Evaluation of tooth discoloration caused by two different calcium silicate-based sealers

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Evaluation of tooth discoloration caused by two different calcium silicate-based sealers

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This certifies that the Master's Thesis of

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감사의 글

새로운 재료에 대한 호기심으로 시작한 연구가 논문이라는 정제된 글로 완성되기까지는 많은 분들의 가르침과 응원이 있었습니다. 수련과 대학원을 병행하는 것에 대해 걱정과 두려움도 있었지만 많은 조언과 격려 덕분에 무사히 마칠 수 있었습니다. 논문을 위해 고민했던 시간과 경험들은 앞으로도 굉장히 보람되고 의미 있는 시간이 될 것으로 생각됩니다.

아무런 준비가 되어있지 않은 제게 주제 선정부터 실험 설계 등 매순간 방향성을 제시해주신 신수정 교수님, 하나부터 열까지 모든 것을 챙겨주신 덕분에 논문을 완성할 수 있었습니다. 진심으로 감사합니다. 3 년의 수련기간 동안 가까이에서 보존과 치과의사로 성장할 수 있게 많은 것을 알려주시고 지도해주신 김예미 교수님 감사합니다. 바쁘신 가운데도 귀중한 시간을 할애 하셔서 심사위원장을 맡아 주시고 제가 석사 논문을 무사히 마칠 수 있도록 세심하게 배려해주신 정일영 교수님 감사합니다.

대학원 재학 동안 수업을 통해서 많은 가르침을 주신 노병덕 교수님, 박성호 교수님, 김의성 교수님, 박정원 교수님, 신유석 교수님, 김선일 교수님, 김도현 교수님 감사드립니다. 치과보존학에 매력을 느끼게 해주시고 제가 보존과 치과의사가 될 수 있도록 멘토가 되어주신 신주희 교수님 진심으로 감사드립니다. 그리고 임상가로서 환자를 대하는 마음가짐과 태도를 가르쳐 주신 김선종 교수님, 장영은 교수님 감사합니다. 실험 진행과 결과값 분석을 가능하게 도움을 주신 이혜아 교수님과 손민경 선생님, 그리고 보존과 의국원들에게도 감사드립니다.

마지막으로 언제나 한결 같은 마음으로 저를 응원해주시는 부모님과 장인어른, 장모님, 처남 그리고 멀리서도 항상 응원해주는 누나에게 감사의 마음을 전합니다. 그리고 본과 2 학년때부터 인턴, 레지던트 그리고 두 번의 시험과 이번 논문까지, 힘든 시기에 제 곁에서 큰 힘과 위로가 되어준 아내 현희에게 무한한 감사와 사랑을 드립니다. 특히 새로운 출발과 함께 저희에게 찾아온 축복이 건강하길 바라며 저희 가족과 저를 이끌어주신 모든 분들의 앞날이 행복으로 가득하길 바랍니다.

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김 형 종

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Abstract

Evaluation of tooth discoloration caused by two different calcium silicate-based sealers

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(Directed by Professor Su-Jung Shin, D.D.S., M.S.D., Ph.D.)

The purpose of this study was to evaluate the discoloration resulting from two newly developed calcium silicate–based sealers in comparison with the original mineral trioxide aggregate (MTA).

Fifty-two intact human premolars were resected 2 mm apical to the cementoenamel junction (CEJ). The specimens were randomly divided into the following groups according to the sealer and the timing of core placement: (1) positive control: ProRoot WMTA (Dentsply, Tulsa, OK, USA) + immediate core; (2) negative control: composite only; (3)

Endoseal MTA (Maruchi, Wonju, Korea) + immediate core; (4) Endoseal MTA + delayed core; (5) Endoseal TCS (Maruchi) + immediate core, and (6) Endoseal TCS + delayed core. An access cavity was made using #330 (Komet Dental, Lemgo, Germany) and Endo-Z burs (Dentsply Maillefer, Ballaigues, Switzerland), and the canal orifice was enlarged using a #5 Gates Glidden drill (Dentsply Maillefer). The thickness of the buccal cavity was measured at the center and 2 mm above the CEJ using a caliper. The sealer or cement was placed as follows. First, mixed ProRoot WMTA cement or sealer was filled to 4 mm above the CEJ. Then, for the samples in the immediate resin core groups, composite resin (Filtek Z350 XT; 3M ESPE, St. Paul, MN, USA) was applied in combination with etchant (Ultra-Etch; Ultradent, South Jordan, UT, USA) and the bonding system (Adper Single Bond 2; 3M ESPE) after the remaining sealer was removed. For the delayed resin cores, a composite resin core was placed 1 week later. Specimens were stored in a soaked flower oasis at 37°C and 100% humidity during the experiment. The colors (CIE-Lab*) were measured by a spectrophotometer (Spectroshade; MHT) at baseline and at 1, 2, 4, 8, and 24 weeks. The results of color change (ΔE, ΔL) were statistically analyzed by repeated-measures analysis of variance, and post-hoc testing was done using the Bonferroni method at the $p < 0.05$ level.

Significant differences in ΔE and ΔL were found depending on the filling material. ProRoot WMTA showed significantly higher changes than the other groups ($p < 0.05$), and the Endoseal MTA groups displayed significant differences from the composite resin group

($p < 0.05$). In contrast, the Endoseal TCS groups were not significantly different from the composite resin group ($p > 0.05$), except for the ΔL value of the delayed core group.

Endoseal TCS demonstrated significantly less discoloration than Endoseal MTA due to differences in its composition. Within the limitations of this study, it is concluded that Endoseal TCS can be used as a sealer with minimal tooth discoloration.

