Effect of desensitizing agents on dentin permeability and dentin tubule occlusion

Justine L. Kolker\textsuperscript{a} / Marcos A. Vargas\textsuperscript{a} / Steven R. Armstrong\textsuperscript{a} / Deborah V. Dawson\textsuperscript{b}

\textsuperscript{a}Department of Operative Dentistry & \textsuperscript{b}Department of Preventive and Community Dentistry, The University of Iowa, Iowa City, Iowa 52242, USA

\textbf{ABSTRACT}

\textbf{Purpose:} The aim of this study was to evaluate: 1) the effect of five dentin desensitizing agents (DDAs) on permeability, using hydraulic conductance, and 2) morphological tubule changes, with scanning electron microscopy (SEM). The agents can be categorized by their proposed mechanism of decreasing fluid flow in the dentinal tubules; i.e., resin occlusion: Seal and Protect, Gluma & HurriSeal, precipitation of proteins: Gluma, or precipitation of crystals: D/Sense 2 & Super Seal.

\textbf{Materials and Methods:} Thirty extracted human molars were sectioned into 1mm mid-coronal dentin disks. Dentin permeability was measured at baseline and after treatment using bovine serum and phosphate-buffered saline at 10psi. Treatments were applied to the occlusal surfaces of dentin according to the manufacturers’ instructions. Representatives from each group were selected for SEM observation. Kruskal-Wallis ANOVA and Tukey’s were used to evaluate differences between groups.

\textbf{Results:} Mean percent reduction in dentin permeability for each group: SuperSeal = 97.5±4.0, HurriSeal = 54.2±35.3, D/Sense 2 = 46.6±20.4, Gluma = 39.6±26.7, and Seal & Protect = 33.8±19.4. The data provided strong evidence of differences in permeability reduction among the agents (p<0.01). Pairwise comparisons of means demonstrated the effects of SuperSeal differed significantly from the reductions achieved using Seal & Protect, Gluma, and D/Sense 2. Differences in the degree and content of dentinal tubule occlusion were seen among all DDAs under SEM.

\textbf{Conclusions:} Of the materials tested, SuperSeal may be the most beneficial when treating dentin sensitivity. The wide range of results may reflect the various approaches and chemistries used to occlude tubules.
studies concentrating on fluid flow within the dentin whenever pain-producing stimuli were applied to teeth. The theory proposes that movement of fluid in the dentin tubules, in either direction, stimulates sensory nerves in dentin or pulp. Open tubules allow fluid flow leading to sensitive dentin. Dentin permeation is proportional to the product of tubule number and diameter. Pashley found that the hydraulic conductance of a tissue expresses the ease with which fluid can move across a unit surface area under a unit pressure per unit of time. The hydraulic conductance is determined by a number of variables, which include the pressure moving fluid across the dentin, the length of the dentinal tubules, the viscosity of the fluid and the radius of the tubule. The most important variable is the radius of the dentinal tubules raised to the fourth power. Small changes in the functional radius of tubules can have a very large effect on fluid flow because of the large exponent.

The measurement of hydraulic conductance is a convenient measure of dentin permeability. Changes in the hydraulic conductance of dentin have been used as a method of screening the efficacy of desensitizing agents. This model works well for agents that desensitize by occluding tubules but is unsuitable for those that modify nerve activity. Filling the dentinal tubules with a protein solution more closely simulates dentinal fluid. A dilution of plasma with phosphate-buffered saline (PBS) provides the opportunity to evaluate the effects of desensitizing agents or methods that might precipitate plasma proteins in dentinal fluid.

Using dentin disks, in vitro, to evaluate the potential tubule occluding properties of desensitizing agents has been previously reported to be a useful screening method. Agents that significantly occlude tubules, in vitro, may be effective clinically. Those agents that do not block tubule orifices in the dentin disk model may still be effective in vivo since they may operate via a mechanism other than occlusion of dentin tubules, or they may block tubules in vivo by a mechanism that cannot be observed in this laboratory model. Currently there are at least two recognized mechanisms of action of desensitizing agents. One involves blocking fluid movement by occluding dentin tubules, while the other involves blocking pulpal nerve activity by altering the excitability of sensory nerves. Effective treatments for hypersensitive dentin should involve agents that either occlude dentin tubules or modify nerve sensitivity.

