitizing agents.

Agents	CP	MV	FP	SF	DK
Mean (MPa)	51.80[ab]	36.89[c]	45.77[b]	42.11[bc]	55.85[a]
SD	3.69	2.03	3.00	3.45	2.85
95% CI	49.51-54.09	35.64-38.15	43.91-47.63	39.97-44.25	54.08-57.62

Different lowercase letters within the same row indicate statistically significant differences ($p < 0.05$). SD, standard deviation; CI, confidence interval. CP, Clinpro; MV, MI Varnish; FP, Fluor Protector; SF, Shield Force Plus; DK, Desensibilize KF 2% (active control).

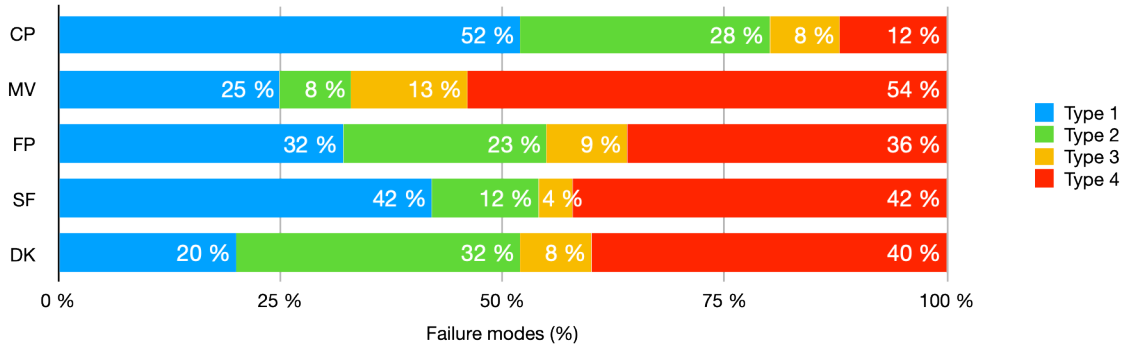


Figure 4. Frequency distribution of failure modes after the application of dentin desensitizing agents. CP, Clinpro; MV, MI Varnish; FP, Fluor Protector; SF, Shield Force Plus; DK, Desensibilize KF 2% (active control). Type 1 (adhesive, resin–dentin); Type 2 (cohesive in dentin); Type 3 (cohesive in resin); Type 4 (mixed).

DISCUSSION

The present study evaluated the bonding performance of a universal adhesive system applied using the self-etch strategy to eroded cervical dentin previously treated with different dentin desensitizing agents, as well as the morphological changes induced by these agents. The results showed that Clinpro maintained bond strength values comparable to the active control, whereas MI Varnish exhibited the lowest values. Fluor Protector was associated with greater substrate modification, reducing the percentage of open dentinal tubules. However, although MI Varnish, Fluor Protector, and Shield Force Plus showed a higher descriptive prevalence of surface precipitate scores, this did not translate into improved adhesive performance. Therefore, tubule occlusion or precipitate formation alone did not guarantee higher bond strength. Since no statistically significant differences in bond strength were observed among most agents, the null hypothesis is accepted, indicating that the application of dentin desensitizing agents does not significantly enhance the adhesion of the universal adhesive system to eroded dentin.

The literature supports the idea that varnishes or dentin desensitizing agents can effectively occlude dentinal tubules, contributing to both caries prevention and the treatment of dentin hypersensitivity (17). Although studies on Clinpro's impact on dentin adhesion are limited, its cytocompatibility and effectiveness in managing hypersensitivity are well documented, suggesting that, when properly used, it may not compromise adhesion (18). Our findings confirm that the universal adhesive system maintains stable bond strength to eroded dentin treated with Clinpro, with values higher than those obtained with MI Varnish.

On the other hand, the interaction between desensitizing agents and adhesives can vary significantly (19). Our results show that MI Varnish was associated with lower bond strength of the universal adhesive system. This could be due to the agent altering the dentin surface characteristics, potentially affecting adhesive systems. However, since research on this topic is still limited, further investigation is needed to draw definitive conclusions.

MI Varnish contains fluoride, known for its remineralizing properties. Although fluoride strengthens enamel and dentin, it may also influence adhesion by altering the surface energy or chemical composition of dentin (20). The combination of CPP-ACP and sodium fluoride in MI Varnish promotes dentinal tubule occlusion and reduces dentin permeability, which could affect adhesion by modifying the surface characteristics of dentin (5). In line with this, MI Varnish was among the agents showing a higher descriptive prevalence of surface precipitate scores.

In contrast, Fluor Protector was the desensitizing agent that exhibited the lowest percentage of open dentinal tubules, suggesting greater substrate modification compared to the other agents evaluated. Fluorosilane-based agents like Fluor Protector promote dentin remineralization, a particularly beneficial effect during acid exposure, where fluoride can restore mineral content in demineralized areas (21-23). Furthermore, fluoride application—including silane-based formulations—may create a protective layer on the dentin surface, helping to reduce erosion and wear (22).