Keywords: Mineral trioxide aggregate, spectrophotometer, tooth discoloration, calcium silicate sealer, Endoseal MTA, Endoseal TCS

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I. INTRODUCTION

Mineral trioxide aggregate (MTA), which is made of Portland cement, was developed in the mid-1990s. For more than 20 years, it has shown excellent biocompatibility and low cytotoxicity in root canal treatment (Torabinejad et al. 1995, Torabinejad, Parirokh 2010). MTA is mainly composed of tricalcium silicate, dicalcium silicate, tricalcium aluminate, bismuth oxide, and other mineral oxides, and has been used in regenerative endodontic procedures, pulpotomy, and other treatments where calcium hydroxide was previously used, due to MTA's ability to form hard tissue and high sealing ability (Camilleri, Pitt Ford 2006, Sarkar et al. 2005). It is also used for various types of root canal treatment, and is considered the gold-standard retrograde filling material in surgical endodontic procedures such as apicoectomy and replantation. MTA is a reliable material that has shown long-term good outcomes in various laboratory and clinical studies, with useful characteristics such as its ability to harden in a hydrated environment and high sealing ability (Parirokh, Torabinejad 2010a, b, Torabinejad, Parirokh 2010).

Although MTA shows good results in endodontic treatment, it is inconvenient to use due to its long setting time (Felman, Parashos 2013, Ioannidis et al. 2013b, Parirokh, Torabinejad 2010b). Another important disadvantage of MTA is tooth discoloration resulting from bismuth oxide, which is added to increase its radiopacity (Marciano et al. 2014, Steffen, van Waes 2009, Valles et al. 2013). In an anaerobic environment, bismuth oxide is broken down into dark metallic crystals and oxygen, resulting in dark discoloration. Furthermore, if NaOCl comes into contact with MTA, bismuth oxide oxidizes and reacts with carbon dioxide to form bismuth carbonate. This substance is sensitive to light and also causes tooth discoloration (Lee et al. 2016). Tooth discoloration over time is a barrier to using MTA to treat anterior teeth, as 31.6% to 57% of patients have been reported to complain of such discoloration (Thomson et al. 2012). In contrast, a previous study by Kang et al. showed that Endocem Zr (Maruchi, Wonju, Korea) or Retro MTA (BioMTA, Seoul, Korea) yielded significantly less discoloration than ProRoot MTAs (Kang et al.

2015). Those MTA cements do not include bismuth oxide as radiopacifier, thereby potentially solving the problem of discoloration induced by MTA (Kang et al. 2015).

In light of the many favorable results reported in preclinical and clinical studies of calcium silicate cements, several calcium silicate–based sealers have been developed and used. Multiple recent studies demonstrated that calcium silicate–based sealers had low cytotoxicity and satisfactory sealing ability to other sealers (Asawaworarit et al. 2016, Seo et al. 2019). Compared with resin-based sealers such as AH Plus (Dentsply, Konstanz, Germany), calcium silicate–based sealers showed higher cell viability, which interfered with the activation of osteoclasts by high alkalinity and facilitated hard tissue formation (Lee et al. 2019, Lim et al. 2015). Furthermore, in studies comparing the solubility of a calcium silicate–based sealer with that of AH Plus, the calcium silicate–based sealer showed lower solubility, gradually expanded slightly because of its ability to absorb water, and showed better sealing ability over time (Asawaworarit et al. 2016, Vitti et al. 2013).

Endoseal MTA (Maruchi, Wonju, Korea) is a recently developed calcium silicate–based sealer that consists of calcium silicates, calcium aluminates, calcium aluminoferrite, and calcium sulfates, as well as a radiopacifier and thickening agent. Based on the manufacturer's instructions, this sealer is of the pre-mixed syringe type, which does not require powder/liquid mixing, making it easy to use as it is hardens in the air after injection. The setting time is 12.31 minutes, which provides sufficient working time, and it has also shown high biocompatibility and strong antibacterial effects in comparative studies with

AH Plus (Hwang et al. 2015, Lim et al. 2015). Calcium silicate–based cement has many advantages in endodontic treatment, but few studies have investigated the issue of potential discoloration caused by this type of sealer. A previous study by Lee et al. showed that Endoseal MTA caused significantly less discoloration than ProRoot MTA, and also found comparable results in discoloration between Endoseal MTA and AH Plus (Lee et al. 2016). The recently developed Endoseal TCS (Maruchi) uses zirconium oxide instead of bismuth oxide as a radiopacifier to improve possible discoloring problems in Endoseal MTA. Bismuth oxide was previously used as a radiopacifier in ProRoot MTA and some calcium silicate–based sealers. The manufacturer of Endoseal TCS also claimed that it has excellent biocompatibility. However, no study has investigated the degree of discoloration caused by Endoseal TCS and Endoseal MTA applied to tooth structures. In addition, there remains no consensus regarding the potential issue of discoloration caused by Endoseal MTA.

The purpose of this study was to compare the effects of Endoseal MTA and Endoseal TCS on discoloration of the coronal aspects of teeth. We also investigated the effect of the timing of composite resin core placement on tooth discoloration by these sealers. The null hypotheses were as follows: first, that Endoseal TCS and Endoseal MTA would not cause more tooth discoloration than composite resin filling; and second, that the degree of discoloration would be affected by the timing of core placement.

