The synthesis and characterization of a novel potassium chloride-fluoridated hydroxyapatite varnish for treating dentin hypersensitivity

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Dentin hypersensitivity is treated using materials that occlude the dentinal tubules or release potassium ions that induce nerve desensitization. In this study we formulated a novel varnish containing potassium chloride and fluoridated hydroxyapatite and evaluated its physical properties and cytotoxicity. Potassium ion release from the varnish was measured. Dentin permeability was evaluated by measuring the hydraulic conductance of etched dentin discs treated with the varnish. The direct contact test and MTT assay were performed to evaluate the varnish’s cytotoxicity. We found that the varnish released potassium ions over 6 h, and demonstrated a statistically higher reduction in dentin permeability compared to commercial fluoride varnish or control. Dentin disc scanning electron microscopy images demonstrated occluded dentinal tubules in the novel varnish group after brushing. The cytotoxicity tests indicated the varnish was biocompatible with gingival and pulpal fibroblasts. We propose the novel varnish is a potential material for use in hypersensitivity management.

Keywords: Varnish, Potassium chloride, Fluoridated hydroxyapatite, Dentin hypersensitivity, Dentin permeability

INTRODUCTION

Dentin hypersensitivity (DH) is one of the most common oral problems in adults. The reported prevalence of DH ranges from 4–74%⁴⁻⁵. This variation may be due to differences in the study populations and methods used. The increasing percentage of the geriatric population who are retaining many of their teeth has led to a higher risk for developing cervical DH due to physiological gingival recession that results in the exposure of cervical dentin⁶. DH presents as a short sharp pain typically arising at the area of the exposed dentin⁶. DH affects a patient’s daily life and leads to a reduction in their quality of life⁶. Thus, DH should be considered an important clinical condition.

The most widely accepted theory to explain DH is the hydrodynamic theory proposed by Brannstrom in 1964⁷. This theory is based on the movement of dentinal fluid in response to stimuli, such as cooling, evaporation, or the application of hypertonic chemical substances that activate dentinal tubule nerve endings⁸⁻⁹. The hydrodynamic theory generated two basic approaches for DH treatment, reduction of intradental nerve excitability and occluding patent dentinal tubules, which led to the development of desensitizing agents based on these concepts¹⁰. Nerve desensitization using potassium salts results from increased extracellular potassium ion concentration. When a sufficient level of potassium ions is reached in the dentinal fluid, nerve conduction is blocked, therefore the nerves do not respond to the stimulus-evoked fluid movement in the tubules¹⁰⁻¹¹. Several forms of potassium salts have been developed for DH management, such as potassium-containing toothpastes and mouthrinses as home-use oral care products for DH relief, and potassium-containing gels and solutions for in-office treatment. Although a number of clinical trials concerning potassium-containing toothpastes have been published, a Cochrane review revealed no clear evidence for the effectiveness of 5% potassium nitrate toothpastes in treating DH¹². A clinical study using 5% potassium nitrate solution also found no DH reduction¹³. However, a study using 10% potassium nitrate gel reported a 35% reduction in DH within 48–96 h¹⁰ and another study using 35% potassium nitrate gel reported a 91% reduction in DH immediately after application¹⁰.

