Dental Materials Journal 2026; : –

The effects of desensitizing agents on dentin permeability using a hydraulic conductance device

Buse SARAÇ[1], Elif ALKAN[1], Ahmad BITTAR[2], Ibrahim OĞRAK[1], Bora KORKUT[1], Kağan ÇELEBİ[3] and Dilek TAĞTEKİN[1]

[1] *Department of Restorative Dentistry, Faculty of Dentistry, Marmara University, Istanbul, Turkey*
[2] *Department of Restorative Dentistry, Faculty of Dentistry, Istinye University, Istanbul, Turkey*
[3] *SPC Cosmetics, Istanbul, Turkey*
Corresponding author, Ahmad BITTAR; E-mail: ahmet.baytar989@gmail.com

This *in vitro* study evaluated the effects of a sodium-fluoride varnish, two surface pre-reacted glass-ionomer (S-PRG)-containing agents, and an experimental glycerol-stabilized calcium phosphate cluster (GCPC) gel on dentin permeability using a custom hydraulic conductance apparatus. Horizontal 1-mm coronal dentin disks were prepared from extracted human molars, conditioned with 2% citric acid, and randomized to ClinPro Fluoride Treatment, PRG Barrier-Coat, PRG Pro-Care Gel, experimental GCPC gel, or distilled-water control (n=10/group). Hydraulic conductance was calculated at 3 psi from the time required for 50 μL of water to pass through each specimen. ClinPro and PRG Barrier-Coat significantly reduced permeability after the first post-treatment evaluation, whereas ClinPro and both PRG agents produced near-zero values after the second evaluation. GCPC yielded a moderate but significant reduction. Scanning electron microscopy findings were consistent with progressive dentinal tubule occlusion.

Keywords: Desensitizing agents, Dentin hypersensitivity, Dentin permeability, Hydraulic conductance, Dentinal fluid flow

INTRODUCTION

Dentin hypersensitivity (DH) is characterized by a short, sharp pain arising from exposed dentin in response to thermal, evaporative, tactile, osmotic, or chemical stimuli that cannot be ascribed to another dental defect or disease[1]. According to Brännström's hydrodynamic theory[2], pain is triggered by rapid movement of fluid within patent dentinal tubules, which mechanically stimulates pulpal nerve endings. Clinically, DH can impair quality of life and complicate routine oral hygiene and restorative procedures[3-6].

Current treatment strategies are broadly divided into tubule-occluding agents, which reduce dentin permeability, and nerve-desensitizing agents, which decrease the excitability of pulpal nerves[4-6]. Desensitizing products may contain glutaraldehyde-based systems, inorganic salts such as potassium oxalate, sodium-fluoride varnishes and toothpastes, bioactive glasses, and calcium-phosphate formulations[4-10]. Many of these materials have been shown, *in vitro*, to reduce hydraulic conductance of dentin, and a systematic review confirmed that several are clinically effective when combined with control of erosive and abrasive etiologic factors[6].

Fluoride-containing agents can increase the microhardness and remineralization of enamel and dentin and contribute to dentinal tubule occlusion[4,5,7-9]. Bioactive glass and calcium-phosphate-based materials can form apatite-like mineral deposits within opened tubules, thereby decreasing fluid flow[8,10]. Giomer-type materials incorporating surface pre-reacted glass-ionomer (S-PRG) fillers represent another class of desensitizing and preventive agents. S-PRG-containing materials can release fluoride, sodium, strontium, aluminum, silicate, and borate ions, and exhibit sustained bioactive effects that support mineral induction and surface protection[11].

Calcium-phosphate systems have also attracted considerable interest as desensitizing agents. Experimental bioactive glasses and biphasic calcium phosphate derived from natural sources have been shown to decrease dentin permeability and occlude tubules while maintaining favorable biological responses[8,10]. More recently, glycerol-stabilized calcium phosphate clusters (GCPC) have been introduced as a novel enamel remineralization strategy. These subnanometric clusters can rapidly transform into a compact hydroxyapatite layer on enamel when triggered by water, leading to fast remineralization and recovery of mechanical properties[12]. However, their performance on dentin, particularly with respect to hydraulic conductance reduction, remains unclear.

To investigate the effect of desensitizing agents on dentin permeability, several fluid-filtration and hydraulic conductance models have been developed[4,13-24]. Pashley and co-workers first described *in vitro* devices to measure dentin hydraulic conductance and evaluated the influence of smear layer removal and blood components on fluid flow[4,13,14]. Subsequent modifications by Santiago, Camps, Koutsi, Erturk and Kirzioglu, Prati, Ishihata, Carvalho, Hu, and Jiang refined pressure conditions, flow detection, and specimen preparation to improve standardization and reproducibility[15-24].

Against this background, the present *in vitro* study evaluated the effects of three chairside desensitizing agents (ClinPro Fluoride Treatment, PRG Barrier-Coat, and PRG Pro-Care Gel) and an experimental GCPC gel on the dentin permeability of citric-acid-

Received Jan 20, 2026: Accepted Jun 24, 2026
doi:10.4012/dmj.2026-016 JOI JST.JSTAGE/dmj/2026-016

This is an open access article under the CC BY license
https://creativecommons.org/licenses/by/4.0/

conditioned human dentin. Scanning electron microscopy (SEM) observations were used as a complementary morphological assessment of dentinal tubule occlusion after treatment. The null hypotheses were that (1) no differences would exist in permeability reduction among the tested agents and (2) the custom apparatus would not differentiate permeability values between treated and untreated specimens.