II. MATERIALS AND METHODS

1. Sample preparation

Fifty-two freshly extracted intact human premolar teeth were used in this study. The protocol was approved by the institutional review board (IRB: 2019-07-008). The experiment was conducted using healthy teeth without cracks, caries, tooth fractures, or discoloration. Soft tissue and calculus were removed using a hand scaler after the teeth were soaked in 2.5% NaOCl for 10 minutes.

All teeth were resected 2 mm apical to the cementoenamel junction (CEJ) using a diamond-coated disc (Komet Dental, Lemgo, Germany). After an endodontic access cavity was made using #330 (Komet Dental) and Endo-Z burs (Dentsply Maillefer, Ballaigues, Switzerland), the canal orifice was enlarged using a #5 Gates Glidden drill (Dentsply Maillefer). The thickness of the buccal access cavity was measured at 1 mm above the CEJ on the buccal side by using a caliper after sufficient irrigation of the access cavity with 2.5% NaOCl. Additionally, 17% ethylenediaminetetraacetic acid (EDTA) was applied for 1 minute and the cavity was irrigated with sterile saline (Klenzo; JW Pharmaceutical, Seoul, Korea). Then, the cavity was soaked in 5% NaOCl for 5 minutes. Finally, the cavity was rinsed with 10 mL of saline and dried.

2. Experimental setup

The specimens were divided randomly into the following groups according to the sealer type and timing of resin core placement: (1) positive control: ProRoot WMTA + immediate core (n=6), (2) negative control: composite only (n=6), (3) Endoseal MTA + immediate core (group 1; n=10), (4) Endoseal MTA + delayed core (group 2; n=10), (5) Endoseal TCS + immediate core (group 3; n=10), and (6) Endoseal TCS + delayed core (group 4; n=10).

The process of canal filling was as follows. The specimen was placed on top of a flat glass plate after the plate was cleaned. The sealer was applied to the cavity from the bottom, ensuring that the wall was sufficiently coated, and gutta-percha was slowly injected to 4 mm above the CEJ using a Duo-Beta device (B&L Biotech, Gunpo, Korea). The gutta-percha was compacted with an endodontic plugger (S-Kondenser; Obtura Spartan Endodontics, Earth City, MO, US) with a thickness of 1.2 mm.

For the samples in the immediate resin core placement groups, composite resin (Filtek Z350 XT; 3M ESPE, St. Paul, MN, USA) was applied in combination with etchant (Ultra-Etch; Ultradent, South Jordan, UT, USA) and the bonding system (Adper Single Bond 2; 3M ESPE) after the remaining sealer on the wall was removed. For the groups with delayed resin core placement, a composite resin core was placed 1 week after removing the extra sealer under microscopy (Fig. 1). All specimens were stored in a soaked flower oasis at 37°C and 100% humidity.

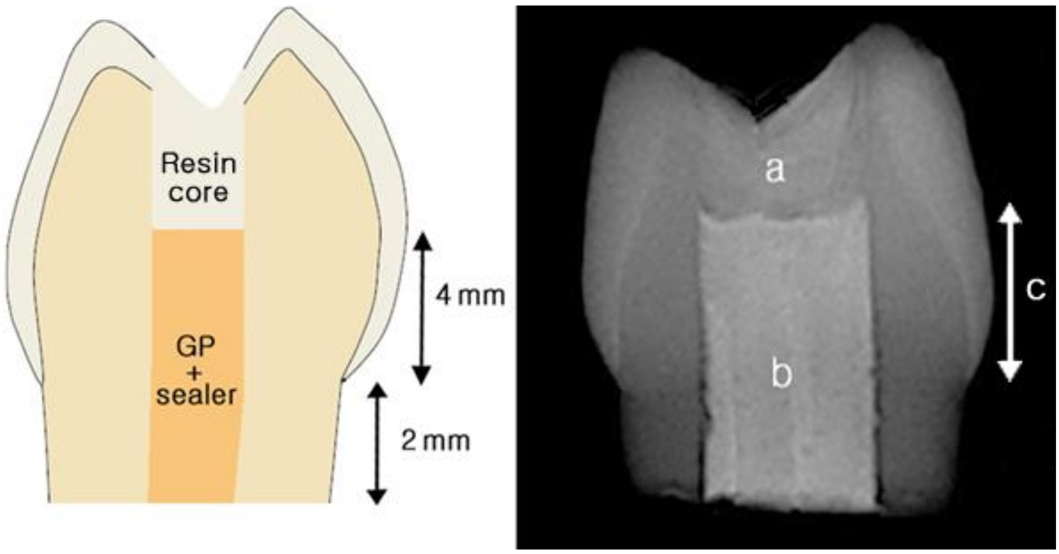

Figure 1. Schematic and radiograph of specimens

(A) Resin core. (B) Gutta-percha (GP) with sealer. (C) Discoloration measurement site.