A wide range of agents have been shown to relieve DH by occluding the dentinal tubules, thus reducing stimulus-evoked fluid flow¹⁰. Calcium phosphate is a promising agent for DH management. Calcium phosphate is bioactive, biocompatible, and is the major component of human bone and tooth structure. Thus, calcium phosphate seems to be an appropriate material to use for occluding dentinal tubules¹⁶⁻¹⁷. Apatite is a well-known form of calcium phosphate and is widely used in dental materials, such as hydroxyapatite or fluorapatite. Fluorapatite was superior to hydroxyapatite followed by CaF₂ in its ability to saturate a synthetic saliva solution¹⁸. Both apatites were highly supersaturated and readily deposited on the tooth surface, while CaF₂...
easily dissolved in the synthetic saliva\textsuperscript{38}. The application of powdered apatite glass ceramic, after treating with an acidic solution of fluoride and a \textit{LaCl}_\text{3} paste, immediately occluded the dentinal tubules and had a superior resistance against toothbrush abrasion\textsuperscript{19,20}. Clinically, the precipitation of hydroxyapatite powder on exposed dentin surfaces was reported to significantly reduce hypersensitive symptoms, and scanning electron microscopy (SEM) images confirmed that the dentinal tubules were occluded\textsuperscript{17}. It is preferable for exposed dentinal tubules to be occluded with calcium phosphate, which does not inhibit spontaneous remineralization of the tooth surface\textsuperscript{40}.

Varnish is composed of a sustained release carrier, such as an acrylic polymer, resin, or natural rosin and is a popular dental material for DH treatment. The use of varnish for DH treatment was introduced in 1986\textsuperscript{21}. Varnish is applied on the pulpal floor of the tooth cavity before a filling material is placed as a restoration, creating a thin layer covering the dentin surface, resulting in DH reduction\textsuperscript{22}. Pashley \textit{et al.}\textsuperscript{23} found that applying varnish decreased dentin permeability between 20–50\%. Furthermore, varnishes containing chemicals, such as strontium chloride or sodium fluoride, reduced tooth sensitivity\textsuperscript{4,24-28}. Fluoride varnish is a well-known agent that is not stain the tooth\textsuperscript{32-34}, is easy to apply, rapid action with long-term effects, non-irritating to the pulp, painless, and should be placed on exposed dentin\textsuperscript{26}. The compositions of the varnishes used in dentistry have been extensively modified to improve their characteristics, such as ease in applying, requiring less patient compliance, and sustained release of specific constituent agents\textsuperscript{29,30}. The chemicals released from varnishes remain in the saliva, adhering to the pellicle and establishing a reservoir that can be slowly released over time, and penetrating into tooth structure\textsuperscript{31}.

Desensitizing agents are classified as oral care products for personal use, such as toothpastes and mouthrinses, or in-office products for professional use. The ideal requirements of a dentin desensitizing varnish are: easy to apply, rapid action with long-term effects, non-irritating to the pulp, painless, and should not stain the tooth\textsuperscript{32-34}. Although many desensitizing agents have been introduced, none contain all of the ideal properties. Consequently, novel biomaterials with superior properties for DH treatment need to be developed. These materials should produce deep sealing into the dentinal tubules to ensure a sustained effect, and occlude the orifices of the dentinal tubules producing a long-lasting seal\textsuperscript{35,36}. Moreover, it is desirable that a material produces both nerve desensitization and dentinal tubule occlusion, be biocompatible with oral tissues, and convenient to use. The aim of this study was to synthesize a novel varnish containing potassium chloride (KCl) and fluoridated hydroxyapatite (FHA) and evaluate its physical properties and cytotoxicity.

### MATERIALS AND METHODS

**FHA synthesis and analysis**

FHA was synthesized using a precipitation method as described by Okazaki \textit{et al.}\textsuperscript{37}. We mixed 0.5 L of 0.2 M \textit{Ca(CH}_3\text{COO})_2\text{•H}_2\text{O} and 0.5 L of 0.12 M \textit{NH}_4\text{H}_2\text{PO}_4, containing 0.05 M \textit{NH}_4\text{F}, with 1 L of \textit{CH}_3\text{COONH}_4 buffer at 60±1ºC and stirred for 3 h. The pH was maintained at 7.4±0.1 by the addition of \textit{NH}_3\text{OH}. The solution was kept at room temperature for 24 h and the resultant slurry was filtered and dried at 60°C for 48 h. The morphology of the powder was investigated using SEM (JSM-5410LV, JEOL, Tokyo, Japan). The chemical analyses of the FHA were performed using X-ray photoelectron spectroscopy (XPS) (AXIS-HS, Kratos, Manchester, UK) and Fourier transmission infrared spectroscopy (FTIR) (FT 8400S, Shimadzu, Kyoto, Japan).

