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Effect of tooth-brushing with microcurrent on dentinal tubule occlusion and surface roughness

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Effect of tooth-brushing with microcurrent on dentinal tubule occlusion and surface roughness

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This certifies that the Masters Thesis of

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감사의 글

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논문 학기와 의국장을 같이 하며 일이 바쁘다는 핑계로 의국원을 잘 챙기지 못했었던 것 같아 의국원들에게 미안함을 전하며, 힘든 순간마다 격려와 응원을 많이 해준 의국 동기들에게 특히 감사드립니다. 앞으로 남은 수련 기간동안 제가 받은 감사함을 교수님들, 의국원들에게 베풀며 열심히 수련하는 모습 보이도록 하겠습니다.

마지막으로 6 년의 치과대학 과정과 4 년의 전공의 과정 동안 많은 지원과 응원을 해주신 아버지, 어머니에게 사랑과 감사하는 마음을 전합니다.

2019 년 6 월

김 강 재

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Effect of tooth-brushing with microcurrent on dentinal tubule occlusion and surface roughness

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The purpose of this study was to investigate whether tooth-brushing with a microcurrent was effective in inducing dentinal tubule occlusion and surface roughness. The specific aims of the study were (1) to evaluate the effectiveness of tooth-brushing with a microcurrent on dentinal tubule occlusion by using scanning electron microscopy (SEM); 2) to compare the surface roughness after tooth-brushing with microcurrents, and (3) to compare the dentinal fluid flow rate after tooth-brushing with a microcurrent by using a sub-nanoliter–scaled fluid flow measuring device (NFMD).

Thirty dentin discs from extracted human third molars were cut perpendicular to the long axis of the tooth each with a thickness of 3.0 mm above the cemento-enamel junction (CEJ) and 3.0 mm below the CEJ by using a low-speed diamond cutter (Metsaw-LS, R&B Co. Ltd.) with water as the coolant. After preparation of the specimens, the occlusal surface of each specimen was sanded with 600-grit silicon carbide paper for 30 s to create a standard smear layer. The smear layer was subsequently removed by etching with 37% phosphoric acid (Vericom Co. Ltd.) for 20 s and rinsing thoroughly with water for 10 s. Next, the specimens were grouped and treated using Colgate Total (Colgate-Palmolive company) as follows: group 1: phosphoric acid-etched specimens without any treatment; group 2: phosphoric acid-etched specimens brushed without microcurrents; groups 3, 4, 5, 6: phosphoric acid-etched specimens brushed with microcurrents (20, 100, 200, and 500 μA). A toothbrush (Oral-B) without a microcurrent and one with a microcurrent were applied to the dentin surface for 1 min/day using tap water for 7 days. Next, we analyzed the specimens with SEM and surface roughness for the preliminary experiment. After SEM and surface roughness analysis, groups 1, 2, and 4 were chosen for dentinal fluid flow measurement using the NFMD. The dentinal fluid flow rate was calculated by dividing the total dentinal fluid flow by 5 min. One-way ANOVA and Tukey’s post-hoc test were used to determine inter-group significance ($P < 0.05$).

After application of 37% phosphoric acid for 20 s, the dentin surfaces were free of smear layers and smear plugs, and almost all of the dentinal tubules were open. All tested treatments produced morphological modifications to the dentin surface. Groups 2, 3, 5, and

6 showed remnants of dentifrice abrasives in the dentinal tubules. Group 4 showed a dentin surface characterized by irregular crystal-like layer deposits occluding many dentinal tubule orifices. All experimental groups showed an increase in surface roughness in comparison with group 1. There was no particular relationship between the ampere and Ra values. In dentinal fluid flow rate measurements, while group 1 showed a constant increase in dentinal fluid flow over time, groups 2 and 4 showed a "step-like" increase in dentinal fluid flow. Moreover, group 4 showed a significantly lower dentinal fluid flow rate than groups 1 and 2 ($p < 0.05$).

All experimental groups showed partially occluded dentinal tubules and the formation of crystal-like structures at specific microcurrent intensity (100 μA) indicated that tooth-brushing with a microcurrent could efficiently occlude dentinal tubules. There was no direct correlation between surface roughness and dentinal tubule patency. The decrease in dentinal fluid flow rate in the tooth-brushing with microcurrents group indicates that dentinal tubules were occluded and the flow of dentinal fluid had decreased.

Keywords : dentin hypersensitivity; dentinal tubules; microcurrent; nanoliter-scaled fluid flow measuring device; SEM

Effect of tooth-brushing with microcurrent on dentinal tubule occlusion and surface roughness

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I. Introduction

Dentin hypersensitivity is a common disease caused by exposure of the dentinal tubules that allow the movement of intradentinal fluid (Orchardson and Gillam, 2006). Several hypotheses have been proposed to explain the mechanism underlying dentin hypersensitivity. The most commonly accepted hypothesis for explaining pulpal stimulus transmission was provided by the Brannstrom hydrodynamic theory in 1966. Brannstrom proposed that the inflicting stimulus causes dynamic intradentinal fluid flow in dentinal tubules, resulting in deformation of odontoblastic processes along with adjacent nerve fibers and leading to dentin hypersensitivity (Brannstrom, et al., 1968).

The hydrodynamic hypothesis has stimulated further clinical research by suggesting two methods for reducing dentin hypersensitivity: (1) reducing the ability of the intradental nerves to respond to fluid flows and (2) reducing stimuli-evoked dentinal fluid flow (DFF) in the dentinal tubules by reducing dentin permeability. To date, many desensitizing agents have been developed to reduce dentin hypersensitivity, and the most accessible such agent is toothpaste. Desensitizing toothpastes use both or at least one of those two mechanisms of action to reduce dentin hypersensitivity. If daily brushing with a desensitizing toothpaste occludes open dentinal tubules, it could be an effective method to reduce dentin hypersensitivity (Wang, et al., 2010). Using scanning electron microscopy (SEM), Ling et al. showed that different desensitizing toothpastes were able to occlude dentinal tubules. They also confirmed that brushing dentin surfaces with toothpastes using many desensitizing agents created smear layers or smear plugs in dentinal tubules that could reduce dentin hypersensitivity (Ling, et al., 1997).