Table 1. Calcium silicate cement and calcium silicate–based sealers used in this study

Material	Manufacturer	Composition	Initial setting time
ProRoot WMTA	Dentsply, Tulsa, OK, USA	Tricalcium silicate, dicalcium silicate, tricalcium aluminate, tetracalcium aluminoferrite, free calcium oxide, bismuth oxide	210 min
Endoseal MTA	Maruchi, Wonju, Korea	Dicalcium silicate, tricalcium silicate, calcium aluminoferrite, phyllosilicate mineral, zirconium oxide, bismuth oxide, N-methyl-2-pyrrolidone	12.31 min
Endoseal TCS	Maruchi, Wonju, Korea	Tricalcium silicate, phyllosilicate mineral, zirconium oxide, dimethyl sulfoxide	29.50 min

3. Tooth discoloration measurement

Molds were made using putty (Charmflex; Dentkist, Gyeonggi, Korea) for each tooth to measure the color of the tooth under consistent conditions, and a zig was used to maintain a constant distance between the spectrophotometer (MHT Spectroshade Micro; MHT Medical High Technologies, Verona, Italy) and teeth (Fig. 2). The upper 4 mm of the CEJ filled with gutta-percha was measured three times, and the average value was recorded. The colors of the teeth (CIE-Lab*) were measured by a spectrophotometer at baseline (pre-operation), immediately after canal filling, and at 1, 2, 4, 8, and 24 weeks after canal filling. Color changes (ΔE) and luminosity changes (ΔL) were calculated as follows :

$$\Delta E = ([L^*2 - L^*1]^2 + [a^*2 - a^*1]^2 + [b^*2 - b^*1]^2)^{1/2}$$

$$\Delta L = L^*2 - L^*1$$

Where L* represents lightness, ranging from 0 (black) to 100 (white); a* represents greenness (negative a*) / redness (positive a*); and b* represents blueness (negative b*) / yellowness (positive b*) (Joiner 2004).

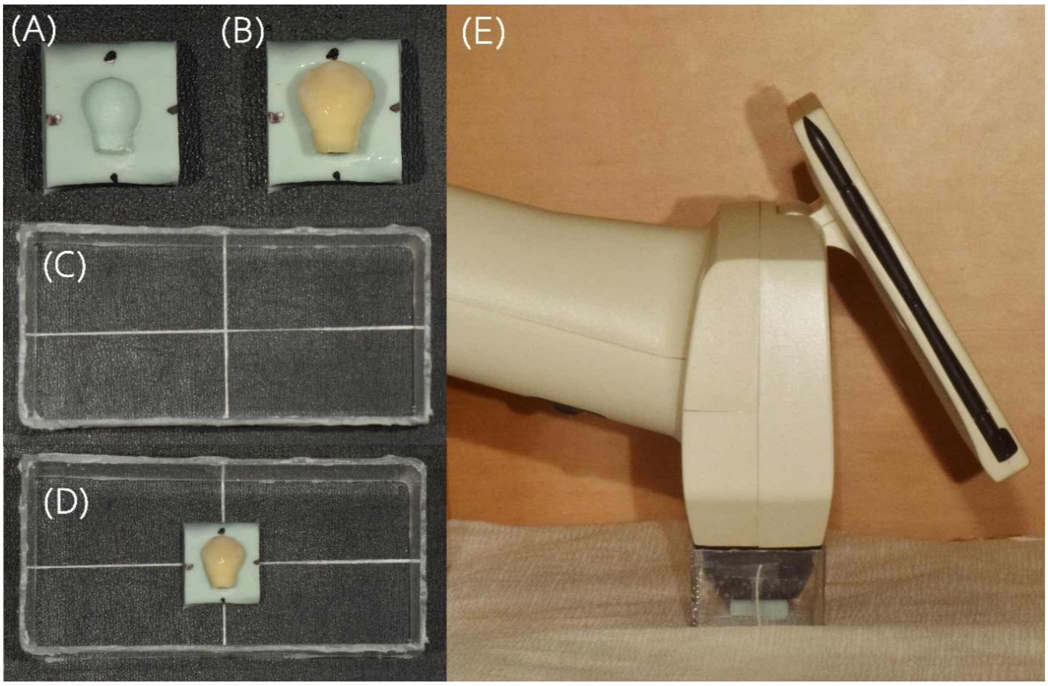

Figure 2. A customized mold and zig for measurement

(A) A mold made using putty. (B) A tooth specimen was placed into the mold. (C) A zig used for the study. (D) The customized mold with the tooth was placed into the zig for measurement. (E) Tooth shade measurement by the spectrophotometer and zig.

4. Microscopy evaluation

After 24 weeks, tooth specimens from each group were selected for light microscopy and SEM observations. Teeth were sectioned longitudinally in the bucco-lingual direction and observed using light microscopy (SMZ745T, Nikon, Tokyo, Japan, ×6.7). The specimens were then dehydrated with a graded series of aqueous ethanol solutions (30%, 50%, 70%, 90%, and 100%). The specimens were dried, sputter-coated using gold, and examined by SEM (Sigma 500, ZEISS Microscopy, Germany). The interface between the canal filling material and the dentinal wall was examined at ×20, ×500, and ×1000 magnifications.

5. Statistical analysis

Statistical analyses were performed using SPSS version 25.0 (IBM Corp., Armonk, NY, USA), unless otherwise specified. Repeated-measures analysis of variance and Bonferroni post-hoc testing were used to evaluate the statistical significance of color change (ΔE, ΔL) at the 95% confidence level. Statistical significance was accepted at the level of $p < 0.05$. Pearson correlation analysis was conducted to verify whether there was a correlation between the thickness of the buccal wall of teeth and color change (ΔE, ΔL) using SAS version 9.4 (SAS Institute, Cary, NC, USA) at a significance level of 95%.

III. RESULTS

The magnitude of color and luminosity change over time are shown in Figures 3-6. The positive control group (PC group) filled with ProRoot WMTA showed significantly higher color change (ΔE) than the other groups ($p < 0.05$). Endoseal MTA resulted in a significantly lower ΔE than the positive control, but a significantly higher ΔE than Endoseal TCS ($p < 0.05$). Endoseal TCS did not show a significant difference in ΔE compared with the negative control group (NC group), which was filled with composite resin only ($p > 0.05$).