MATERIALS AND METHODS

Dentin disk preparation

This *in vitro* study used extracted, caries-free human molars removed for periodontal or prosthodontic reasons unrelated to the present investigation. The protocol was approved by the Marmara University Faculty of Dentistry Clinical Research Ethics Committee (decision date: 27 Nov 2025; approval no.: 2025-12-02/2025-111) and was conducted in accordance with the Declaration of Helsinki. Teeth were anonymized and stored in 0.1% thymol solution until use. Soft-tissue remnants were removed, and 1-mm-thick horizontal coronal dentin disks were prepared using a precision cutting machine (ISOMET 1000, Buehler, Lake Bluff, IL, USA) equipped with a diamond disk (Fig. 1).

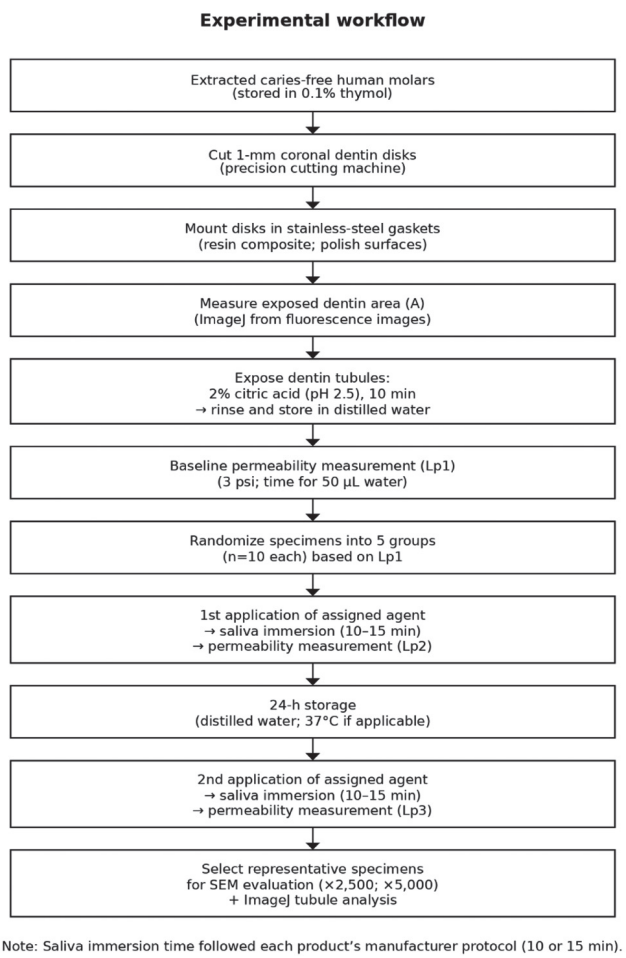

Fig. 1 Flowchart of specimen preparation, dentin permeability measurements (Lp1–Lp3), and SEM evaluation.

After enamel removal, the dentin disks were mounted into stainless-steel gaskets with an outer diameter of 23.7 mm and an inner diameter of 8.5 mm. Before mounting, the inner surfaces of the gaskets were air-abraded with 53-µm aluminum oxide particles (Aquacare, Velopex, London, UK) and treated with a silane-containing metal primer (G-Multi Primer, GC, Tokyo, Japan) to enhance bonding. Each dentin disk was centered within the gasket, and the space between dentin and metal was filled with a resin composite (Quadrant Universal-LC, Cavex, Haarlem, the Netherlands). The composite was light-cured for 20 s from both the occlusal and pulpal sides using an LED curing unit (Valo X, Ultradent, South Jordan, UT, USA). The external surfaces were then wet-polished with 600-grit silicon-carbide paper to remove composite overhangs and obtain a flat gasket surface (Fig. 2).

Surface area measurement

The exposed dentin area of each specimen was calculated using ImageJ software (National Institutes of Health, Bethesda, MD, USA). Standardized photographs were taken with a digital camera (Nikon D7100, Nikon, Tokyo, Japan; ISO 1250, f/13) while specimens were illuminated in 'black-light' mode (395–415 nm) with a Valo X light-curing unit. The fluorescence image clearly delineated the dentin area within the metal gasket; this region was manually outlined and measured in ImageJ. The measured area (A, cm^2) was later used in the permeability calculations (Fig. 3).

Hydraulic conductance measurement

Hydraulic conductance was measured using a custom-designed apparatus assembled in our department on the basis of previously described hydraulic-conductance and fluid-filtration principles[4,13-24]. The system consisted of an air-pressure regulator connected to a tank containing ultrapure water, a filtration cell that held the specimen

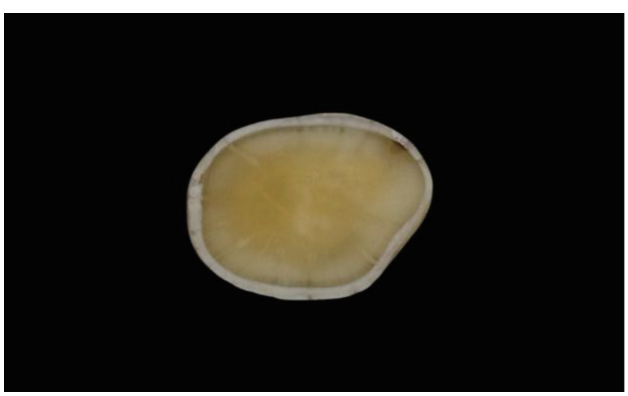

Fig. 2 Representative 1-mm-thick coronal dentin disk obtained after sectioning of the tooth with the precision cutting machine.