Although many studies have revealed an abundance of desensitizing agents, no single agent can be considered ideal for long-term relief from dentin hypersensitivity. Therefore, new ways to decrease dentin hypersensitivity were introduced in dentistry, with iontophoresis being one of them. Iontophoresis is a well-known medical treatment technique that increases the skin penetration of medicinal drugs with the same charge by using electrostatic repulsion and allows the simultaneous penetration of neutral molecular chemicals when water is infiltrated using electro-osmosis (Herndon, 2007). Iontophoresis was first used in the early 1960s to treat dentin hypersensitivity (Patil, et al., 2017). A previous study reported that using iontophoresis treatment with fluoride, dentin hypersensitivity can be reduced by blocking the dentinal tubules, which are coated with CaF_2 (Wilson, et al., 1984). Another study suggested that fluoride iontophoresis treatment is effective and safe and significantly decreases dentin hypersensitivity (Carlo, et al., 1982). However, iontophoresis treatment is expensive and requires special equipment, preventing its daily use by patients suffering from dentin hypersensitivity.

Recently, a smart toothbrush using a microcurrent (Microworld, Seoul, Korea) has been developed, and it can be used more easily with similar effects as iontophoresis. The toothbrush contains a chip behind the head. This chip is an ultra-thin membrane-type microcurrent cell and is composed of staneless steel and aluminum. These two metals cause oxidation-reduction reactions with saliva and the fluoride-containing toothpaste. The microcurrent cell and the toothbrushes are electrically connected to supply microcurrents directly to the teeth with an electrolyte. Thus, without an additional source of electric power, when the smart brush is applied with saliva in the mouth, it can generate microcurrents, which are expected to occlude dentinal tubule efficiently. However, no previous studies have assessed the effectiveness of such smart toothbrushes; therefore, in this study we attempted to determine whether dentinal tubules are actually occluded well when brushing with a smart toothbrush and Colgate Total toothpaste (Colgate-Palmolive Company, New York, USA).

Evaluations of the effects of desensitizing agents on dentinal tubule occlusion are commonly performed by assessing the occlusion of the dentinal tubules using SEM or by observation of changes in dentin permeability by measuring the hydraulic conductance of a dentin disc (Vieira and Santiago, 2009). In this study, dentinal tubule occlusion was observed by using SEM and dentin permeability was measured by a sub-nanoliter–scaled fluid flow measuring device (NFMD).

Assessments of surface topography are commonly performed in dental material science (Austin, et al., 2015). Surface roughness measurements are often used to identify changes in tooth structure following erosive wear and to investigate the efficacy of anti-erosion and remineralizing products (Hara, et al., 2016). Dentinal tubule occlusion can be expected to affect the surface roughness of dentin due to the surface nature of dentin hypersensitivity (Olley, et al., 2015). Therefore, surface roughness can be a useful indicator of tubule patency. When measuring surface roughness, the one parameter that is standardized all over the world and is specified and measured far more frequently than any other is the arithmetic average roughness height, or roughness average. It is called Ra and defined as the arithmetic mean of the departures of the profile from the mean line. An approximation of average roughness (Ra) is obtained by adding the Y values without regard to the sign and dividing the sum by the number of samples taken (Gadelmawla, et al., 2002).

The purpose of this study was to investigate whether tooth-brushing with a microcurrent was effective in inducing dentinal tubule occlusion and surface roughness. Therefore, the specific aims of the study were (1) to evaluate the effectiveness of tooth-brushing with a microcurrent in inducing dentinal tubule occlusion by using SEM; 2) to compare the surface roughness after tooth-brushing with a microcurrent, and 3) to compare the DFF rates after tooth-brushing with a microcurrent by using an NFMD.

II. Materials and methods

1. Dentin sample preparation

Thirty extracted human third molars were collected after obtaining informed consent under a protocol approved by the dental hospital, Yonsei University (IRB approval no:2-2019-0001). Teeth with caries, cracks, or gross irregularities of dentin structure were excluded from the study. The teeth were cleaned thoroughly and stored in distilled water no longer than a month prior to their use.

Thirty dentin discs were cut perpendicular to the long axis of the tooth each with a thickness of 3.0 mm above the cemento-enamel junction (CEJ) and 3.0 mm below the CEJ by using a low-speed diamond cutter (Metsaw-LS, R&B Co. Ltd., Daejeon, Korea) with water as coolant.

2. Preliminary experiment

2-1. Experimental design

After preparation of the specimens, the occlusal surface of each specimen was sanded with 600-grit silicon carbide paper for 30 s to create a standard smear layer. The smear layer was subsequently removed by etching with 37% phosphoric acid for 20 s and rinsing thoroughly with water for 10 s. The etched specimens were kept wet in distilled water to maintain 100% permeability. Then, the specimens were grouped as follows and treated using Colgate Total.

Group 1: Phosphoric acid-etched specimens without any treatment

Group 2: Phosphoric acid-etched specimens brushed without a microcurrent

Group 3: Phosphoric acid-etched specimens brushed with a microcurrent (20 μA)

Group 4: Phosphoric acid-etched specimens brushed with a microcurrent (100 μA)

Group 5: Phosphoric acid-etched specimens brushed with a microcurrent (200 μA)

Group 6: Phosphoric acid-etched specimens brushed with a microcurrent (500 μA)

In group 2, a toothbrush (Oral-B, Seoul, Korea) without microcurrents was applied to the dentin surface at an inclination of about 90° under constant loading at the rate of 40000 strokes/min for 1 min/day in tap water for 7 days. In groups 3-6, the same protocol was applied to the specimens with a smart toothbrush utilizing a microcurrent. After each brushing session, the specimens were washed with distilled water using an ultrasonic bath and kept wet in distilled water.

2-2. SEM analysis

One dentin disc for each treatment group was prepared for transverse observation. Specimens were dried in a desiccator and sputter-coated with gold in a vacuum evaporator (EIKO IB-3 ion coater; Hitachi, Japan). Micrographs of the dentin surface were obtained using a scanning electron microscope (JEOL-7800F; JEOL Ltd. Tokyo, Japan) on September 3, 2018.

2-3. Surface roughness of the dentin surface

One dentin disc from each group was imaged and analyzed for surface roughness by using the surface profiler (DektakXT Stylus Profiler; Bruker, Massachusetts, USA). The surface profiler records the irregularities in the dentin surface as it moves to the end of the specimen, and the Ra value is calculated. The Ra value is used to detect general variations in overall profile height. A change in Ra typically signifies a new variation in the process. Each dentin specimen's Ra value was measured and analyzed.

2-4. Selection of proper microcurrent

Preliminary experiments were performed with one specimen per group, which was assessed using SEM and surface profiler. We selected the group that showed maximum dentinal tubule occlusion. Then, we compared the DFF rate in that group with those in groups 1 and 2 by using eight specimens per group.

3. Main experiment

3-1. Measurement of the DFF rate by using NFMD

The NFMD fabricated for this study consisted of three parts: a glass capillary and photo-sensor to detect fluid movement; a servo motor, lead screw, and ball nut to track fluid movement; and a rotary encoder and computer software to record the data (Fig. 1).