In office treatments for dentin sensitivity include cavity varnishes, anti-inflammatory agents, obturating dentinal tubules, restorative resins, and dentin bonding agents. Topical methods are largely used because they are convenient and have an immediate effect. Desensitizing agents and methods are many in number and constantly changing. They vary in chemical composition, pH, and mechanism of action. Products can be classified either according to their physical or chemical characteristics or according to their presumed mode of action.

There is a lack of information regarding the effects of some of the current agents on dentin tubule permeability and occlusion. Some of these agents claim to have dual action of occluding dentin tubules and the ability to reduce nerve excitability. Evaluating permeability reduction, under the same set of controls, with agents that occlude tubules with resin, or crystals, or have a dual action has not been reported in the literature. The aim of this study was to evaluate the effect of five current dentin desensitizing agents (DDAs) on dentin permeability, by using hydraulic conductance, and morphological tubule changes, with scanning electron microscopy. The null hypothesis is that there is no difference in permeability reduction among DDAs.
MATERIALS AND METHODS

Hydraulic Conductance Analysis -

Mordan et al. claim that the dentin disk is a useful model for the in vitro examination of the physical barrier aspect of the complex phenomenon of dentinal sensitivity. Since there is natural variation in dentin tubules and surface morphology, precise controls in preparation procedures should be followed.

Thirty extracted human molars were used to obtain 1mm thick dentin disks. The teeth were sectioned parallel to the occlusal surface from the top of the pulp horns and occlusally to an approximate 1 mm width using an Iosmet saw (Bueler Ltd., Lake Bluff, IL) with water as coolant. The occlusal surfaces of the dentin disks were polished to remove the smear layer resulting in patent dentinal tubules, the relationship between dentin sensitivity and the patency of dentin tubules in vivo has been established. The sections were polished with 600 and 800 grit paper and 6, 1, and 0.5 µm diamond polishing compound with polishing cloths using an Ecomet polisher (Bueler Ltd.). The samples were placed in water in an ultrasonicator for 30 minutes, and then in 70% ethanol in an ultrasonicator for 10 minutes. This method is similar to Nakabayashi’s method of removing smear layers and smear plugs without demineralizing the.

The pulpal sides of the dentin disks were etched with 35% phosphoric acid, to remove any smear plugs and to mimic open pulpal tubules. A split-chamber apparatus, which has been described by Outhwaite et al. and Pashley, was used to determine the hydraulic conductance.

A solution of fetal bovine serum and PBS in a 1:3 ratios was forced through the dentin disks. This solution, resembling dentin fluid, was used to evaluate the effects of desensitizing agents that may precipitate plasma proteins in the dentin fluid and/or dentin collagen. Dentinal fluid has been compared to blood plasma due to its protein composition. The solution was forced from a modified pressure cooker through polyethylene tubing to a split chamber device holding the dentin disk. The pressure cooker was connected to a compressed nitrogen cylinder. A 25µl micropipette connected to the polyethylene tubing was used to insert an air bubble into the tubing. The rate of air bubble movement was monitored using a millimeter ruler.

Initially the solution was forced through the tubules at 30 PSI. This was to facilitate removal of any remaining diamond particles in the dentin tubules. The pressure used to evaluate the samples was 10psi (703 cm H₂O), which was held throughout the experiment. The fluid was forced from the pulpal to the occlusal side of the dentin disk. By measuring the progress of the air bubble through the pipette over a 6 minute interval, the amount of liquid that flowed through the dentin was quantified as a rate. Dentin permeability as a function of hydraulic conductance was measured for each specimen at baseline and after treatment with each agent. Therefore, each disk served as its own control. Prior to treatment the hydraulic conductance of each sample was measured. This value represented 100% permeability, which represented baseline permeability for the disk.

Agents tested in this study are shown in Table 1. Treatments were applied to the occlusal polished surfaces of dentin and according to the manufactures’ instructions. After application of the desensitizing agent, the hydraulic conductance was assessed over 6 minutes. This rate was used to calculate the percent of permeability reduction using the desensitizing agent.
Scanning electron microscopy analysis-

Two disks from each group were randomly selected for scanning electron microscopy (SEM) observation. The disks were air-dried, fractured, mounted, and sputter-coated with gold-palladium. The samples were prepared in this manner to protect the treated surfaces from distortion that may occur with conventional sample preparation. The samples were fractured for observing both the occlusal surface and the internal tubule morphology. Specimens were examined using a Hitachi S-4000 FE-SEM. Photographs at different magnifications were made of representative areas for each specimen.