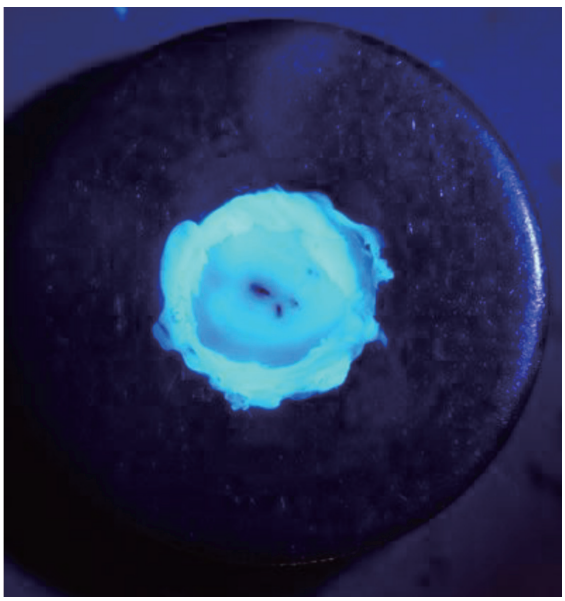

Fig. 3 Dentin disk mounted in the gasket and illuminated in 'black-light' mode (405 nm) with a Valo X light-curing unit to clearly delineate the exposed dentin surface prior to surface-area measurement in ImageJ.

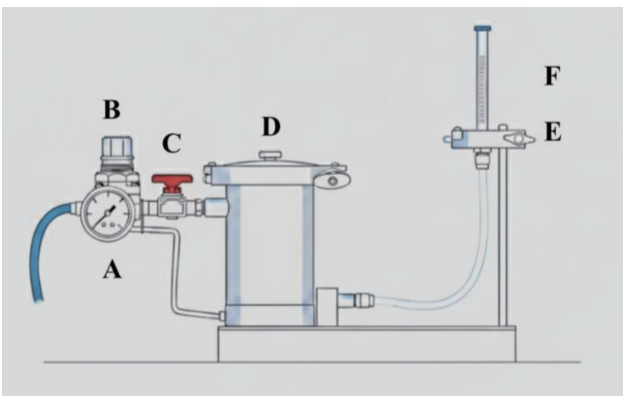

Fig. 4 Schematic representation of the custom hydraulic conductance device used in this study.
A, pressure indicator; B, air regulator; C, on/off valve; D, ultrapure water tank; E, filtration cell containing the specimen and O-rings; F, vertically positioned 500-µL HPLC syringe used to monitor fluid displacement.

between O-rings, and a vertically positioned 500-µL HPLC syringe used to monitor fluid displacement (Fig. 4).

For each measurement, ultrapure water was delivered from the tank into the filtration cell under an air pressure stabilized at 3 psi. The rise of the water column inside the HPLC syringe was monitored as a function of time. The progression of the water meniscus was recorded as video using a smartphone (iPhone 16, Apple, Cupertino, CA, USA) mounted on a tripod.



Fig. 5 Experimental arrangement used for hydraulic conductance measurements.
Ultrapure water under 3 psi air pressure was delivered from the tank to the filtration cell containing the dentin specimen, and displacement of the water column in the 500-µL HPLC syringe was recorded as video using a smartphone mounted on a tripod.

During analysis, the time required for a volume of 50 µL to pass through the dentin disk was determined by frame-by-frame inspection (Fig. 5).

To verify system integrity and exclude fluid leakage through components other than dentin, additional reference specimens were fabricated. A composite reference disk with the same dimensions as the dentin disks, a gasket completely filled with composite, and a metal coin were each mounted in the filtration cell and tested under identical pressure conditions. No fluid displacement was observed during 30 min for any reference assembly, confirming that measurable flow occurred through the dentin disk only (Fig. 6).

Under a nominal full-aperture condition (8.5-mm exposed diameter), the combination of a 50-µL readout window and a 30-min observation period corresponds to an approximate lower observable bound of 0.014 µL/(min・cm^2・cmH_2O). This value should be regarded as a practical device-dependent lower limit rather than a formal validated detection limit.

Experimental groups and treatments

Dentin tubules were exposed by conditioning both sides

of each disk with 2% citric acid solution (pH 2.5) for 10 min to simulate hypersensitive dentin. Specimens were rinsed with distilled water for 30 s and gently air-dried. Each disk was mounted in the filtration cell using O-rings, and baseline permeability (Lp1) was measured. Specimens that did not permit water flow at 3 psi were excluded. The remaining disks were ranked according to baseline Lp and randomly allocated to five groups (n=10) to balance baseline permeability: ClinPro Fluoride Treatment, PRG Barrier-Coat, PRG Pro-Care Gel, experimental GCPC gel, and distilled-water control (Table 1).

For Groups 1–4, the assigned material was applied according to the manufacturer's instructions (Table 1).



Fig. 6. Stainless-steel gasket, reference composite disk, and 1-Turkish-lira coin.
From left to right: metal gasket with central aperture (inner diameter 8.5 mm), composite disk fabricated with the same dimensions as the dentin specimens, and a 1-Turkish-lira coin for scale. The composite disk was used to verify that no fluid leakage occurred through the hydraulic conductance system.

After each application, specimens were kept moist in artificial saliva for 15 min (ClinPro Fluoride Treatment) or 10 min (PRG Pro-Care Gel and GCPC gel); PRG Barrier-Coat specimens were light-cured for 10 s and then kept in artificial saliva for 10 min. Specimens were gently rinsed with distilled water for 10 s and blotted dry before permeability measurement. Hydraulic conductance was recorded after the first application (Lp2). Specimens were then stored in distilled water at 37°C for 24 h, and the same application and measurement protocol was repeated to obtain Lp3.