A water-filled glass capillary with an internal diameter of 0.5 mm was connected between a water reservoir and the tooth. A photo-sensor detected the movement of an air bubble trapped within the capillary, and the minimum measurable volume of water movement was 0.196 nL [(0.25 mm × 0.25 mm × π) × 1 μm, while the diameter of the capillary was 0.5 mm (Kim, et al., 2010; Kim, et al., 2013).

After SEM analysis, group 4 was chosen for DFF measurement. The prepared specimen's pulp tissue was carefully removed without damaging the pre-dentin surface by using an explorer. A metal tube 0.9 mm in diameter was inserted into the tooth and attached using an adhesive (All-bond Universal; Bisco, Schaumburg, IL, USA) and a flowable composite (Metafil flo; Sun Medical Co., Ltd., Moriyama, Shiga, Japan) to confirm that one end of the metal tube was located in the pulp chamber. The outer surface of the bonded interface between the composite resin and the tooth with the metal tube was covered by nail varnish. Finally, the previously prepared specimen was connected to the glass capillary by silicon tubing filled with distilled water (Fig. 1). A hydrostatic pressure of 20 cm H_2O was applied throughout all procedures with a water reservoir to simulate physiological pulp pressure. Each specimen had a stabilizing time of 3 min after being connected to the NFMD, and flow was measured for 5 min. The DFF rate was calculated by dividing the total DFF by 5 min (Kim, et al., 2010; Kim, et al., 2013). We also compared groups 1, 2, and 4 with a control group that showed occlusion of all outer dentin surfaces.

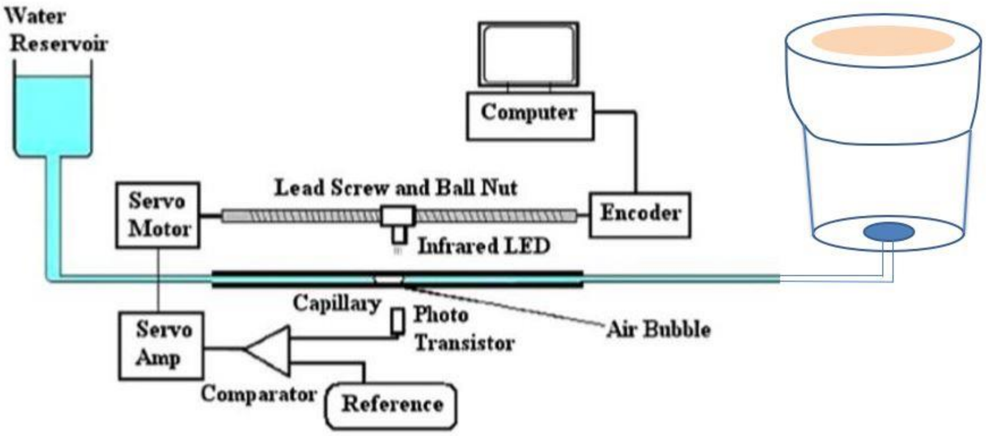

Fig 1. A Schematic diagram of the fluid flow measurement system (Nanoflow; IB systems, Seoul, Korea) modified from the original publication (Kim, et al., 2010; Kim, et al., 2013).

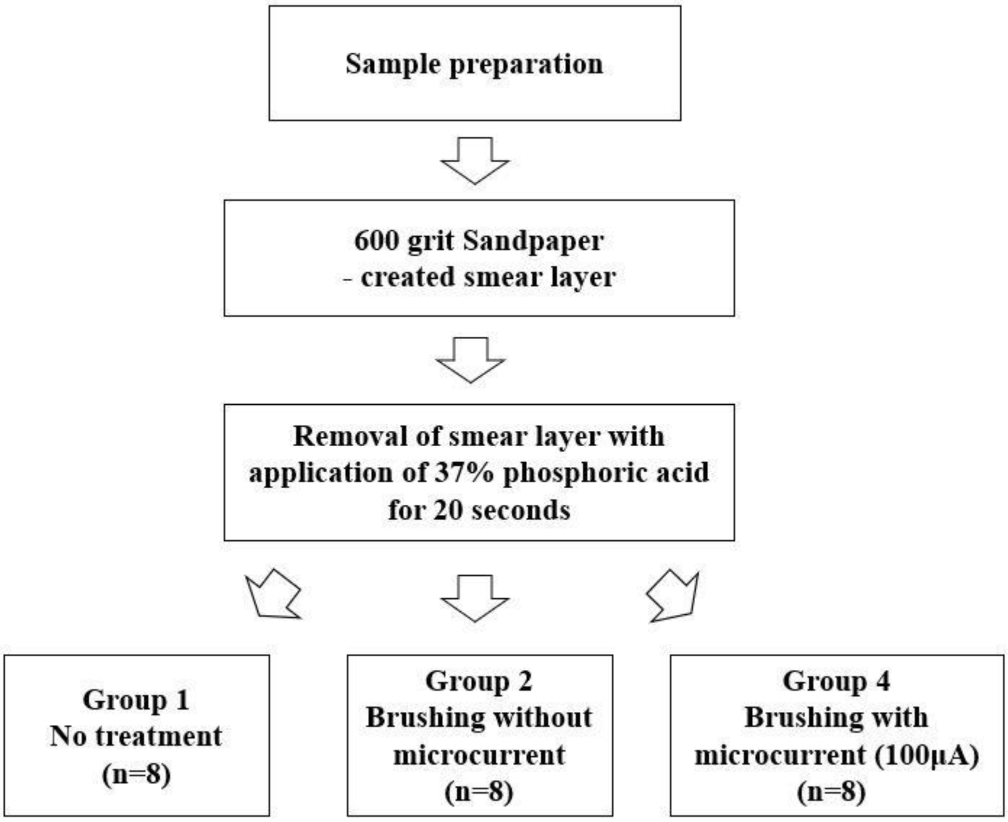

Fig 2. Summary of the experimental design for preparation of dentin specimens for different treatments to occlude dentinal fluid flow.

4. Statistical analysis

Statistical analyses were performed with computer software (IBM SPSS Statistics v23.0; IBM Corp., IL, USA). One-way ANOVA and Tukey's post-hoc test were used to determine inter-group significance. All statistical analyses were performed at the 95% confidence level ($p = 0.05$).

III. Results

1. Preliminary experiment

1-1. SEM evaluation

1-1-1. Phosphoric acid treatment

After application of 37% phosphoric acid for 20 s, the dentin surfaces were free of smear layer and smear plugs and almost all of the dentinal tubules were open (Fig. 3A and 3B).