Statistical analysis-

The nonparametric Kruskal-Wallis procedure was used to evaluate differences in the distribution of percent permeability reduction among the five desensitizing agents, since examination of the data suggested that requirements of the standard analysis of variance model were not met. Pairwise comparisons were performed as described by Conover,¹¹ in conjunction with adjustment for multiple comparisons using the Tukey method, which is the most powerful approach when the set of all possible pairwise group comparisons is of primary interest.²⁵ An overall 5% level of Type I error was associated with the multiple comparisons adjustment.

RESULTS

Hydraulic Conductance Analysis-

Descriptors of the alteration in permeability, expressed as percent hydraulic conductance relative to baseline, are given for each of the five desensitizing agents in Table 2. A graph of the mean percentage of permeability reduction and standard deviations are shown in Figure 1. In particular, permeability reduction was the greatest following treatment with SuperSeal, and the range of response was considerably less for the other four agents.

The data provided strong evidence of differences in permeability reduction among the agents (p<0.01). Pairwise comparisons of means using an experiment-wise Type I error level of .05 demonstrated that the effects of SuperSeal differed significantly from the reductions achieved using D/Sense 2, Gluma, and Seal & Protect. These three agents (D/Sense 2, Gluma and Seal & Protect) were associated with the least amount of reduction in permeability; however, the available data did not support significant differences in effect among the three worst performing agents.

It should be noted that the variability in results appeared to differ considerably among the treatment groups. In particular, the results obtained with SuperSeal were much restricted in range of response, possibly due in part to a ceiling effect. In contrast, the range of response was the greatest for the HurriSeal outcomes, which were among the largest and the smallest observed values in the experiment. Similarly, although the median and mean values suggested that HurriSeal results were intermediate between those of SuperSeal and those associated with the set of three least effective agents, the HurriSeal treatment could not be shown to be significantly different from any of them. We attribute these results to the wide overlap of HurriSeal-associated responses with those of all other treatments.

Scanning electron microscopy analysis-

Representative micrographs for polished dentin and all desensitizing agents on dentin are shown in Figures 2 to 7. All DDAs showed various degrees of tubular occlusion.
**Smear layer-free dentin.** Dentin that was polished to remove the smear layer is depicted in Figure 2. No smear layer and smear plugs were observed. Cracks were observed within the peritubular dentin which did not extend to the intertubular dentin. Lateral canals were observed within the intertubular dentin.

**Seal and Protect.** A resin layer approximately 1 to 2 microns thick was observed covering the treated area. This layer continues and occludes the entrance to the dentinal tubules to a depth of approximately 5 – 10 microns. In some tubules the resin occluding the tubules was not dense and showed pocket formations. Globular structures were present within the dentinal tubules beyond the initial resin penetration. There was no evidence of resin within the lateral canals (Figure 3).

**Gluma.** A layer or thin coat could be seen over the entire treated surface. However, the majority of dentinal tubules appear open. The thin coated was of approximately 200nm. This coat did extend into the dentinal tubules and formed single or multiple bridges that occluded the lumen at various depths. This coat seemed to be in intimate contact with the dentinal tubule walls. In some tubules this coat could be seen up to 20-25 microns deep (Figure 4).

**HurriSeal.** A layer or thin coat could be seen over the entire treated surface. However, the majority of dentinal tubules appear open. Small globular structures were apparent covering the tubule walls to a depth of 10-15 microns (Figure 5).

**D/Sense 2.** A crystal precipitate was observed covering most of the dentinal surface. However the observable dentinal tubules appear open. Micrographs of fractured specimens showed a small amount of tubules that contained a crystal precipitate to a depth of approximately 2-3 microns. This crystal precipitate seemed to be densely packed but not attached to the tubule walls (Figure 6).

**SuperSeal.** Roughly half of the dentinal tubules on the surface micrographs appear closed. Micrographs of the fractured specimens showed almost all tubules occluded by a crystal precipitate that is invaginated from the surface. This precipitate seemed to be dense and in intimate contact with the tubule walls to a depth of approximately 2-3 microns. Below this area several rhombooidal crystals were found to a depth of approximately 15 microns. All tubules presented a slight funnel shape opening towards the surface (Figure 7).