**KCl-FHA varnish preparation**

KCl (AnaLaR® BDH, VWR International, Poole, England) and FHA 10% (w/w) were mixed with fully hydrogenated rosin (Foral™ AX-E, Eastman Chemical BV, Capelle aan den IJssel, The Netherlands), hydrophilic fumed silica (Aerosil® 200 Pharma, Evonik Industries AG, Rheinfielden, Germany) and absolute ethanol (Merck, Merck KGaA, Darmstadt, Germany) (Table 1). The KCl-FHA varnish was placed into a capped syringe and stored at room temperature.

Three additional varnishes were prepared (Table 1) to investigate the effects of the ingredients of the KCl-FHA varnish: plain varnish (a mixture of fully hydrogenated rosin, hydrophilic fumed silica, and absolute ethanol), which served as control, KCl varnish (plain varnish containing 10% (w/w) KCl), and FHA varnish (plain varnish containing 10% (w/w) FHA). These varnishes were placed into capped syringes and

| Formulation       | Rosin % (w/w) | Ethanol % (w/w) | Fumed silica % (w/w) | KCl % (w/w) | FHA % (w/w) |
|-------------------|---------------|-----------------|----------------------|-------------|-------------|
| Plain varnish     | 62            | 35              | 3                    | 0           | 0           |
| FHA varnish       | 52            | 35              | 3                    | 0           | 10          |
| KCl varnish       | 52            | 35              | 3                    | 10          | 0           |
| KCl-FHA varnish   | 42            | 35              | 3                    | 10          | 10          |
stored at room temperature.

**Potassium ion release measurement**

Sample preparation and the method for measuring potassium ion release were performed as previously described\(^3^8\). Briefly, six 2×4 cm\(^2\) polyester sheets were painted with the KCl-FHA varnish on half of the total area on one side (2×2 cm\(^2\)) and air-dried at room temperature for 5 min. Each strip was weighed before and after varnish application to calculate the varnish weight. Each strip was then immersed in a capped container containing 20 mL of deionized water and changed to a new container at 10 min, 1 h, 3 h, and 6 h after the first immersion. The released potassium ions were measured from 10 mL of water from each container using inductively coupled plasma-optical emission spectrometry (ICP-OES) (OPTIMA 7300, PerkinElmer, Shelton, CN, USA). The results were normalized to the weight of each sample.

**Dentin disc preparation**

The study protocols were approved by the Ethics Committee, Faculty of Dentistry, Chulalongkorn University. Extracted caries-free human third molars were obtained from individuals aged between 18–30 years old who had provided informed written consent. The teeth were stored in normal saline solution containing 1,000 units/mL penicillin. The dentin discs were prepared by first decoronating the tooth 2 mm below the cemento-enamel junction parallel to the occlusal surface, and then cleaned in a digital ultrasonic cleaner containing 1,000 units/mL penicillin. The dentin discs were acid-etched with 37% phosphoric acid for 60 s and rinsed with distilled water for 60 s to establish the maximum permeability of each dentin disc. The flow rate was then determined as the maximum dentin permeability of each specimen. Once the maximum value was determined, each specimen was painted with its respective group’s varnish on the etched dentin surface and left for 5 min to allow the solvent to evaporate. The air bubble velocity was again measured to determine the immediate hydraulic conductance after varnish application. The permeability reduction percent (PR%) was calculated by dividing the immediate hydraulic conductance by the maximum hydraulic conductance multiplied by 100 then deducted from 100. The results were statistically analyzed by one-way ANOVA and the Bonferroni post hoc test using statistical software (PASW \(^6\) Statistics 18, SPSS Inc., Chicago, IL, USA).