The artificial saliva consisted of 1.5 mmol/L $CaCl_2$, 50 mmol/L KCl, 0.9 mmol/L KH_2PO_4, and 20 mmol/L Tris buffer (pH 7.4), prepared according to Alkan *et al.*[25]

Control specimens received no desensitizing agent. After baseline measurement, they were kept in distilled water at 37°C and were measured after 24 h (storage-only Lp2) and after an additional 24-h interval (storage-only Lp3) to provide untreated reference values for the same overall observation window.

Dentin permeability calculations

Dentin permeability (Lp) was calculated using the standard hydraulic conductance formula, $Lp=V/(t \cdot A \cdot P)$, where V is the volume of water (μL) passing through the dentin disk, t is the time (min), A is the exposed dentin area (cm^2), and P is the applied hydraulic pressure (cm H_2O). Permeability was expressed in $\mu L/(min \cdot cm^2 \cdot cmH_2O)$. For each specimen, the ImageJ-calculated surface area and the time required for 50 μL of water to pass through the syringe were used to compute Lp at each evaluation.

Table 1 Tested desensitizing agents

Group	Material	Manufacturer	Main components	Application procedure
1	ClinPro Fluoride Treatment	3M ESPE, St. Paul, MN, USA	2.1% sodium fluoride; calcium phosphate	After application, specimens were kept in artificial saliva for 15 min.
2	PRG Barrier-Coat	Shofu Dental, Shanghai, China	PRG (pre-reacted glass), fluoride, sodium, strontium, aluminum, silicate, and borate	After application, the material was polymerized for 10 s (Valo X, Ultradent, South Jordan, UT, USA), then specimens were kept in artificial saliva for 10 min.
3	PRG Pro-Care Gel	Shofu Dental	PRG, fluoride, sodium, strontium, aluminum, silicate, and borate	Applied with a microbrush for 1 min; specimens were then kept in artificial saliva for 10 min.
4	Experimental GCPC gel	Shanghai University, Shanghai, China	GCPC (glycerol-stabilized calcium phosphate cluster)	Applied with a microbrush for 1 min; specimens were then kept in artificial saliva for 10 min.
5	Control	—	Distilled water	Storage-only control. After baseline measurement, specimens were kept in distilled water at 37°C and were measured after 24 h (Lp2) and after an additional 24 h interval (Lp3).

PRG, pre-reacted glass-ionomer; GCPC, glycerol-stabilized calcium phosphate cluster.

SEM evaluation

Selected specimens were examined under SEM to visualize dentinal tubule morphology before and after treatment. SEM evaluation was performed on a specimen set prepared separately from the hydraulic-conductance specimens so that destructive processing would not interfere with permeability measurements.

Two dentin disks served as baseline controls and were treated only with 2% citric acid for 10 min, then stored in distilled water. For each experimental group, two additional disks were subjected to the same acid-etching protocol and then treated twice with the respective desensitizing agent according to the protocol used for permeability measurements. After treatment, each disk was fractured into two pieces. Approximately one-third of each specimen was retained as an internal control (etched but untreated), while the remaining surface received the desensitizing agent. All fragments were mounted on aluminum stubs using carbon and copper conductive tapes, dried in a desiccator for 1 h, sputter-coated with an 80% gold / 20% palladium alloy, and examined in an SEM (EVO MA10, Carl Zeiss, Oberkochen, Germany) at 10 kV and magnifications of ×2,500 and ×5,000.

The SEM images were evaluated descriptively for the presence of patent tubules, surface deposits, and partial or complete tubule occlusion. SEM findings were interpreted as complementary morphological evidence and were not statistically paired with the hydraulic-conductance measurements.

Statistical analysis

Statistical analyses were performed using IBM SPSS Statistics version 25.0 (IBM, Armonk, NY, USA). The normality of the data distribution was assessed with the Shapiro-Wilk test. Between-group comparisons were performed using the Kruskal-Wallis test followed by Dunn's *post hoc* test with Bonferroni correction. Within-group repeated measurements (Lp1, Lp2, and Lp3) were analyzed using Friedman's two-way analysis of variance by ranks, followed by Bonferroni-adjusted pairwise comparisons. Data are presented as median (minimum-maximum), and statistical significance was set at $p<0.05$.

A *post hoc* sensitivity analysis was performed with G*Power version 3.1 (Heinrich Heine University Düsseldorf, Düsseldorf, Germany). For five independent groups, a total sample size of 50, $\alpha=0.05$, and 80% power, the current design was sufficient to detect a large omnibus effect size (Cohen's f=0.515).

Use of AI tools: No AI tools were used for data acquisition, image processing, or statistical analysis. ChatGPT (OpenAI, San Francisco, CA, USA) was used only for language refinment; all scientific content remained the responsibility of the authors.

RESULTS

Dentin permeability measurements

Dentin permeability (Lp) was expressed as μL/(min・cm^2・cmH_2O) and was evaluated at baseline (Lp1), after the first post-intervention/time-point evaluation (Lp2), and after the second evaluation 24 h later (Lp3). The baseline Lp values did not differ significantly among groups ($p=0.167$) and were normalized to 100% (Table 2).