1-1-2. Brushing treatment

All tested treatments produced morphological modifications to the dentin surface. Groups 2, 3, 5, and 6 showed remnants of dentifrice abrasives in the dentinal tubules (Figs. 3C, 3E, 4C, and 4E). Group 4 showed a dentin surface characterized by irregular crystal-like layer deposits leaving many dentinal tubule orifices occluded (Fig. 4A).

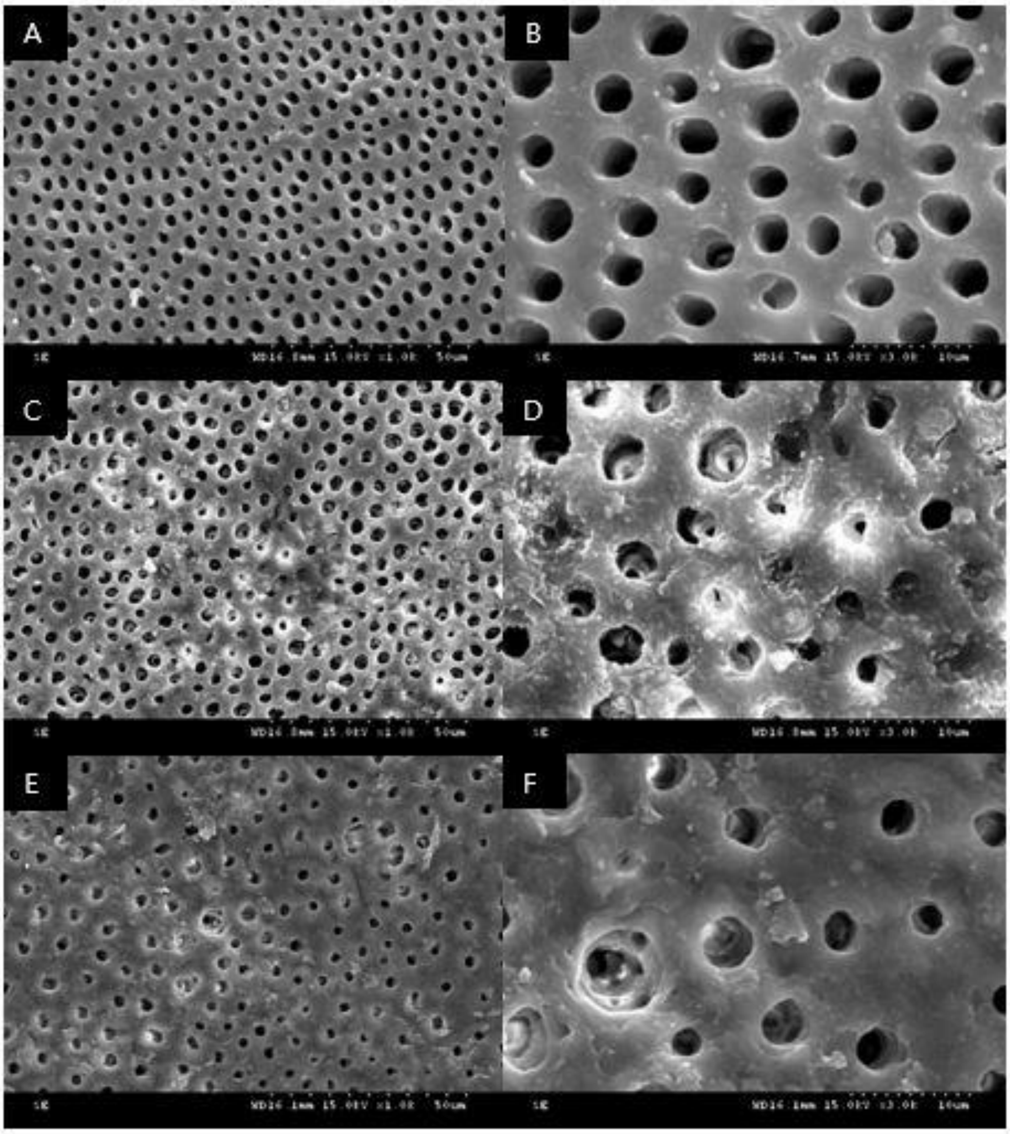

Fig 3. SEM micrographs of the dentin surface morphology in group 1 at 1000x (left) and 3000x (right) magnifications. (A and B) Dentin surface after treatment with brushing without a microcurrent (C and D) and brushing with a 20-μA microcurrent (E and F) at 1000x (left) and 3000x (right) magnifications.