After the dentin permeability measurement, each dentin disc was removed from the acrylic square and immersed in 20 mL of artificial saliva containing KCl, MgCl\(_2\), CaCl\(_2\), K\(_2\)HPO\(_4\), KH\(_2\)PO\(_4\), NaF\(_2\), Na\(_2\)C\(_7\)H\(_5\)O\(_2\), sodium carboxymethylcellulose, sodium benzoate, and sorbitol (Faculty of Dentistry, Chulalongkorn University, Bangkok, Thailand) in a closed container. The samples were placed in an incubator at 37°C for 6 h. The varnish layer covering each dentin disc was then removed by brushing in distilled water using a cross brushing machine (V-8, Sabri Dental Enterprises, Downers Grove, IL, USA) with a soft bristle toothbrush under a brushing pressure of 200 g and a stroke speed of 60 rpm for 2 min. The specimens were subsequently stored in artificial saliva and incubated at 37°C in a humidified atmosphere for 12 h. The specimens were then dried in a desiccator for 72 h and were sputter coated with gold using a Fine coater (JFC-1200, JEOL, Tokyo, Japan) for SEM observation.

**Cytotoxicity tests**

Primary explant cultures of human gingival and pulp fibroblasts were generated using gingival and pulp tissue obtained from first premolars extracted from healthy donor individuals aged 18–30 years old.
for orthodontic reasons with informed consent. The gingival and pulpal tissue were minced into small pieces and placed on 35 mm culture dishes and cultured in growth medium composed of Dulbecco’s modified Eagle’s medium (DMEM) supplemented with 10% fetal bovine serum, 1% L-glutamine and 1% antibiotic-antimycotic solution (Gibco®, Life Technologies, Grand Island, NY, USA). The gingival and pulpal fibroblast cultures were maintained in a humidified atmosphere containing 5% CO₂ at 37°C. The culture medium was changed every 2 days until the cells reached confluence. The cells then were subcultured several times. Cells from the fifth passage were used in this study. We used 3 donor cell lines in our experiments.

1. Direct contact test
Twenty-seven 5×5 mm² cover slips were washed with 70% and 95% ethanol. The cover slips were randomly assigned to 3 groups (n=9/group): Group 1: F varnish; Group 2: KCl-FHA varnish; Group 3: blank control. Each cover slip was applied with a 2 mm-diameter drop of its respective group’s varnish and left for 5 min to allow the solvent to evaporate. The cover slips were placed varnish drops up in 35 mm culture plates. Gingival fibroblasts were then seeded into the culture plates in direct contact with the varnish drops at a concentration 1×10⁶ cells/mL and maintained in a humidified atmosphere containing 5% CO₂ at 37°C for 48 h. The cells were observed using an inverted phase contrast microscope (CKX41, Olympus, Tokyo, Japan) and images obtained using imaging software (cellSens Standard software, Olympus, Tokyo, Japan).

2. MTT assay
Cell viability was measured using an MTT assay. A polyester sheet was trimmed into fifty-four 5 mm-diameter discs that were washed with 70% and 95% ethanol. The discs were randomly divided into 6 groups (n=9/group): Group 1: F varnish; Group 2: KCl-FHA varnish; Group 3: blank control. The upper surface of each disc was applied with its assigned varnish and left for 5 min to allow the solvent to evaporate. Untreated discs served as the blank control group. To compare the relative toxicities of the different varnishes, 24-well culture plates were seeded with either gingival fibroblasts or pulpal fibroblasts (2×10⁴ cells/well) for 24 h. A disc with or without varnish was placed varnish side up into each well. The plates were maintained in a humidified atmosphere containing 5% CO₂ at 37°C for 48 h. After 48 h, the disc and the culture medium in each well were removed and 5 µL of MTT solution (5 mg/mL of 3-(4,5-dimethylthiazol-2-yl)-2,5-diphenyl tetrazolium bromide (MTT, M5655, Sigma-Aldrich, St. Louis, MO, USA) in phosphate buffer saline) and 300 µL of DMEM without phenol red were added. The 24-well plates were incubated for 4 h to allow the formation of formazan crystals by functional mitochondria in viable cells. After the 4-h incubation, the supernatant in each well was replaced by 1 mL of dimethyl sulfoxide (DMSO). The plates were placed on an orbital shaker for 10 min to dissolve the formazan crystals. The absorbance of each well was determined using a spectrophotometer (Ultrospec 3000, Pharmacia Biotech (Biochrom), Cambridge, England) at a wavelength of 570 nm. The results were statistically analyzed by one-way ANOVA and the Bonferroni post hoc test using statistical software.