Table 2 Dentin permeability measurements before and after treatment/time-point evaluations

Group	Absolute Lp			Relative Lp (%)		
	Baseline (Lp1)	First evaluation (Lp2)	Second evaluation (Lp3)	Baseline (Lp1)	First evaluation (Lp2)	Second evaluation (Lp3)
1 (n=10)	0.25 (0.12–0.50)	0.08 (0.00–0.18) [a)]	0.00 (0.00–0.00) [a)]	100 (100–100)	33.39 (0.00–95.43) [a)]	0.00 (0.00–0.00) [a)]
2 (n=10)	0.27 (0.17–0.32)	0.13 (0.00–0.20) [a)]	0.00 (0.00–0.13) [ac)]	100 (100–100)	46.80 (0.00–77.65) [a)]	0.00 (0.00–42.02) [ac)]
3 (n=10)	0.28 (0.23–0.33)	0.23 (0.17–0.31) [b)]	0.00 (0.00–0.00) [a)]	100 (100–100)	87.75 (70.78–97.59) [bc)]	0.00 (0.00–0.00) [a)]
4 (n=10)	0.25 (0.19–0.39)	0.15 (0.11–0.25) [ab)]	0.13 (0.10–0.23) [bc)]	100 (100–100)	66.66 (47.38–75.94) [ac)]	60.52 (45.35–73.27) [bc)]
5 (n=10)	0.25 (0.22–0.28)	0.22 (0.21–0.27) [b)]	0.23 (0.21–0.28) [b)]	100 (100–100)	93.51 (86.67–97.50) [b)]	97.26 (86.22–100.84) [b)]
χ^2	6.468	31.813	43.717	—	33.429	45.113
p	0.167	<0.001	<0.001	—	<0.001	<0.001

*Kruskal-Wallis test followed by Dunn's *post hoc* test with Bonferroni correction. Different superscript letters within the same column indicate significant differences ($p<0.05$). Control-group Lp2 and Lp3 values represent storage-only reference time points without desensitizing-agent application. Within-group paired comparisons are reported in the RESULTS section.

After the first evaluation (Lp2), ClinPro Fluoride Treatment and PRG Barrier-Coat showed significantly lower permeability than the untreated control (p<0.001), whereas PRG Pro-Care Gel and GCPC showed partial reductions. The relative median Lp2 values were 33.39% for ClinPro, 46.80% for PRG Barrier-Coat, 87.75% for PRG Pro-Care Gel, 66.66% for GCPC, and 93.51% for the control. After the second evaluation (Lp3), ClinPro and both PRG-containing agents yielded values indistinguishable from zero, whereas GCPC showed a moderate but significant reduction. The control group showed little change over the same storage-only observation window (relative Lp3 median 97.26%).

Within-group repeated-measures analysis revealed a statistically significant difference among Lp1, Lp2, and Lp3 [Friedman $\chi^2(2)=18.667$, p<0.001]. Bonferroni-adjusted pairwise comparisons showed that, in the ClinPro Fluoride Treatment and PRG Barrier-Coat groups, both Lp1–Lp3 (p<0.001) and Lp1–Lp2 (p=0.022) were significant, whereas Lp2–Lp3 was not significant (p=0.539). In the PRG Pro-Care Gel and GCPC gel groups, only Lp1–Lp3 reached statistical significance

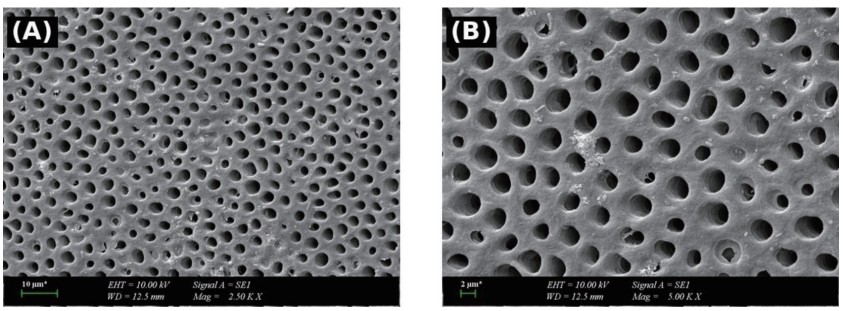

Fig. 7. SEM images of baseline dentin specimens after 2% citric acid (pH 2.5) conditioning for 10 min. (A) ×2,500 and (B) ×5,000 magnification. Dentinal tubules are widely open with minimal surface deposits, representing the hypersensitive dentin model before treatment.

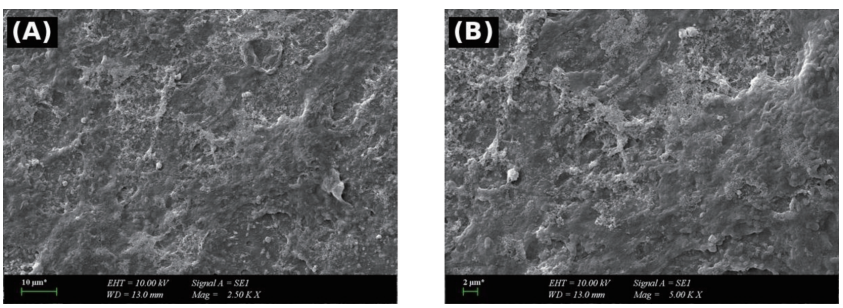

Fig. 8 SEM images of dentin specimens after the second application of ClinPro Fluoride Treatment (Group 1). (A) ×2,500 and (B) ×5,000 magnification. A continuous irregular mineral layer covers most of the surface, and many dentinal tubule orifices are partially or completely occluded, consistent with the marked reduction in dentin permeability in this group.