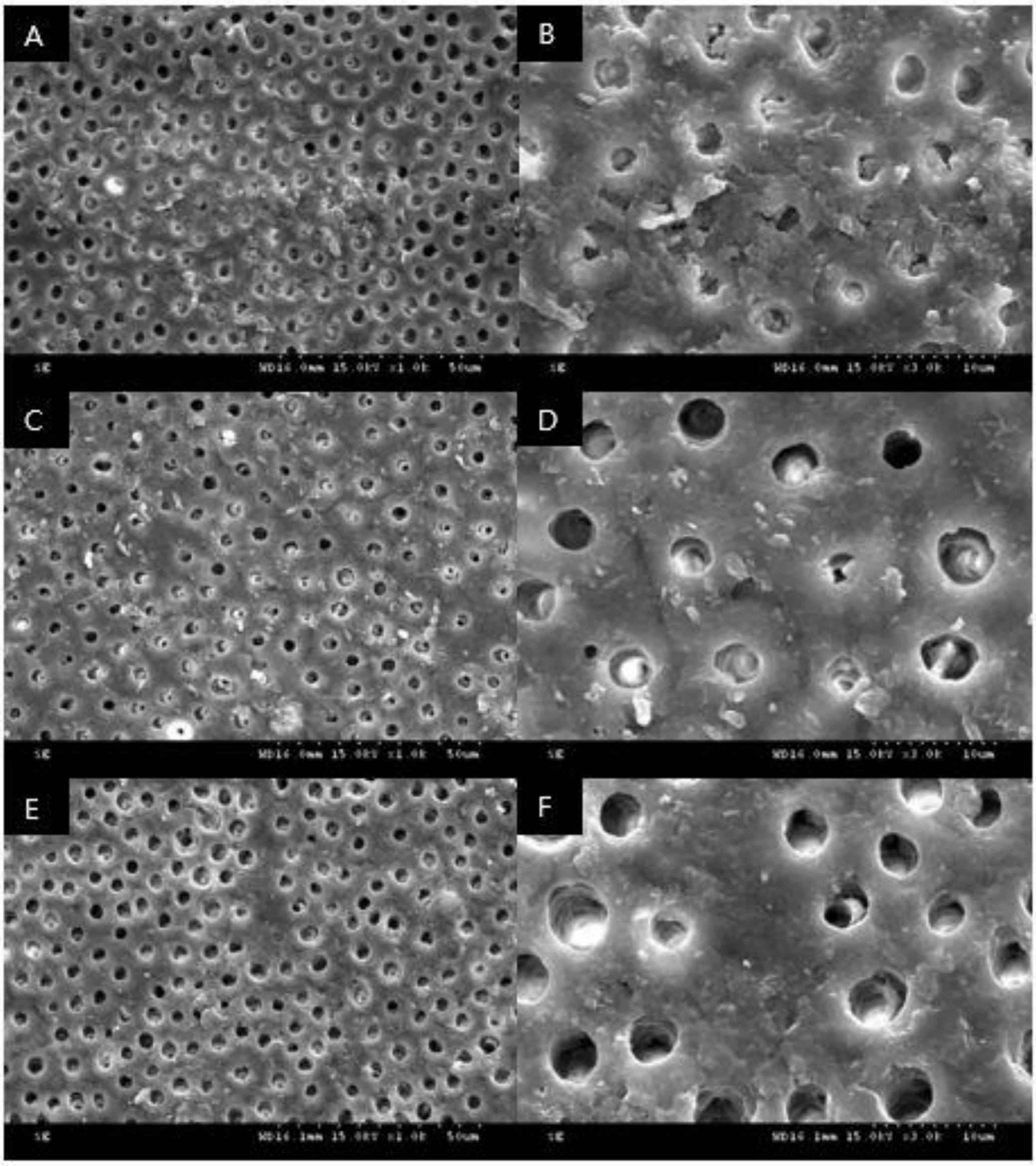

Fig 4. SEM micrographs of the dentin surface after brushing with 100-μA (A and B), 200-μA (C and D), and 500-μA (E and F) microcurrents at 1000x (left) and 3000x (right) magnifications.

1-2. Surface roughness evaluation

All experimental groups showed an increase in surface roughness in comparison with group 1. The Ra value of each group is shown in Table 1. Group 1 (control group) showed lower Ra values than the other experimental groups, and group 4 (tooth-brushing with a 100-μA microcurrent) showed the second-lowest Ra value among the groups. There was no particular relationship between the ampere and Ra values.

Table 1. Ra values of different groups measured by Surface Profiler

Group	1	2	3	4	5	6
Ra (nm)	319.62	427.73	445.23	358.64	627.67	506.66

2. Main experiment

2-1. DFF measurement using NFMD

The representative graphs of DFF according to time are shown in Figure 5. While group 1 shows a constant increase in DFF over time, groups 2 and 4 show a "step-like" increase in DFF while the control group shows a zero value for the DFF rate. DFF rates of each group and average DFF rates are shown in Table 2 and Figure 6. Group 4 showed a significantly lower DFF rate than groups 1 and 2 ($p < 0.05$).

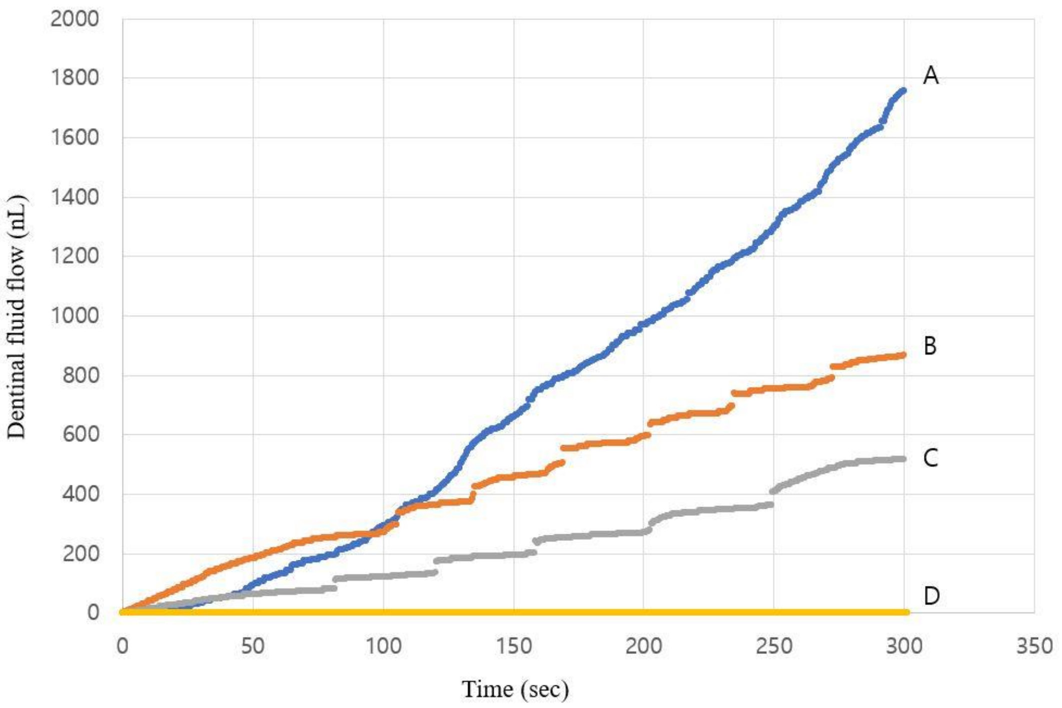

Fig 5. Representative graphs of dentinal fluid flow in each group (A: group 1, B: group 2, C: group 4, D: control)

Table 2. Average and standard deviation values of dentinal fluid flow rates in each group

Specimen	Group 1	Group 2	Group 4
Mean	6.14 [A]	2.99 [B]	1.86 [C]
S. D.	1.04	0.85	0.52

* Different uppercase letters denote significant differences among specimen groups ($p < 0.05$).