**DISCUSSION**

This study was performed to evaluate dentin permeability changes after the application of dentin desensitizing agents (DDAs). This study tested a variety of DDAs that use different approaches to reduce dentin fluid flow. HurriSeal, Gluma, and Seal & Protect occlude dentinal tubules with resin; Gluma precipitation of proteins as well as tubule occlusion with resin; and SuperSeal and D/Sense 2 deposit a crystalline salt precipitate.

The DDAs tested showed a wide range of dentin permeability reduction, which may reflect the various approaches and chemistries used to treat dentin sensitivity. The variation observed may also be due to differences in dentin morphology. Even though an attempt was made to obtain dentin of the same area of the tooth, supra-pulpal mid-coronal dentin and of approximately 1mm width, replication of the dentin substrate is impossible due to natural variations in dentin such as, number and diameter of tubules. It was also observed that all DDAs, except SuperSeal, showed a broad range in percentage of permeability reduction with coefficients of variation (CV = SD/mean) from 43.7 to 67.5. HurriSeal had the most noticeable range of values from 7 to 100%. It is
unknown why such a range was present but it was probably due to technique sensitivity. Conversely, the consistency of SuperSeal’s values should be noted, it reduced permeability by a narrow range of 97% to 100% (CV = 4.2%).

The DDAs evaluated in this study occluded tubules with resin deposition or a salt precipitate. These two mechanisms may differ substantially in their ability to occlude dentinal tubules. The constituent monomers in the tested DDAs are HEMA and PENTA. HEMA which is used in Gluma and HurriSeal may act as a carrier/wetting agent to Benzalkonium Chloride and glutaraldehyde. It is proposed that on application of Gluma, amino group-containing substances in dentin react with glutaraldehyde and start the formation of a HEMA polymer. Resin may last longer due to higher abrasion resistance and may prove to be less soluble than some precipitates. In an in vitro study evaluating resistance to acid erosion Gluma was completely dissolved in the acid solution, while two dentin bonding agents showed levels of acid dissolution resistance. D/Sense 2 and SuperSeal form crystal precipitates that block the dentinal tubules. Soluble potassium oxalate and ferric oxalate solutions make available oxalate ions that can react with calcium ions in the dentinal fluid to form insoluble calcium oxalate crystals that are deposited in the dentinal tubules.

Gluma contains glutaraldehyde and HEMA. Glutaraldehyde is a biological fixative, which upon reacting with the proteins in the dentin fluid induces a precipitation and thus a partial or total occlusion of dentin tubules. Bergenholz et al. demonstrated in animal experiments, the flux of serum albumin over time into a prepared dentin cavity is completely inhibited by topical treatment with Gluma for 1 minute, as opposed to cavities treated with saline solution in which serum albumin was continuously released. In Camps et al. study, a decrease in hydraulic conductance was observed when the dentin was treated with Gluma desensitizing agent when the tubules were filled with bovine serum in PBS, yet there was no decrease in hydraulic conductance when PBS was used alone. In an article by Schupbach et al. some of the SEM specimens of Gluma displayed transverse septa in the lumen of dentinal tubules. If was concluded that the septa in the tubules may counteract the hydrodynamic mechanism for dentinal sensitivity. These transverse septa were similar to what was observed in this study. Although protein precipitates may block fluid flow, the bridges are more consistent with the appearance of resin, which may be due to the HEMA in Gluma. Gluma is one of the only desensitizers that has been shown to be effective clinically.

Dondi and Malferrari found that Gluma showed a highly significant reduction in sensitivity between baseline and postoperative pain scores (P<0.05) and between the postoperative and the 1-week responses (P<0.05). The sensitivity scores were not different between 1 week and 6 months.

Another method to control dentin sensitivity is the suggestion that potassium ions might exert their desensitizing effects directly on intradental nerves. It is thought that the high extra-cellular concentration of potassium inhibits the nerve cells’ repolarization and the transmission of the pain impulse. This hypothesis is based on evidence from animal experiments. Markowitz et al. proposed that the desensitizing effects of potassium ions were due to increased potassium ion concentration ([K+]) in the extracellular fluids surrounding the intradental nerves. The increased [K+] causes a sustained depolarization of the nerves, resulting in inactivation of action potential
generation through a mechanism such as axonal accommodation. Unfortunately, our study does not test this concept and therefore does not support or disprove this theory.