RESULTS

FHA morphology and chemical analysis
SEM images of the FHA powder at 500× magnification demonstrated typical needle-like crystals in aggregated globules approximately 10–50 µm in size (Fig. 1a) and in particles 2–5 µm in size at 10,000× magnification (Fig. 1b). FTIR analysis revealed peaks at 564 cm⁻¹, 601 cm⁻¹, 961 cm⁻¹, 1,032 cm⁻¹ and 1,092 cm⁻¹ corresponding to the PO₄³⁻ functional groups (Fig. 2). The peak at 1,644 cm⁻¹ corresponds to the CO ³⁻ functional groups. The XPS wide spectrum of the FHA powder (Fig. 3) and the surface chemical analysis (Table 2) indicated the presence of calcium, phosphorus, oxygen, carbon, and fluorine as elements in the FHA powder.

Potassium ion release
The concentration of released potassium ions and the amount of released potassium ions from the KCI-FHA varnish at different time points were reported in Table 3. The amount of potassium ions was normalized to the weight of each sample and expressed in mg of the released

Fig. 1  SEM images of FHA powder (a) at 500× magnification and (b) at 10,000× magnification.
**Fig. 2** FTIR spectra of the FHA powder exhibiting PO$_4^{3-}$ peaks at 564, 601, 961, 1,032, and 1,092 cm$^{-1}$.

**Table 2** Chemical analysis of the FHA powder

| Peak  | Position BE (eV) | Atomic Concentration (%) | Mass Concentration (%) |
|-------|-----------------|--------------------------|------------------------|
| O 1s  | 528.400         | 54.79                    | 38.31                  |
| Ca 2p | 344.700         | 20.61                    | 36.09                  |
| P 2p  | 130.600         | 13.29                    | 17.98                  |
| C 1s  | 282.800         | 5.79                     | 3.04                   |
| F 1s  | 681.500         | 5.53                     | 4.59                   |

**Table 3** Concentration of released potassium ions and amount of released potassium ions (expressed in mg of released potassium ions per g of varnish) from the KCl-FHA varnish at different time points

| Time point | Concentration of released potassium ions (ppm) | Amount of released potassium ions (mg/g) |
|------------|-----------------------------------------------|----------------------------------------|
| 10 min     | 35.92                                        | 3.23                                   |
| 1 h        | 41.06                                        | 3.72                                   |
| 3 h        | 39.52                                        | 3.59                                   |
| 6 h        | 12.65                                        | 1.14                                   |

**Fig. 3** XPS wide spectrum (0–1100 eV) of the FHA powder exhibiting P 2p, C 1s, Ca 2p, O 1s and F 1s peaks at 130, 282, 344, 528 and 681 eV respectively.

**Fig. 4** Cumulative amount of potassium ions released from the KCl-FHA varnish over 6 h (expressed in mg of released potassium ions per g of the varnish).

**Fig. 5** Average permeability reduction percent (PR%) after each specimen was painted with the assigned varnish and left for 5 min ($n=15$/group) (Same superscript letters signifies no significant difference.).
Fig. 6  Representative SEM images of the dentin discs after treatment with the 5 types of varnishes and stored in artificial saliva for 12 h; (a, b) F varnish, (c, d) plain varnish, (e, f) KCl varnish, (g, h) FHA varnish, (i, j) KCl-FHA varnish, at 1,000× and 5,000× magnification.
ion per g of the varnish. The cumulative potassium ion release over 6 h was demonstrated in Fig. 4 and the ion release rate was the highest 10 min after immersion as determined from the average slope of the best-fit line.