Comparing the difference in ΔE at each measurement time, it could be seen that the amount of change in the PC group was significantly greater than that of other groups after 1 week, except for the time point of immediately after filling ($p < 0.05$). In the NC group, after 4 weeks, significant differences were found between the PC and Endoseal MTA groups ($p < 0.05$). There were no significant differences in the Endoseal TCS groups until 8 weeks ($p > 0.05$), but significant differences were observed at 24 weeks ($p < 0.05$). The groups filled with Endoseal MTA showed significant differences from the PC and NC groups after 4 weeks ($p < 0.05$). In contrast, the group filled with Endoseal TCS did not show significant differences from the NC group up to 8 weeks ($p > 0.05$), but did show significant differences at 24 weeks ($p < 0.05$).

The luminosity change (ΔL) demonstrated significant darkening in the PC group compared to all other groups ($p < 0.05$). Endoseal MTA showed a significantly lower ΔL than the PC group, but a significantly higher ΔL than Endoseal TCS ($p < 0.05$). Endoseal TCS showed a significantly lower ΔL than ProRoot WMTA and Endoseal MTA ($p < 0.05$), but only the delayed core group showed significant differences in ΔL ($p < 0.05$), and the immediate core group showed no significant differences ($p > 0.05$).

Comparing the changes in ΔL values at each measurement time, the PC group showed significant differences from the NC and Endoseal TCS groups immediately after filling ($p < 0.05$), and showed significant differences from all groups after 1 week ($p < 0.05$). The NC group showed significant differences from the PC group and the Endoseal MTA groups at all measurement points ($p < 0.05$), but the Endoseal TCS groups showed significant differences only at 2 and 24 weeks ($p < 0.05$). The Endoseal MTA groups showed significant differences from the PC group after 1 week ($p < 0.05$), and significant differences from the Endoseal TCS groups at 1 week and 24 weeks ($p < 0.05$).

For both Endoseal MTA and Endoseal TCS, no significant differences were found in ΔE values between the immediate core groups and the delayed core groups across the entire period of the study ($p > 0.05$). Furthermore, for both calcium silicate–based sealers, there were no significant differences in ΔL values between the immediate core groups and delayed core groups ($p > 0.05$).

No significant correlations were found between buccal thickness and color change or luminosity change ($p > 0.05$).

Clinical photographs of the buccal side of each group according to the measurement time are shown in Figure 7. The ProRoot WMTA group exhibited grayish color changes. SEM images of the interface between the canal filling materials and dentin of each specimen are shown in Figure 9.

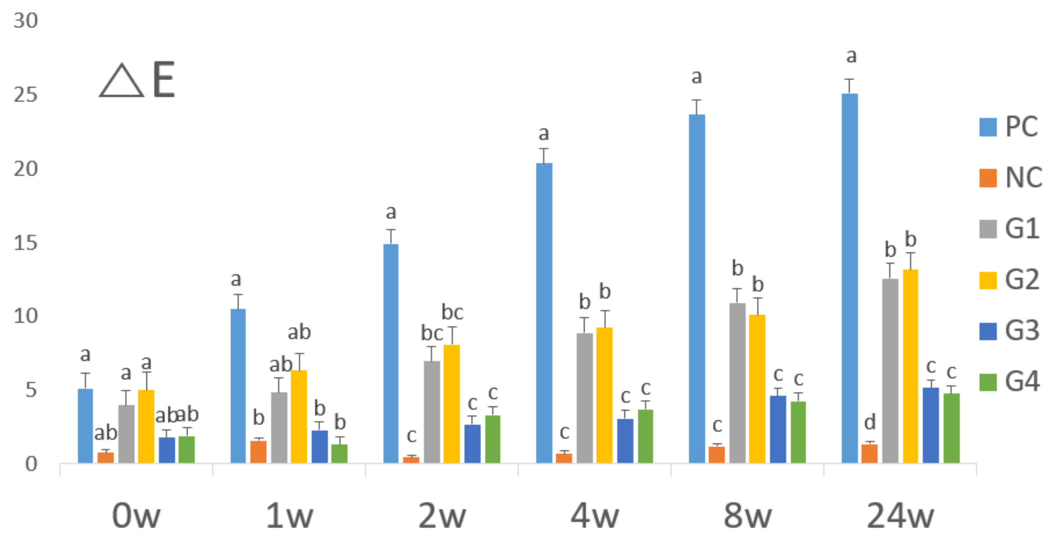

Figure 3. ΔE values (mean ± standard deviation) for each group at seven different time points.

Different letters indicate statistically significant differences between the groups ($p < 0.05$). The Y-axis represents the magnitude of color change, while the X-axis shows the time elapsed after filling. W, week; PC, positive control; NC, negative control; G1, group 1 (Endoseal MTA + immediate core); G2, group 2 (Endoseal MTA + delayed core); G3, group 3 (Endoseal TCS + immediate core); G4, group 4 (Endoseal TCS + delayed core).