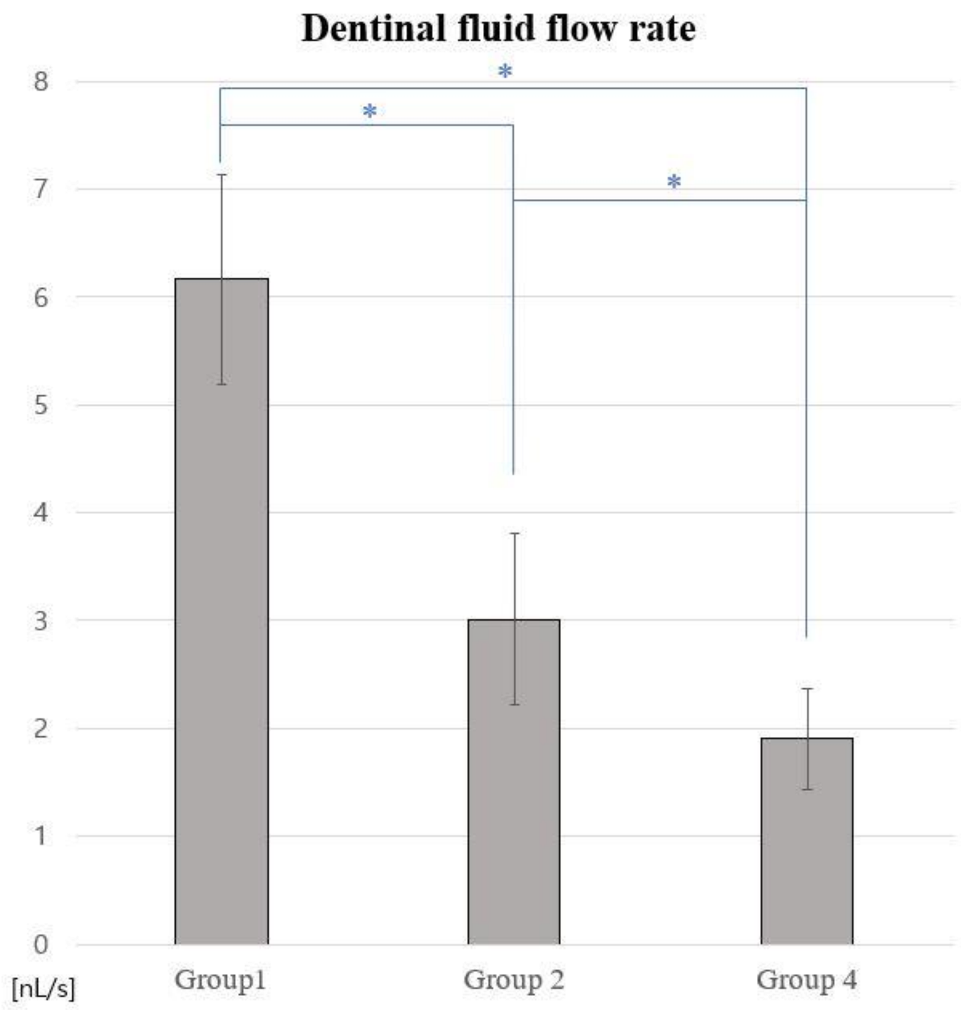

Fig 6. Bar graph of dentinal fluid flow rates over 5 min. The blue line and asterisk indicate significant differences between groups ($p < 0.05$).

IV. Discussion

This is the first study to assess the dentinal tubule occluding ability of tooth-brushing with a microcurrent by using an NFMD. While most previous studies on dentin hypersensitivity used a regular toothbrush with desensitizing agents, this study used a smart toothbrush with a microcurrent that had a similar effect as iontophoresis.

Although many hypotheses have been proposed to explain dentin hypersensitivity, the definite principle underlying this phenomenon remains unknown. The most commonly accepted hypothesis for explaining dentin hypersensitivity was proposed in the Brannstrom hydrodynamic theory in 1966 (Brannstrom, et al., 1968). Therefore, any substance that causes a reduction in DFF by occluding the dentinal tubules can reduce the symptoms of dentin hypersensitivity (Markowitz and Pashley, 2008). Several in vitro and in vivo studies have already shown the ability of different desensitizing toothpastes to occlude dentinal tubules (Arrais, et al., 2003; Markowitz and Pashley, 2008). Furthermore, iontophoresis has been used to further increase the effectiveness of desensitizing agents, and many studies have shown the effect of iontophoresis in reducing dentin hypersensitivity (Carlo, et al., 1982; Patil, et al., 2017). This study aimed to confirm dentinal tubule occlusion by a smart toothbrush that used a similar principle as iontophoresis.

In the SEM micrographs, group 1 showed completely exposed dentinal tubules and groups 2, 3, 4, 5, and 6 showed partially occluded dentinal tubules (Figs. 3 and 4). All experimental groups used a Colgate Total toothpaste, which contains 0.24% sodium fluoride, when tooth-brushing the dentin specimen. Dentifrice abrasives can have an occluding effect on dentinal tubules. This phenomenon occurs via generation of a smear layer during tooth-brushing using the dentifrice (Prati, et al., 2002). Thus, tooth-brushing both with or without microcurrents can occlude dentinal tubules by generating smear layers. In comparison with group 2, groups 3, 4, 5, and 6 used microcurrents and were thus expected to show effects similar to those seen with fluoride iontophoresis. Fluoride is known to occlude the dentinal tubule by forming CaF_2 crystals (Greenhill and Pashley, 1981). Some previous studies have reported that the dentinal tubule occlusion effect of fluoride is insignificant and that the crystal structure cannot be observed in SEM images of fluoride-applied dentin specimens (Paes Leme, et al., 2004; Pashley, 1986). Other clinical studies, on the other hand, reported good effects when using fluoride to treat dentin (Thrash, et al., 1992; Yates, et al., 2004). Thus, the mechanism and effects of fluoride in dental hypersensitivity appear to be the subject of some controversy. In this study, groups 2, 3, 5, and 6 did not show a crystal structure but instead showed a resinous plug in the dentinal tubules (Figs. 3C, 3E, 4C and 4E). This could have occurred because fluoride does not easily form crystals with calcium ions because CaF_2 can be easily dissolved as a result of its chemical instability in a humid environment (Kim, et al., 2013). In this study, tooth-brushing was performed for 1 min/day in tap water for 7 days to enhance the effect of dentinal tubule occlusion. After tooth-brushing each day, the dentin specimen was kept in distilled water, and this aspect of the study design possibly created a humid environment that facilitated easy dissolution of CaF_2 crystals. Moreover, the tooth-brushing force could have affected crystal formation and dentinal tubule occlusion. A previous study by Sehmi et al. compared three brushing forces—100 g, 200 g, and 400 g (low, medium, and high)—and showed significant differences in dentinal tubule patency between the 100-g and 400-g tooth-brushing forces. At 100-g, formation of a smear layer after tooth brush abrasion occurred, but at 400 g, there were significant increases in dentinal tubule patency, which is clinically relevant for patients with dentin hypersensitivity (Sehmi and Olley, 2015). Because of the use of an electric toothbrush in this study, the brushing force may have acted more strongly and interfered with crystal formation. However, group 4 showed a crystal-like layer on the dentin surface in SEM micrographs (Fig. 4A). This may indicate that the 100-μA microcurrent is most effective value to facilitate dentinal tubule occlusion.