Shield Force Plus, in turn, acts by obliterating dentinal tubules, reducing fluid movement and relieving sensitivity (24). Our results are consistent with this mechanism, as Shield Force Plus, along with MI Varnish and Fluor Protector, showed a higher descriptive prevalence of surface precipitate scores on the eroded dentin surface. Unlike the other agents evaluated, Shield Force Plus possesses additional properties that support dentin remineralization and enhance its bonding potential (25,26). However, these benefits were

not reflected in our results, indicating a need for further studies to explore its potential in biomimetic strategies.

Regarding bond strength, our results indicate that the universal adhesive system showed similar adhesion to eroded dentin treated with most agents, except for the MI Varnish group, which exhibited weaker adhesion. This could be explained by the fact that varnishes or dentin desensitizing agents may form a barrier on the dentin surface, interfering with the adhesive's interaction with the substrate. Such a barrier could hinder proper adhesive penetration, compromising the formation of a stable bond (27). In addition, previous studies have shown that the presence of a smear layer or other surface contaminants can interfere with the performance of self-etch adhesives, which require direct contact with dentin to achieve optimal bonding (28). These findings align with our results, suggesting that the higher amount of surface precipitates observed after MI Varnish application may have impeded the universal adhesive system's bonding to dentin.

Microtensile testing showed that mixed failures predominated across the experimental groups, suggesting that failure was not restricted exclusively to the adhesive interface (29). The literature indicates that mixed failures may be associated with stronger bonding patterns, since stress can be distributed across both the adhesive interface and adjacent substrates rather than being concentrated only at the resin–dentin interface (30). However, these findings should be interpreted cautiously, since failure mode analysis alone does not demonstrate long-term interfacial stability. Moreover, they should not be considered evidence of direct bonding between the desensitizing agents and dentin, because the μTBS test evaluated the bonding performance of the universal adhesive system after previous dentin treatment. Further studies are needed to assess the effect of these agents under long-term aging conditions and their potential influence on interfacial degradation and restoration longevity (31,32).

This study has limitations inherent to its *in vitro* design, which cannot fully replicate clinical conditions, such as the interaction with oral fluids or masticatory forces. An untreated eroded dentin group was not included, which should be considered when interpreting the findings. DK was used as an active clinical comparator because the study aimed to compare clinically applicable desensitizing/protective approaches rather than treatment versus no treatment. Therefore, the present findings should be interpreted as comparisons among active desensitizing strategies before adhesive procedures and not as evidence of superiority over untreated eroded dentin. Future studies should include an untreated eroded dentin group to further clarify the isolated effect of each agent. Although the acid/abrasive challenge affected the eroded cervical dentin, its impact varied depending on the desensitizing agent used. Additionally, agents showing greater descriptive surface precipitate formation did not enhance bond strength, suggesting that tubule obliteration or precipitate formation alone does not ensure better adhesion. However, by including different agents, applying an acid/abrasive challenge, and simulating cervical erosion, this study provides an innovative approach that brings the findings closer to clinical reality. These elements enrich the research and allow for a more realistic evaluation of agents on eroded dentin. While the limitations of the *in vitro* model are evident, the findings raise new opportunities for future studies exploring the clinical effectiveness of these agents under more representative and long-term conditions.

CONCLUSION

Among the evaluated dentin desensitizing agents, Clinpro showed bond strength values comparable to the active control, whereas MI Varnish presented the lowest values on eroded

dentin. Fluor Protector significantly reduced the percentage of open dentinal tubules. Although MI Varnish, Fluor Protector, and Shield Force Plus showed greater surface precipitate formation descriptively, this did not result in improved adhesive performance. These findings highlight the importance of selecting dentin desensitizing agents that provide substrate protection without compromising the bonding performance of universal adhesive systems to eroded cervical dentin.

CONFLICT OF INTEREST: The authors declare no conflicts of interest.

FUNDING: This work was supported by the Jorge Basadre Grohmann National University (UNJBG), Peru, under Finance Code 8719-2021.

AUTHOR CONTRIBUTION STATEMENT: Conceptualization and design: J.B.T., G.M.C.N. and W.G.E.O.; Literature review: C.A.L.C., D.D.P.C. and J.A.B.B.; Methodology and validation: C.A.L.C., D.D.P.C. and J.A.B.B.; Formal analysis: J.B.T., G.M.C.N. and W.G.E.O.; Investigation and data collection: C.A.L.C., D.D.P.C. and J.A.B.B.; Resources: J.B.T., G.M.C.N. and W.G.E.O.; Data analysis and interpretation: J.B.T., G.M.C.N. and W.G.E.O.; Writing-review and editing: J.B.T., G.M.C.N. and W.G.E.O.; Supervision: J.B.T. and W.G.E.O.; Project administration: J.B.T. and W.G.E.O.

ACKNOWLEDGMENTS: The authors would like to thank the Jorge Basadre Grohmann National University (UNJBG) and the Vice-Rectorate for Research of the Catholic University of Santa María (UCSM) for their support in the development of this study.

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