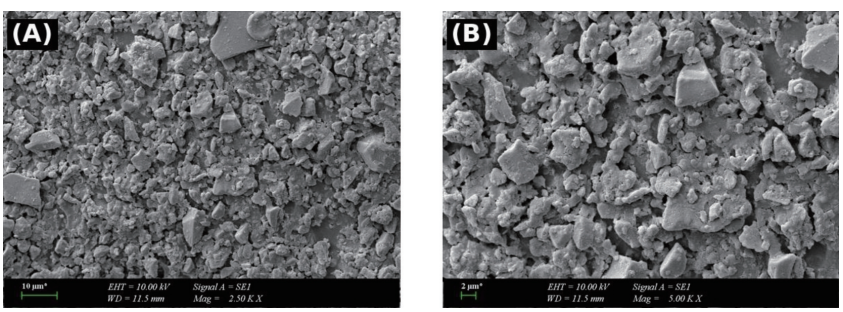

Fig. 9 SEM images of dentin specimens after the second application of PRG Barrier-Coat (Group 2). (A) ×2,500 and (B) ×5,000 magnification. A compact, rough resin-filler layer completely covers the dentin surface; individual tubule openings are no longer distinguishable, indicating almost complete tubule occlusion by the light-cured PRG varnish.

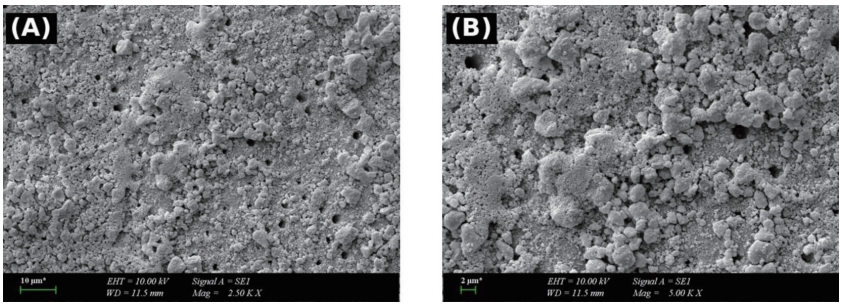

Fig. 10 SEM images of dentin specimens after the second application of PRG Pro-Care Gel (Group 3).
(A) ×2,500 and (B) ×5,000 magnification. Numerous granular deposits derived from the S-PRG filler are present on the surface, effectively narrowing or plugging most dentinal tubules, although a few small openings remain.

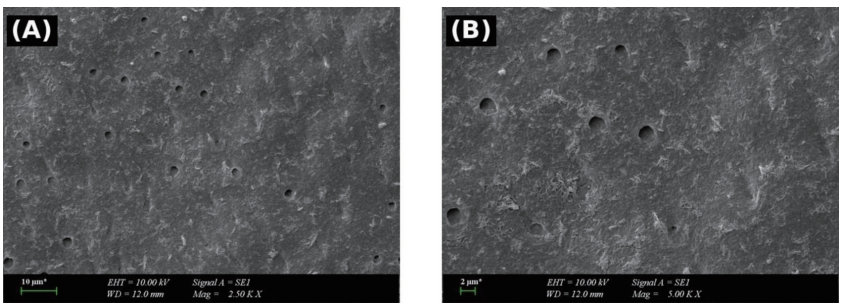

Fig. 11 SEM images of dentin specimens after the second application of experimental GCPC gel (Group 4).
(A) ×2,500 and (B) ×5,000 magnification. The surface appears relatively smooth with scattered small mineral deposits. Several dentinal tubules remain partially patent, indicating only partial tubule occlusion and explaining the moderate reduction in permeability measured for this group.

(p<0.001), while Lp1–Lp2 and Lp2–Lp3 were not significant after Bonferroni correction (p=0.076). In the control group, Lp1–Lp2 was significant (p<0.001), whereas Lp1–Lp3 and Lp2–Lp3 were not significant after Bonferroni correction (p=0.133 for both).

SEM evaluation

Representative SEM images are shown in Figs. 7–11. Dentin conditioned with 2% citric acid showed widely open tubules (Fig. 7). After treatment, ClinPro Fluoride Treatment and PRG Barrier-Coat exhibited extensive surface coverage and tubule occlusion (Figs. 8 and 9), PRG Pro-Care Gel showed granular deposits partially occluding tubules (Fig. 10), and experimental GCPC gel resulted in only partial occlusion (Fig. 11).

These SEM observations were consistent with the hydraulic-conductance pattern and were interpreted qualitatively because the SEM specimens were separate from the permeability specimens.

DISCUSSION

This *in vitro* study evaluated the effects of three commercially available desensitizing agents and an experimental GCPC gel on dentin permeability using a custom hydraulic conductance apparatus. The first null hypothesis was rejected because the tested agents differed in their ability to reduce permeability. ClinPro Fluoride Treatment and PRG Barrier-Coat produced the most rapid reductions, whereas PRG Pro-Care Gel reached similarly low values after repeated application. GCPC yielded a significant but incomplete reduction in permeability. The second null hypothesis was rejected for the present experimental conditions because the apparatus differentiated treated from untreated specimens; however, formal repeatability and external benchmarking were not assessed.

DH is widely accepted to be mediated by fluid movement within open dentinal tubules, as described by Brännström's hydrodynamic theory[1,2]. Accordingly, *in vitro* hydraulic conductance models remain useful tools for quantifying the effects of desensitizing agents under controlled conditions[4,13-24]. The present design intentionally created a high-permeability condition by removing the smear layer and exposing tubules with 2% citric acid. Because dentin permeability is strongly influenced by dentin thickness, tubule density, and smear-layer status, 1-mm-thick coronal dentin disks provide a sensitive model for detecting occluding effects even after short application periods[13,20,21].