There was an increase in the surface roughness of the experimental groups. The brushing force produced a rougher surface using the desensitizing dentifrice. Compared to group 2, 3, 5, 6, the increase in surface roughness of group 4 was the smallest reported any group other than group 1. Thus, the brushing force does seem to have an effect on the surface roughness and the 100-μA microcurrent produced a relatively smoother surface than that observed in the other experimental groups. One possible explanation for this relates to how the Ra value is calculated. Surface roughness refers to the height deviation from the form or overall shape of a surface and changes in Ra typically signify a new variation in the process. A limitation of Ra is that it provides a quantitative mean of the height deviations and cannot show the surface's irregularities (Field, et al., 2010). In group 4, tooth-brushing with a 100-μA microcurrent yielded a crystal-like layer on the dentin surface and occluded the dentinal tubules most effectively. On the basis of this result, the artificial layer created by group 4 may have reduced the height deviations into the exposed patent dentinal tubules and showed a relatively less increase in the Ra value. However, there was no particular correlation between the surface roughness and tubule patency across all groups. Although surface roughness was not a direct indicator of tubule patency in this study, surface roughness measurements were useful to understand of the effects of tooth-brushing and the desensitizing dentifrice on the dentin surface.

After SEM and surface roughness analyses, we chose group 4 for DFF rate measurements. To analyze dentinal tubule occlusion quantitatively, the DFF rate was measured using an NFMD. A previous study using an NFMD showed that the effect of desensitizing agents could be assessed by estimating the DFF rate (Kim, et al., 2013). Many previous studies have investigated the effects of desensitizing agents on dentinal tubule occlusion by assessing dentin permeability on a dentin specimen connected to a capillary in a split chamber (Vieira and Santiago, 2009). Although this study design has been commonly used because of the convenience of dentin specimen preparation, many studies loaded 70 cm H_2O or higher pressures (Elgalaid, et al., 2007; Pashley, et al., 1996), and these loads were higher than the physiologic pulp pressure to accelerate the movement of the air bubble in the capillary of the flow measurement device (Kim, et al., 2013). With an NFMD, a physiologic pulp pressure of 20 cm H_2O could be applied, making it possible to reproduce the clinical situation. Moreover, the NFMD has a high resolution, so it can show more details of DFF (Kim, et al., 2010).

The change in DFF rate according to the groups was reflected as a specific curve on the representative graph of the NFMD (Fig. 5). Group 1 presented a constantly increasing pattern and for groups 2 and 4, the graph showed a “step-like” pattern. The specimens in group 1 did not receive any treatment except acid etching, so dentinal tubules were open and free of the smear layer, resulting in a constant increase in DFF. In contrast, groups 2 and 4 received tooth-brushing using Colgate Total toothpaste; thus, the dentinal tubules were partially occluded, resulting in a “step-like” increase in the graph.

There was a significant difference between the mean DFF rate in group 4 compared to those in groups 1 and 2 ($P < 0.05$). Group 4 specimens were brushed using a smart toothbrush, in which a chip consisting of staneless steel and aluminum causes oxidation-reduction reactions with saliva and fluoride-containing toothpaste. Thus, the microcurrent cell and the toothbrushes are electrically connected to supply a microcurrent directly to the teeth with electrolyte, and group 4 can be thought of as having a similar effect as iontophoresis using fluoride. In iontophoresis with fluoride, the fluoride is absorbed under the walls of the dentinal tubules as well as on the surface of calcium, forming calcium fluoride with the tooth substance (Wilson, et al., 1984). This creates a new physical barrier and occludes the dentinal tubules, reducing their permeability. This could probably explain why tooth-brushing with a microcurrent yielded the lowest DFF rates among the three groups.

After we investigated dentinal tubule occlusion by measuring the DFF and analyzing SEM micrographs, we concluded that tooth-brushing with microcurrents was effective in occluding the dentinal tubules. However, it may be difficult for the desensitizing agent to be retained on an exposed dentin surface because of interactions with saliva and cyclic brushing in clinical situation. And unlike clinical situation, dentin surface was tooth-brushed in the tap water during the experiment. Therefore, extrapolation of these results to the clinical situation should be performed carefully. Moreover, there is limited clinical assessment data for dentin hypersensitivity. Further clinical and long-term studies using microcurrents should be performed to determine the effect of tooth-brushing with microcurrents on reducing dentin hypersensitivity.

V. Conclusions

Within the limitations of this study, the following conclusions were reached:

1) All experimental groups showed partially occluded dentinal tubules and the formation of crystal-like structures at a specific microcurrent intensity (100 μA) indicated that tooth-brushing with microcurrents could occlude dentinal tubules efficiently.

2) There was no direct correlation between surface roughness and dentinal tubule patency.

3) The decrease in DFF rate in the tooth-brushing with microcurrent groups indicated that dentinal tubules were occluded and that the flow of dentinal fluid had decreased.

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References

Arrais CAG, Micheloni CD, Giannini M, Chan DCN: Occluding effect of dentifrices on dentinal tubules. Journal of Dentistry 31(8): 577-584, 2003.

Austin RS, Mullen F, Bartlett DW: Surface texture measurement for dental wear applications. Surface Topography: Metrology and Properties 3(2): 023002, 2015.

Brannstrom M, Linden LA, Johnson G: Movement of dentinal and pulpal fluid caused by clinical procedures. J Dent Res 47(5): 679-682, 1968.

Carlo GT, Ciancio SG, Seyrek SK: An evaluation of iontophoretic application of fluoride for tooth desensitization. J Am Dent Assoc 105(3): 452-454, 1982.

Elgalaid TO, Creanor SL, Creanor S, Hall AF: The permeability of natural dentine caries before and after restoration: An in vitro study. J Dent 35(8): 656-663, 2007.

Field J, Waterhouse P, German M: Quantifying and qualifying surface changes on dental hard tissues in vitro. J Dent 38(3): 182-190, 2010.

Gadelmawla ES, Koura MM, Maksoud TMA, Elewa IM, Soliman HH: Roughness parameters. Journal of Materials Processing Technology 123(1): 133-145, 2002.

Greenhill JD, Pashley DH: The effects of desensitizing agents on the hydraulic conductance of human dentin in vitro. J Dent Res 60(3): 686-698, 1981.

Hara AT, Livengood SV, Lippert F, Eckert GJ, Ungar PS: Dental Surface Texture Characterization Based on Erosive Tooth Wear Processes. J Dent Res 95(5): 537-542, 2016.

Herndon CM: Iontophoretic drug delivery system: focus on fentanyl. Pharmacotherapy 27(5): 745-754, 2007.