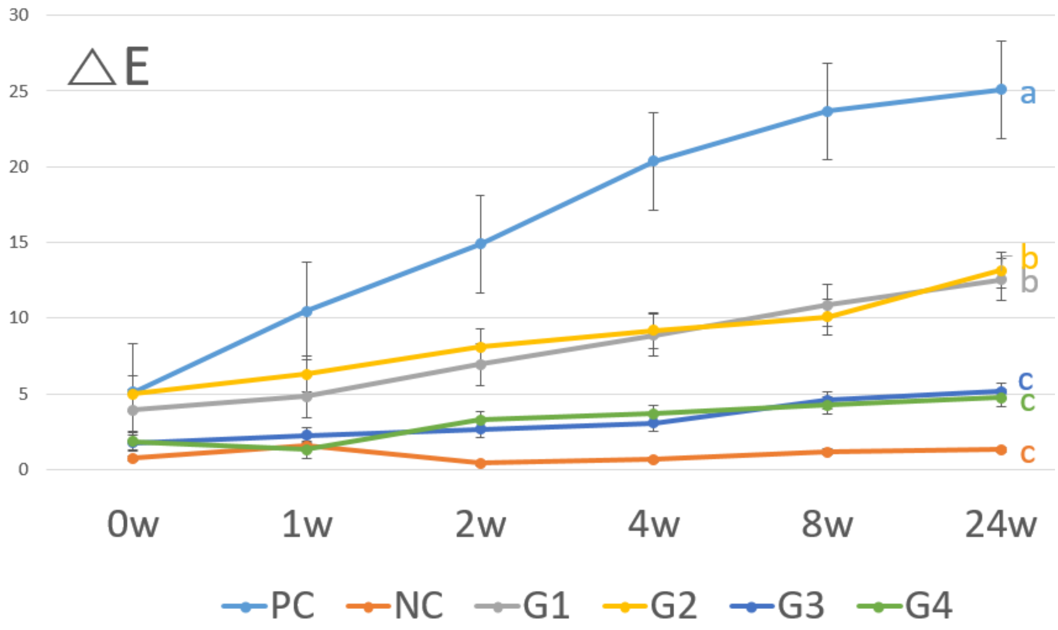

Figure 4. Change of ΔE values over the course of 24 weeks.

Different letters indicate statistically significant differences between the groups ($p < 0.05$). The Y-axis represents the magnitude of color change, while the X-axis shows the time elapsed after filling. W, week; PC, positive control; NC, negative control; G1, group 1 (Endoseal MTA + immediate core); G2, group 2 (Endoseal MTA + delayed core); G3, group 3 (Endoseal TCS + immediate core); G4, group 4 (Endoseal TCS + delayed core).

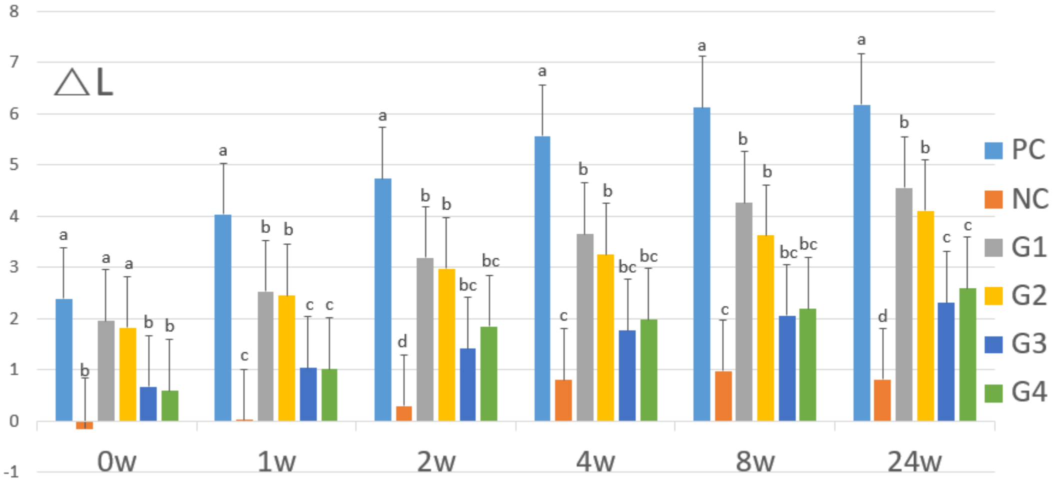

Figure 5. ΔL values (mean ± standard deviation) for each group at seven different time points.

Different letters indicate statistically significant differences between the groups ($p < 0.05$). The Y-axis represents the magnitude of luminosity change, while the X-axis shows the time elapsed after filling. W, week; PC, positive control; NC, negative control; G1, group 1 (Endoseal MTA + immediate core); G2, group 2 (Endoseal MTA + delayed core); G3, group 3 (Endoseal TCS + immediate core); G4, group 4 (Endoseal TCS + delayed core).