Frequently, evaluation of morphological changes on dentin with DDAs is done by studying the top dentinal surface.\textsuperscript{9,23,25,28,39} Unfortunately, many of these desensitizing agents thinly coat the dentin surface and leave the appearance of open dentin tubules, yet in the fractured sample the tubules are blocked just below the visible surface layer (Gluma, D/Sense 2, SuperSeal). Just observing the occlusal surface may not be an accurate presentation of tubule occlusion and penetration. Therefore, it is necessary to present fractured sample micrographs to look at the internal perspective of tubes.

A combination of hydraulic conductance and morphological analyses allows measuring the rate of fluid flow and visualization of morphological changes in the same samples. The micrographs of Seal & Protect show densely filled tubules. Without performing the hydraulic conductance analysis it may be assumed by looking at these densely filled tubules that Seal & Protect would decrease permeability and therefore reduce sensitivity. Conversely, in this study Seal & Protect had the lowest amount of permeability reduction. This particular example demonstrates the necessity to perform the hydraulic conductance and SEM analyses conjointly. Dentinal tubules may be occluded, but not necessarily sealed.

Zhang et al.\textsuperscript{42} found similar results. In their study, there did not seem to be a very good correlation between the SEM appearance of the dentin surfaces and its permeability. Surfaces covered with a thick amorphous material had hydraulic conductance levels near the control, indicating that the layer of resin was not necessarily occluding the tubules.

In the SEM analysis, Seal and Protect and SuperSeal displayed tubule funneling to the surface of dentin. This is due to dentin demineralization. This demineralization is most likely due to the low pH of the solutions. In the case of SuperSeal this demineralization may help promote the sealing of the tubules by attacking peritubular dentin and using calcium to form insoluble calcium oxalate crystals that block the dentinal tubules. On the contrary Seal & Protect may work as a self-etching primer to demineralize and seal the dentin by the formation of a hybrid layer.

This was an in vitro study and therefore cannot be directly applied to clinical use of these desensitizing agents. Future clinical studies would be beneficial by adding evidence to the information that we use to make clinical decisions. Absi et al.\textsuperscript{1} have shown the relationship between tubule patency and sensitivity. Therefore, the results of this study can be used to rationally evaluate these materials for clinical use; with the acknowledgement that clinical evidence is necessary in the future.

Inflammation of the dental pulp is a normal consequence when bacteria byproducts reach the pulp. The dentin pulp complex may react to seal the exposed dentinal tubules by two mechanisms: the formation of sclerotic dentin within the lumen to the tubule complex or the deposition of a patch of new reparative dentin at the pulp-predentin interface by new odontoblastoid cells. Sclerotic dentin is a type of dentin that forms by increased mineral deposition in the dentinal tubules as a response to various external irritations, and the deposition may continue until complete obliteration of the involved tubules. If an intact dentin barrier remains over the injured pulp, healing primarily involves focal proliferation of fibroblasts and granulation tissue to replace the damaged odontoblast layer with fibrous tissue. Damaged primary odontoblasts are then replaced by fibroblasts making a reparative dentin bridge to cover the lesion. DDAs may promote the formation of sclerotic and reparative dentin by blocking the tubules from
bacteria by-products and therefore diminishing the pulpal inflammatory response. The pulp may then have an opportunity to heal and the thresholds and distribution of sensory fibers should return to normal, leaving the patient relatively comfortable.\textsuperscript{36}

Dentin sensitivity may occur periodically, or be of short duration, because of a positive response by the tooth’s defense mechanisms. Unlike this study, clinically tubules are usually not completely open. The distribution of the plasma proteins, cells, cell remnants from the pulp, salivary products and bacteria from the oral cavity can cause a dramatic reduction in the rate of outward flow when fluid is lost. In this way dentin sensitivity may be reduced or even eliminated. Conversely, if there is poor host response and tubules remain open, sensitivity may continue and cause further pulpal damage.\textsuperscript{6} Also, there seems to be controversial opinions concerning the effect of plaque on dentin sensitivity and even in apparently identical situations many different factors, both in the dentin and in the pulp may result in contradictory effects.\textsuperscript{3}