**Dentin permeability reduction**

Figure 5 shows the average percent reduction in hydraulic conductance of the 5 varnish groups. The highest reduction was observed in the KCl-FHA varnish group at 54.02%, followed by the FHA varnish group at 48.13%. The difference between these groups was not significant ($p>0.05$). The hydraulic conductance reduction of the F varnish group (38.56%) was significantly lower than that of the KCl-FHA varnish and the FHA varnish groups ($p<0.05$) and higher, but not significantly, than the KCl varnish group (32.49%) ($p>0.05$). The plain varnish group had the lowest percent reduction at 23.17%, which was significantly different compared to the other groups ($p<0.05$).

**Dentinal tubule occlusion**

We used SEM to analyze the ability of the 5 vanishes to occlude the dentinal tubules of dentin discs (Fig. 6). The SEM images demonstrated that the F (Fig. 6a, b), plain (Fig. 6c, d), and KCl (Fig. 6e, f) varnishes did not occlude the dentinal tubules. The FHA varnish was able to occlude many of the dentinal tubules (Fig. 6g, h). Most, but not all, of the dentinal tubules were observed to be occluded by the KCl-FHA varnish (Fig. 6i, j).

**Direct contact test**

To investigate the biocompatibility of the KCl-FHA varnish with gingival fibroblasts compared to that of commercial F varnish, we performed a direct contact assay. Phase contrast images indicated that after 24 h the gingival fibroblasts presented a typical fusiform morphology, with some round cells observed. While the cells did not attach directly to the varnish drops, they were present in close proximity to both the F varnish (Fig. 7a) and the KCl-FHA (Fig. 7c) varnish drops. After 48 h, the gingival fibroblasts had proliferated, but still did not contact the F (Fig. 7b) or KCl-FHA (Fig. 7d) varnish drops.

**MTT assay**

We further investigated the biocompatibility of the KCl-FHA varnish compared to that of the F varnish using gingival and pulpal fibroblasts in an MTT assay. The results of this assay, normalized to the blank control results, showed that the cell viability of the gingival fibroblasts in the F varnish group and KCl-FHA varnish group was 122.8% and 113.8%, respectively, of the viability of the control group. However, the multiple comparison test indicated that there was not
were released from the varnish during the first 3 h. It was determined that the majority of the potassium ions was inversely proportional to the immersion time. We found that the KCl-FHA varnish demonstrated its ability to provide a large amount of potassium ions, which would increase the concentration of potassium ions in saliva after applying the varnish to the tooth surface. This suggests that KCl-FHA varnish could be a suitable DH treatment. However, in vivo and clinical studies are required to investigate the degree of nerve desensitization induced by the KCl-FHA varnish to identify the appropriate percentage of KCl to add into the varnish. If 10% KCl is insufficient, a higher percentage of KCl incorporation should be considered and tested. The amount of potassium ions required to be released to induce nerve desensitization after each varnish application on the dentin surface should also be investigated.

Our study demonstrated that the FHA rosin-based varnish groups had the highest reduction in dentin permeability among the groups and showed a significant reduction in permeability compared to the F varnish group. This result, combined with the result of SEM analysis, suggests that the superior reduction in dentin permeability by FHA varnishes resulted from dentinal tubule occlusion by the apatite. The reduction in dentin permeability seen in the other groups may have resulted from tubule occlusion by resin or other varnish components, such as KCl or NaF, as has been previously suggested. Although the mechanism of action of fluoride varnish is not yet clear, a study has suggested that the dentinal tubule occlusion results from CaF$_2$ crystal formation by the chemical reaction between fluoride ions from fluoride varnish and calcium ions from dentin. CaF$_2$ crystals are generally very small in size, approximately 0.05 µm, hence a single varnish application may not completely occlude the tubules. Moreover, CaF$_2$ crystals are soluble, thus, they can dissolve in saliva.