The applied pressure (3 psi≈210.1 cm H_2O) lies within the range used in previous hydraulic conductance studies[4,16-23]. Camps *et al.* showed that permeability is pressure-dependent, but that low and

high pressures yield proportional conductance values if the same pressure is used consistently across groups[16]. Accordingly, the present results are best interpreted comparatively, rather than as physiological outward pulpal-flow values. In addition, the relationship between residual permeability and visible tubule morphology is not expected to be strictly linear, because fluid flow through narrow tubules changes disproportionately with small changes in tubule radius.

ClinPro Fluoride Treatment produced the most rapid and pronounced reduction in dentin permeability. After a single application, median Lp2 values decreased to approximately one-third of baseline, and after the second evaluation, Lp3 values were effectively zero within the practical detection range of the device. These findings agree with the classic work of Greenhill and Pashley, who showed that some fluoride-containing desensitizing agents can reduce hydraulic conductance of acid-etched human dentin by up to 95%[4], and with later studies reporting substantial permeability reductions and tubule occlusion after sodium-fluoride-based applications[8,9,19,20].

The two PRG-containing materials showed a progressive pattern of permeability reduction. PRG Barrier-Coat, a light-cured resin coating, significantly reduced permeability after the first application, whereas PRG Pro-Care Gel, a non-cured gel, showed a more modest early effect but reached near-zero values after the second application. This difference is consistent with the SEM findings: PRG Barrier-Coat formed a compact resin-filler film that masked tubule orifices, whereas PRG Pro-Care Gel produced granular deposits that accumulated with repeated application. The ion-releasing profile and mineral-inducing potential of S-PRG fillers are well documented[11], which supports the present interpretation of a combined physical-chemical mechanism.

Experimental GCPC gel produced an intermediate reduction in dentin permeability, with median relative values of approximately 67% after the first evaluation and 60% after the second. GCPC systems can rapidly transform into hydroxyapatite on enamel when triggered by water[12], but the present dentin model showed only partial tubule occlusion. The discrepancy may reflect structural and compositional differences between enamel and dentin, including the presence of organic matrix and the tubular architecture of dentin, which may hinder deep penetration and crystallization inside the tubules. The short application periods and storage in distilled water, without prolonged exposure to artificial saliva, mechanical loading, or pH cycling, may also have limited the performance of GCPC under the present conditions.

The magnitude of permeability reduction observed here is broadly consistent with previous peer-reviewed hydraulic-conductance studies[4,15-24]. Greenhill and Pashley reported large reductions after desensitizer application to acid-etched dentin[4], whereas later studies showed product-dependent differences associated with crystalline precipitation, resin-based sealing, or adhesive infiltration of tubules[15,22-24]. The present SEM findings followed the same general pattern, with more complete occlusion corresponding to lower residual permeability values.

This study has several limitations. First, it was an *in vitro* experiment using extracted teeth and therefore cannot fully reproduce the oral environment, including outward pulpal pressure and the protein content of dentinal fluid. Second, specimens were not subjected to thermal cycling, toothbrushing abrasion, or erosive challenges after treatment; thus, the durability of the occluding layers could not be assessed. Third, the first treated-group post-application measurements were obtained immediately after material use, whereas untreated control measurements reflected storage-only intervals; therefore, between-group Lp2 comparisons should be interpreted cautiously. Fourth, permeability was measured at a single pressure (3 psi), so absolute values cannot be directly compared with those from different devices or pressure settings. Fifth, placebo formulations were not evaluated, and the contributions of the carrier matrix and active ingredients could not be separated. Sixth, SEM and permeability datasets were obtained from different specimen sets, so microscopy should be interpreted as complementary morphological evidence rather than direct verification of the same specimens. Finally, although the custom apparatus differentiated treatment-related changes under the present conditions, formal repeatability/reproducibility testing and external benchmarking against an established reference system were not performed.

Within these limitations, ClinPro Fluoride Treatment and PRG Barrier-Coat appear to provide the most rapid reductions in dentin permeability, supporting their chairside use in the management of DH. PRG Pro-Care Gel may be better suited to protocols involving repeated professional or combined professional-home applications. The experimental GCPC gel showed promising but incomplete permeability reduction, indicating that dentin-specific optimization of formulation and application protocol is still needed.

CONCLUSIONS

Within the limitations of this *in vitro* study, the following conclusions can be drawn:

1. ClinPro Fluoride Treatment, PRG Barrier-Coat, and PRG Pro-Care Gel significantly reduced dentin permeability compared with the untreated control condition.
2. ClinPro Fluoride Treatment produced the greatest and most rapid reduction in permeability, with near-zero values after the second evaluation.
3. PRG Barrier-Coat and PRG Pro-Care Gel achieved similarly low permeability after repeated application; the barrier-coat material showed a stronger initial effect, probably because of resin-film formation.
4. The experimental GCPC gel significantly reduced dentin permeability, but it did not achieve the

near-complete tubule occlusion observed with the fluoride and PRG-containing agents.

5. Under the present experimental conditions, the custom hydraulic conductance apparatus differentiated treatment-related changes in dentin permeability; however, formal repeatability testing and external benchmarking remain necessary.

CONFLICT OF INTEREST

The authors declare no competing interests. Kagan Celebi is affiliated with SPC Cosmetics, Istanbul, Turkey. SPC Cosmetics did not fund the study, provide any tested desensitizing material, or have any role in the study design, data collection, statistical analysis, interpretation of the data, manuscript preparation, or the decision to submit the manuscript.