If tubules remain open, dentin sensitivity can be continuous. After exposure of tubules for some time, the dentin may be very sensitive, even when the apertures of the dentinal tubules are covered by a smear layer or pellicle. When the pulp is inflamed and covered with a smear layer, tubular apertures may still be extremely sensitive to probing, blasting with air or application of a bur. Prolonged exposure of dentin may thus further complicate the situation.\textsuperscript{6}

This study analyzed the immediate effects of desensitizing agents. Further studies should be done to analyze the long-term effects of desensitizers. Simulating intraoral conditions including dentin abrasion is necessary. It is unclear how long dentinal tubules will be occluded before the superficial dentin is abraded. Desensitizers may cover the dentin surface without completely occluding the dentinal tubules. These materials may not be effective as materials that infiltrate the tubules. It is also unknown if the length of tubule infiltration will benefit the longevity of the desensitizer.

The clinical effectiveness of these materials is also unknown. In particular is the patient who has poor oral hygiene and dentin sensitivity. If it is not possible to remove plaque or the smear layer due to sensitivity, a desensitizer may be applied on top. It is unclear if desensitizers will be effective when placed on top of the smear layer or plaque. Lastly, the effectiveness of using desensitizers below restorations is not known. It would be beneficial to know if desensitizers could be used in conjunction with current restorative methods.

**CONCLUSIONS**

The DDAs tested showed a wide range of dentin permeability reduction that may reflect the various approaches and chemistries they use to occlude dentin tubules. Of all the DDAs tested SuperSeal may be the most beneficial when treating dentin sensitivity.

When morphologically evaluating dentinal tubule occlusion with DDAs it is necessary to study the surface and the extent of penetration within the tubules. Often SEM evaluation of fractured samples demonstrated tubule occlusion, although this was not always seen by viewing strictly from the dentin surface.

SEM evaluation did not demonstrate a clear relationship with the hydraulic conductance analysis. However, this study demonstrates the necessity to perform the hydraulic conductance and SEM analyses conjointly, since dentinal tubules may appear occluded, but not necessarily sealed.
REFERENCES


<table>
<thead>
<tr>
<th>Desensitizing agent</th>
<th>Tubule occlusion</th>
<th>Active components*</th>
<th>Procedure</th>
<th>pH*</th>
<th>Lot #</th>
</tr>
</thead>
<tbody>
<tr>
<td>Seal and Protect (DENTSPLY Caulk)</td>
<td>Resin</td>
<td>– Di- and Trimethacrylate resins (urethane demethacrylate resin, polymerizable trimethacrylate resins), PENTA (dipentaerythritol pentaacrylate phosphate), Nanofillers-Amorphous Silicon Dioxide, Photoinitiators, Stabilizers, Cetylamine hydrofluoride, Triclosan, Acetone</td>
<td>20 sec application, dry 5 sec, LC 10 Sec, apply second layer</td>
<td>1.5</td>
<td>000309</td>
</tr>
<tr>
<td>Gluma (Heraeus Kulzer)</td>
<td>Resin and protein precipitation</td>
<td>– 5% Glutaraldehyde, HEMA (2-hydroxyethyl methacrylate), purified water</td>
<td>Apply and leave for 60 sec, dry, rinse</td>
<td>3.4</td>
<td>020032D</td>
</tr>
<tr>
<td>HurriSeal (Beutlich Pharmaceutical)</td>
<td>Resin</td>
<td>– 5% Benzalkonium Chloride, 35% HEMA, .5% sodium fluoride, water</td>
<td>Apply for 20 sec, dry, repeat 2 more times</td>
<td>6.4</td>
<td>00283-0697-82</td>
</tr>
<tr>
<td>D/Sense 2 (Centrix Direct)</td>
<td>Crystal precipitation</td>
<td>– Liquid 1 - Potassium phosphate, potassium carbonate, sodium methylparaben, deionized water</td>
<td>Apply step 1 for 10 sec, apply step 2 for 10 sec, dry</td>
<td>neutral</td>
<td>A391</td>
</tr>
<tr>
<td>D/Sense 2 (Centrix Direct)</td>
<td>Crystal precipitation</td>
<td>– Liquid 2 – Calcium chloride, strontium chloride, sodium benzoate, deionized water</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Super Seal (Phoenix)</td>
<td>Crystal precipitation</td>
<td>– Oxalic Acid Potassium Salt</td>
<td>Apply 30 sec, dry</td>
<td>2.7</td>
<td>991521</td>
</tr>
</tbody>
</table>