The SEM images of the dentin discs after varnish treatment, toothbrushing, and immersion in artificial saliva for 12 h showed patent dentinal tubules in the F varnish group. In contrast, FHA is not soluble, which was confirmed by the SEM images of the FHA varnish treated samples. The SEM results also revealed that the dentinal tubules were only occluded in the varnish groups that contained FHA. These findings indicate that the FHA containing varnishes could be a treatment for DH at exposed cervical dentin, because even after toothbrushing the exposed dentinal tubules would remain occluded, resulting in long-term relief. These precipitates might be the FHA itself from the FHA containing varnishes or new insoluble compounds that formed when the elements in artificial saliva interacted with the FHA and/or the tooth. Thus, the chemical analysis of the precipitates should be conducted in future studies.

One of the ideal properties of desensitizing agents is to have a long-lasting effect. Although the present study demonstrates the ability of the FHA containing varnishes to produce precipitates that occluded dentinal tubules after immersion in artificial saliva over 12 h, it only represents the situation without food or beverage consumption. Consequently, an acid resistance test is suggested in future studies to determine the long-lasting
effect of this biomaterial.

Our results demonstrated that incorporating both KCl and FHA into varnish increased its ability to reduce dentin permeability. The KCl-FHA group showed the highest reduction in dentin permeability of all the groups, and while slightly higher than that of the FHA varnish group, the difference was not significant. The KCl varnish group showed a significantly higher dentin permeability reduction compared to that of the plain varnish group. This suggests that the addition of both KCl and FHA to varnish had an additive effect on the reduction in dentin permeability. The KCl-FHA varnish demonstrated both sustained potassium ion release and occluded tubules, which are the 2 main mechanisms for DH relief. Based on these results, the KCl-FHA varnish appears to be a promising dental material for use in DH management.

Our cell culture experiments indicated that the KCl-FHA varnish was biocompatible with both gingival and pulpal fibroblasts. The KCl-FHA varnish was only tested with gingival fibroblasts in the direct contact test because it is designed to be applied on the dentin surface when there is no pulp exposure. We found that the gingival fibroblasts were able to attach close to the KCl-FHA varnish drops in the same fashion as they did with the F varnish drops. Less than 20% of the cells were round or showed changes in morphology in either varnish group. Moreover, the cells proliferated over the next 24 h. These results indicate that there are no cytotoxic effects by the KCl-FHA and F varnishes based on ISO 10993-5 biological evaluation of medical devices, and that they are of similar biocompatibility. The MTT assay also confirmed that the varnishes were not cytotoxic. Both varnish groups demonstrated similar cell viability, which were not significantly different from the control group. Furthermore, the KCl-FHA and F varnish groups had significantly more viable pulpal fibroblasts compared to control. This might possibly be due to the potassium and fluoride ions released from the varnishes. Our results indicate that the KCl-FHA varnish is biocompatible with gingival and pulpal fibroblasts and appears to be safe for applying on dentin surfaces.

The results from the present study suggest that the novel varnish might be developed as an in-office product for professional use or a home-use product for DH management. Dentists may apply the varnish on an exposed dentin surface with minimal loss of tooth structure when restoration is not required. Moreover, patients may routinely apply the varnish on their sensitive areas under the supervision of dentists to achieve long-lasting DH relief. However, further investigation is required to confirm the clinical efficacy and safety of this biomaterial.

CONCLUSION

The present study introduced a novel material for DH treatment, a varnish containing 10% (w/w) KCl and 10% (w/w) FHA. This varnish may be effective based on its release of potassium ions for nerve desensitization and dentinal tubule occlusion by FHA. The in vitro tests of the varnish properties and biological responses suggest the potential of this material for use in DH management.

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