Kim SY, Ferracane J, Kim HY, Lee IB: Real-time measurement of dentinal fluid flow during amalgam and composite restoration. J Dent 38(4): 343-351, 2010.

Kim SY, Kim EJ, Kim DS, Lee IB: The evaluation of dentinal tubule occlusion by desensitizing agents: a real-time measurement of dentinal fluid flow rate and scanning electron microscopy. Oper Dent 38(4): 419-428, 2013.

Ling TY, Gillam DG, Barber PM, Mordan NJ, Critchell J: An investigation of potential desensitizing agents in the dentine disc model: a scanning electron microscopy study. J Oral Rehabil 24(3): 191-203, 1997.

Markowitz K, Pashley DH: Discovering new treatments for sensitive teeth: the long path from biology to therapy. J Oral Rehabil 35(4): 300-315, 2008.

Olley RC, Moazzez R, Bartlett D: Effects of dentifrices on subsurface dentin tubule occlusion: an in situ study. Int J Prosthodont 28(2): 181-187, 2015.

Orchardson R, Gillam DG: Managing dentin hypersensitivity. J Am Dent Assoc 137(7): 990-998; quiz 1028-1029, 2006.

Paes Leme AF, dos Santos JC, Giannini M, Wada RS: Occlusion of dentin tubules by desensitizing agents. Am J Dent 17(5): 368-372, 2004.

Pashley DH: Dentin permeability, dentin sensitivity, and treatment through tubule occlusion. J Endod 12(10): 465-474, 1986.

Pashley DH, Matthews WG, Zhang Y, Johnson M: Fluid shifts across human dentine in vitro in response to hydrodynamic stimuli. Arch Oral Biol 41(11): 1065-1072, 1996.

Patil AR, Varma S, Suragimath G, Abbayya K, Zope SA, Kale V: Comparative Evaluation of Efficacy of Iontophoresis with 0.33% Sodium Fluoride Gel and Diode Laser Alone on Occlusion of Dentinal Tubules. J Clin Diagn Res 11(8): ZC123-ZC126, 2017.

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 73(2): 183-190, 2002.

Sehmi H, Olley RC: The effect of toothbrush abrasion force on dentine hypersensitivity in-vitro. J Dent 43(12): 1442-1447, 2015.

Thrash WJ, Jones DL, Dodds WJ: Effect of a fluoride solution on dentinal hypersensitivity. Am J Dent 5(6): 299-302, 1992.

Vieira AH, Santiago SL: Management of dentinal hypersensitivity. Gen Dent 57(2): 120-126; quiz 127-128, 2009.

Wang Z, Sa Y, Sauro S, Chen H, Xing W, Ma X, et al.: Effect of desensitising toothpastes on dentinal tubule occlusion: a dentine permeability measurement and SEM in vitro study. J Dent 38(5): 400-410, 2010.

Wilson JM, Fry BW, Walton RE, Gangarosa LP, Sr.: Fluoride levels in dentin after iontophoresis of 2% NaF. J Dent Res 63(6): 897-900, 1984.

Yates RJ, Newcombe RG, Addy M: Dentine hypersensitivity: a randomised, double-blind placebo-controlled study of the efficacy of a fluoride-sensitive teeth mouthrinse. J Clin Periodontol 31(10): 885-889, 2004.

Abstract (In Korean)

미세전류를 이용한 칫솔질의 상아세관 봉쇄 및 표면 거칠기에 미치는 영향

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(지도교수 신 유 석)

본 연구의 목적은 미세전류를 이용한 칫솔질 이후에 1) 주사전자현미경을 이용하여 상아세관 봉쇄 효과를 비교하기 위해 2) 상아질의 표면거칠기를 비교하기 위해 위해, 그리고 3) 상아세관액 흐름의 속도를 비교하기 위함이다.

삼십개의 사람의 제3대구치를 법랑-상아질 경계 상방 3mm, 하방 3mm가 되도록 장축에 수직이 되도록 잘랐다. Silicon carbide paper를 이용하여 연마

를 시행하였고, 37% 인산을 20초간 적용하여 도말층을 모두 제거하였다. 이후 Colgate Total 치약을 사용하여 아래 군과 같이 처리하였다. 제 1군 : 아무 처리 하지 않은 군, 제 2군 : 미세전류 없이 칫솔질만 시행한 군, 제 3, 4, 5, 6 군 : 미세전류를 이용한 칫솔질을 시행한 군 (20, 100, 200, 500μA). 이후 군당 1개의 시편을 이용하여 주사전자현미경 사진 촬영 및 표면 거칠기를 측정 하여 상아세관 봉쇄 정도를 관찰하는 예비 실험을 진행하였다.

이후 가장 효과적인 상아세관 봉쇄를 보인 제 4군을 선택하여 제 1군, 2군과 함께 sub-nanoliter scaled fluid flow measuring device를 이용하여 상아세관액 흐름의 속도를 비교하였다. 각 군당 8개의 시편을 사용하였으며 상아세관액 흐름 속도의 평균을 측정하였고, 평균 비교를 하기 위해 One-way ANOVA와 Tukey's post hoc test를 시행하였다.

주사전자현미경 사진에서 대조군에서는 모든 상아세관이 열려있는 것을 확인할 수 있었으며 미세전류를 이용하지 않은 군과 미세전류를 이용한 군 모두 상아세관의 일부 봉쇄를 보였다. 제 4군에서는 crystal-like한 구조가 나타났으며 다른 실험 군에 비해 상아세관 봉쇄가 효과적으로 나타났다. 표면 거칠기의 경우 대조군에 비해 실험군에서 모두 Ra 값의 증가를 보였으나 실험 군간의 특정한 상관관계는 보이지는 않았다.

상아세관액 흐름 속도의 차이에서는 제 4군이 제 1, 2군에 비하여 통계적으

로 유의미하게 작은 수치를 나타냈다. 제 2군도 제 1군에 비하여 통계적으로 유의미하게 작은 수치를 나타냈다(P<0.05).

칫솔질을 시행한 모든 군에서 상아세관의 일부 봉쇄를 나타냈다. 또한 미세전류를 이용한 칫솔질은 특정한 전류값 (100 μA)에서 효과적으로 상아세관 봉쇄를 일으켰으며, 표면 거칠기와 상아세관 개방 정도는 직접적인 상관관계를 보이지 않았다. 상아세관액 흐름 속도의 감소는 상아세관의 봉쇄가 일어남으로 인한 것임을 알 수 있었다.

핵심 되는 말 : 미세전류; 상아세관; 주사전자현미경; 치아 과민증; nanoliter-scaled fluid flow measuring device