* According to manufacturers
<table>
<thead>
<tr>
<th>Agent</th>
<th>n</th>
<th>Median</th>
<th>Mean</th>
<th>S.D.</th>
<th>Minimum-maximum</th>
</tr>
</thead>
<tbody>
<tr>
<td>Seal and Protect (DENTSPLY Caulk)</td>
<td>6</td>
<td>31.8</td>
<td>33.8</td>
<td>19.4</td>
<td>11.5 – 67.5</td>
</tr>
<tr>
<td>Gluma (Haraeus Kulzer)</td>
<td>6</td>
<td>39.4</td>
<td>39.6</td>
<td>26.7</td>
<td>5.7 – 81.3</td>
</tr>
<tr>
<td>HurriSeal (Beutlich Pharmaceutical)</td>
<td>6</td>
<td>59.1</td>
<td>54.2</td>
<td>35.3</td>
<td>7.0 – 100.0</td>
</tr>
<tr>
<td>D/Sense 2 (Centrix Direct)</td>
<td>6</td>
<td>49.9</td>
<td>46.6</td>
<td>20.4</td>
<td>17.2 – 73.6</td>
</tr>
<tr>
<td>Super Seal (Phoenix)</td>
<td>6</td>
<td>100.0</td>
<td>97.5</td>
<td>4.1</td>
<td>90.7 – 100.0</td>
</tr>
</tbody>
</table>

* Values represent percentage of permeability reduction from baseline.
FIGURES

Figure 1. Percent permeability reduction of the dentin desensitizers tested. Mean and standard deviation showed.
Figure 2. Scanning electron micrographs (SEM) of polished dentin. No smear layer or smear plugs are observed on the dentin. a. A lateral canal is observed within the intertubular dentin and is also devoid of smear-layer and –plug (black arrow). P: peritubular dentin; I: intertubular dentin. Micron bar figure a = 5µm. Micron bar figure b = 2µm.

Figure 3. SEM of Seal and Protect, fractured specimen. A resin layer (RL) covers the surface and infiltrates the tubules with a resin plug (RP). Globular structures are present below the RP within the dentinal tubules (white arrows). The RP occluding the tubule shows a pocket formation (black arrows). P: peritubular dentin; I: intertubular dentin. Micron bar = 5µm.

Figure 4. SEMs of Gluma. a. top surface. A thin coat (C) is seen over the dentin. Some of the tubules appear to be open (OT) and some appear closed (CT). Micron bar = 2µm. b. fractured specimen. A thin coat covers the dentin surface (black arrows) it extends within the tubules covering the walls (black open arrows) and forming bridges between them (white arrows). P: peritubular dentin; I: intertubular dentin. Micron bar = 1µm.

Figure 5. SEMs of HurriSeal. a. top surface. Most of the dentinal tubules appear to be open. Micron bar = 10µm. b. fractured specimen. A coat covers the dentin surface (black arrows). Globular structures are present within the dentinal tubules (white arrows). P: peritubular dentin; I: intertubular dentin. Micron bar = 1µm.

Figure 6. SEMs of D/Sense 2. a. top surface. A crystal precipitate (white arrow) is seen covering part of the dentin. Tubules that can be seen appear open. Micron bar = 10µm. b. fractured specimen. A thin coat covers the dentin surface (black arrows). Within the tubule crystals (white arrow) form a fairly dense mass, yet do not appear to be attached to the tubules (black open arrows). An open lateral canal free of crystals is marked with a white *. P: peritubular dentin; I: intertubular dentin. Micron bar = 1µm.

Figure 7. SEMs of SuperSeal. a. top surface. About half of the dentinal tubules appear to be closed. A few crystals are apparent on the dentin surface (white arrow). Micron bar = 10µm. b. fractured specimen. A thin coat covers the dentin surface (black arrows) and invaginates (white *) into the dentinal tubule. Below the invagination crystals have formed a dense mass (white arrows) and have intimate contact with the dentin wall (open black arrows). Micron bar = 1µm.