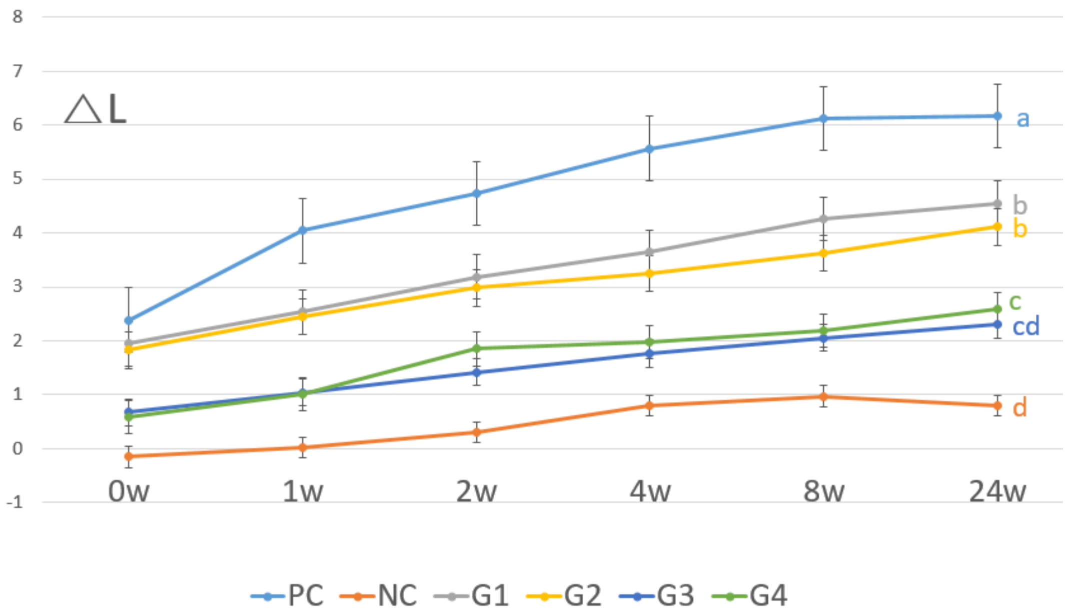

Figure 6. Change of ΔL values over the course of 24 weeks.

Different letters indicate statistically significant differences between the groups ($p < 0.05$). The Y-axis represents the magnitude of luminosity change, while the X-axis shows the time elapsed after filling. W, week; PC, positive control; NC, negative control; G1, group 1 (Endoseal MTA + immediate core); G2, group 2 (Endoseal MTA + delayed core); G3, group 3 (Endoseal TCS + immediate core); G4, group 4 (Endoseal TCS + delayed core).

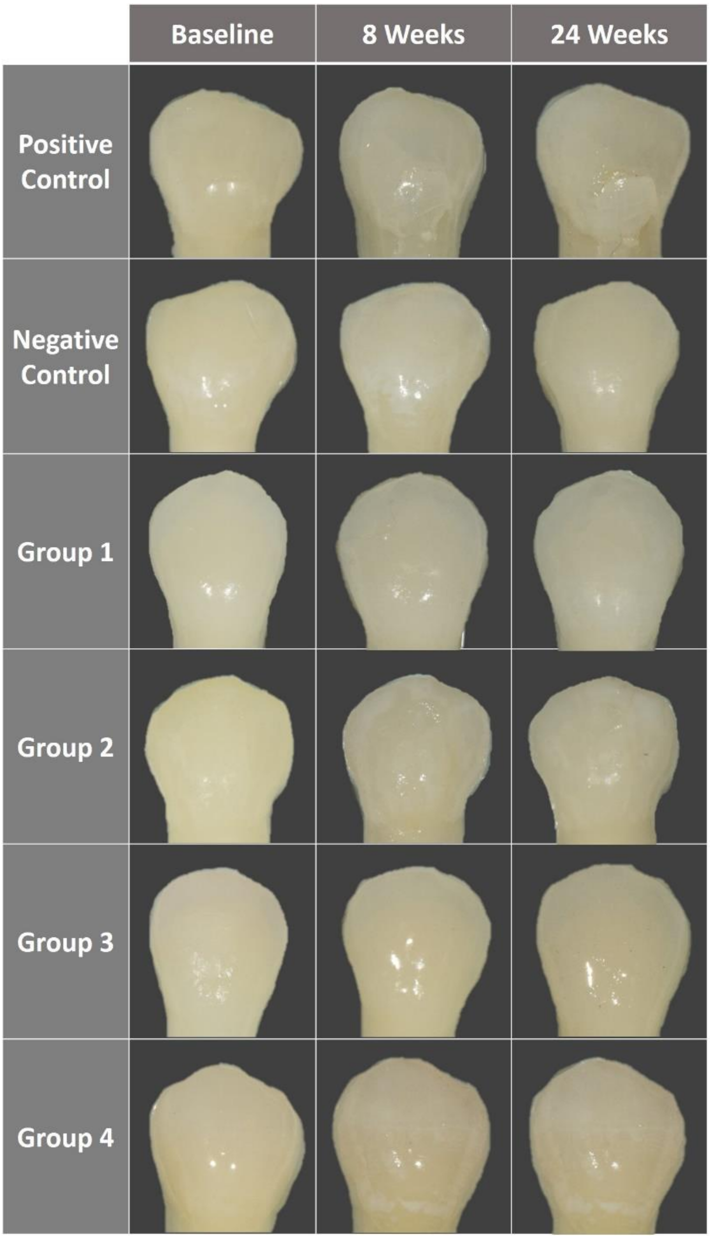

Figure 7. Photographs of the experimental groups and control groups.

Positive control (ProRoot WMTA); Negative control (Composite only); Group 1 (Endoseal MTA + immediate core); Group 2 (Endoseal MTA + delayed core); Group 3 (Endoseal TCS + immediate core); Group 4 (Endoseal TCS + delayed core).

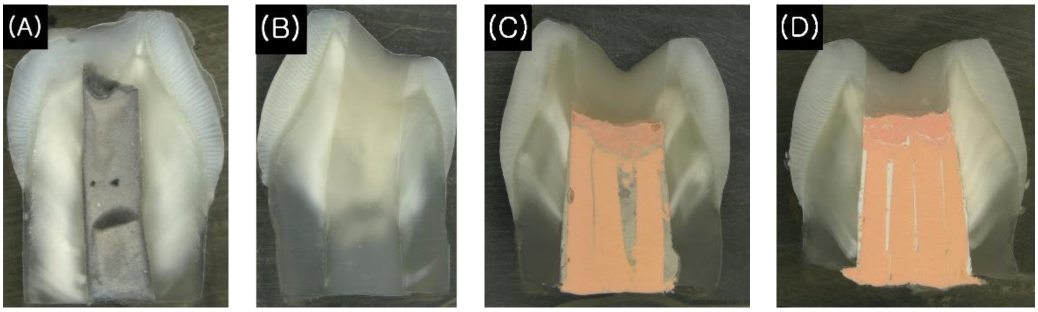

Figure 8. Representative light microscopy images (×6.7) of each specimen.