REFERENCES

1) Holland GR, Narhi MN, Addy M, Gangarosa L, Orchardson R. Guidelines for the design and conduct of clinical trials on dentine hypersensitivity. J Clin Periodontol 1997; 24: 808-813.
2) Brännström M. The elicitation of pain in human dentine and pulp by chemical stimuli. Arch Oral Biol 1962; 7: 59-62.
3) Orchardson R, Collins WJ. Clinical features of hypersensitive teeth. Br Dent J 1987; 162: 253-256.
4) Greenhill JD, Pashley DH. The effects of desensitizing agents on the hydraulic conductance of human dentin *in vitro*. J Dent Res 1981; 60: 686-698.
5) Sgreccia PC, Barbosa RES, Dame-Teixeira N, Garcia FCP. Low-power laser and potassium oxalate gel in the treatment of cervical dentin hypersensitivity—A randomized clinical trial. Clin Oral Investig 2020; 24: 4463-4473.
6) Marto CM, Baptista Paula A, Nunes T, Pimenta M, Abrantes AM, Pires AS, *et al.* Evaluation of the efficacy of dentin hypersensitivity treatments—A systematic review and follow-up analysis. J Oral Rehabil 2019; 46: 952-990.
7) João-Souza SH, Scaramucci T, Borges AB, Lussi A, Carvalho TS, Correa Aranha AC. Influence of desensitizing and anti-erosive toothpastes on dentine permeability: An *in vitro* study. J Dent 2019; 89: 103176.
8) Silva Ramos FS, de Castro Oliveira L, Albertinazzi L, Bezerra SJC, Santos VR, Scaramucci T, *et al.* Analysis of dentin wear and biological properties promoted by experimental in office desensitizing materials. BMC Oral Health 2024; 24: 607.
9) Sivapriya E, Sridevi K, Periasamy R, Lakshminarayanan L, Pradeepkumar AR. Remineralization ability of sodium fluoride on the microhardness of enamel, dentin, and dentinoenamel junction: an *in vitro* study. J Conserv Dent 2017; 20: 100-104.
10) Degli Esposti L, Ionescu AC, Gandolfi S, Ilie N, Adamiano A, Brambilla E, *et al.* Natural, biphasic calcium phosphate from fish bones for enamel remineralization and dentin tubule occlusion. Dent Mater 2024; 40: 593-607.
11) Imazato S, Nakatsuka T, Kitagawa H, Sasaki JI, Yamaguchi S, Ito S, *et al.* Multiple-ion releasing bioactive surface pre-reacted glass-ionomer (S-PRG) filler: Innovative technology for dental treatment and care. J Funct Biomater 2023; 14: 236.
12) Luo N, Lu BQ, Deng YW, Zeng H, Zhang Y, Zhan JY, *et al.* The glycerol stabilized calcium phosphate cluster for rapid remineralization of tooth enamel by a water-triggered transformation. Nat Commun 2025; 16: 58.
13) Pashley DH, Michelich V, Kehl T. Dentin permeability: Effects of smear layer removal. J Prosthet Dent 1981; 46: 531-537.
14) Pashley DH, Nelson R, Williams EC. Dentin hydraulic conductance: Changes produced by red blood cells. J Dent Res 1981; 60: 1797-1802.
15) Santiago SL, Pereira JC, Martineli AC. Effect of commercially available and experimental potassium oxalate-based dentin desensitizing agents on dentin permeability: Influence of time and filtration system. Braz Dent J 2006; 17: 300-305.
16) Camps J, Giustiniani S, Dejou J, Franquin JC. Low versus high pressure for *in vitro* determination of hydraulic conductance of human dentine. Arch Oral Biol 1997; 42: 293-298.
17) Camps J, Pizant S, Dejou J, Franquin JC. Effects of desensitizing agents on human dentin permeability. Am J Dent 1998; 11: 286-290.
18) Ertürk MS, Kirzioğlu Z. *In vitro* evaluation of dentin permeability of fluorotic primary teeth with a new electronic hydraulic conductance measurement system with photosensors. Arch Oral Biol 2007; 52: 1057-1063.
19) Hu ML, Zheng G, Jiang RD, Han JM, Zhang YD, Lin H. The evaluation of the desensitization effect of a desensitizing agent and desensitizing toothpastes *in vitro*. Dent Mater J 2020; 39: 855-861.
20) Jiang R, Xu Y, Wang F, Lin H. Effectiveness and cytotoxicity of two desensitizing agents: A dentin permeability measurement and dentin barrier testing *in vitro* study. BMC Oral Health 2022; 22: 391.
21) Koutsi V, Noonan RG, Horner JA, Simpson MD, Matthews WG, Pashley DH. The effect of dentin depth on the permeability and ultrastructure of primary molars. Pediatr Dent 1994; 16: 29-35.
22) Prati C, Venturi L, Valdre G, Mongiorgi R. Dentin morphology and permeability after brushing with different toothpastes in the presence and absence of smear layer. J Periodontol 2002; 73: 183-190.
23) Ishihata H, Finger WJ, Kanehira M, Shimauchi H, Komatsu M. *In vitro* dentin permeability after application of Gluma desensitizer as aqueous solution or aqueous fumed silica dispersion. J Appl Oral Sci 2011; 19: 147-153.
24) Carvalho AO, Oliveira MT, Nikaido T, Tagami J, Giannini M. Effect of adhesive system and application strategy on reduction of dentin permeability. Braz Oral Res 2012; 26: 397-403.
25) Alkan E, Tağtekin D, Korkmaz N. Evaluation of the effect of *Moringa oleifera* on dental hard tissues. Nobel Med 2025; 21: 30-39.