(A) ProRoot WMTA, (B) Composite resin, (C) Endoseal MTA, (4) Endoseal TCS.

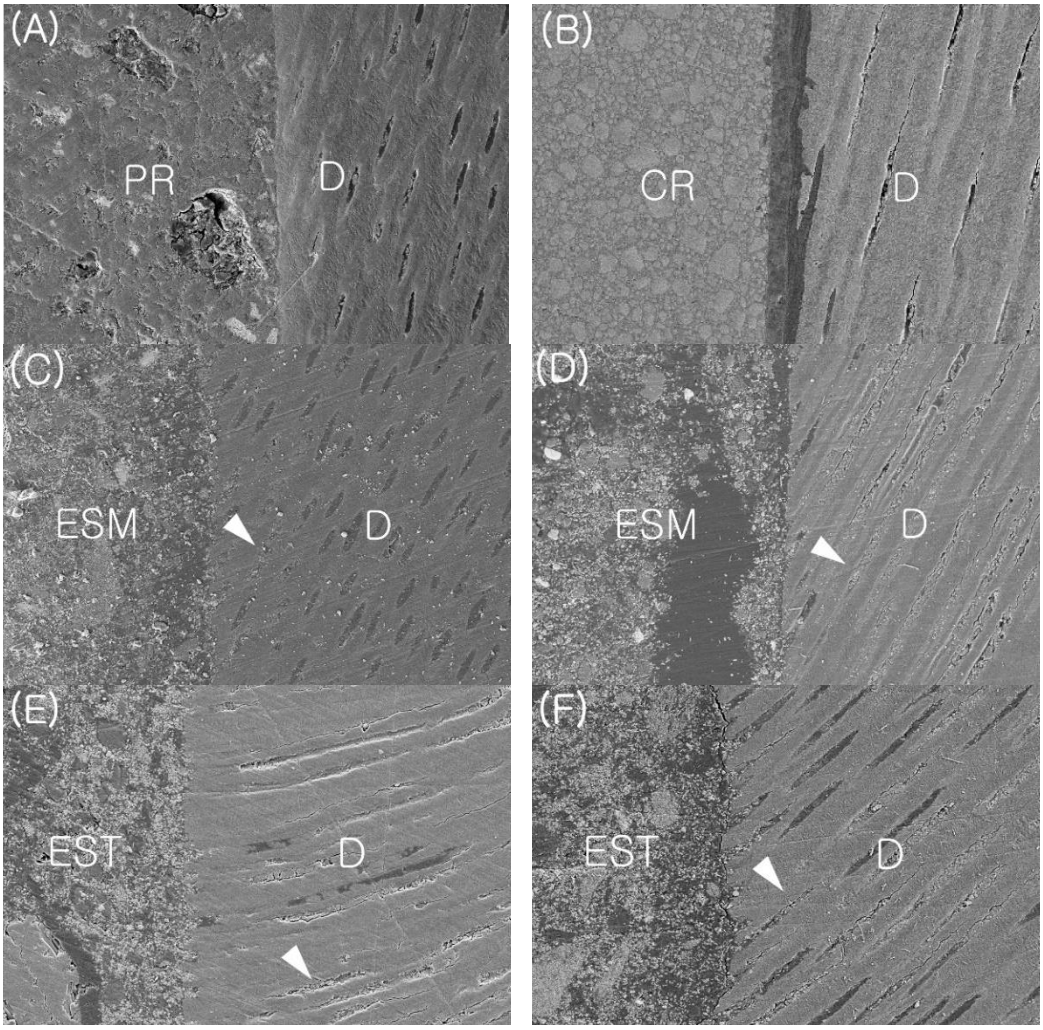

Figure 9. Representative SEM images (×1000) of each specimen.

(A) ProRoot WMTA (positive control), (B) Composite resin (negative control), (C) Endoseal MTA + immediate core, (D) Endoseal MTA + delayed core, (E) Endoseal TCS + immediate core, (F) Endoseal TCS + delayed core. D, dentin; PR. ProRoot WMTA; CR, Composite resin; ESM, Endoseal MTA; EST, Endoseal TCS. The white arrow indicates sealer penetration into the dentinal tubule.

IV. DISCUSSION

This study compared the effects of two calcium silicate–based sealers (Endoseal MTA and the newly-released Endoseal TCS) on discoloration of the coronal aspect of teeth. ProRoot WMTA was used as a positive control group, as it has been established to cause discoloration in several previous studies (Jang et al. 2013, Kang et al. 2015, Krastl et al. 2013, Ramos et al. 2016, Valles et al. 2015). The negative control group received composite resin filling only. In previous studies with similar methodology to that of this study, Kang et al. showed that the color change of ProRoot WMTA value (ΔE) was 20 units over the course of 4 months, and Valles et al. showed a ΔE value of 16.65 units over the same period (Kang et al. 2015, Valles et al. 2015). Their findings align with those of our study, as the values of ΔE were 23.6 and 25.1 units at 2 and 6 months after canal filling, respectively. The greatest degree of discoloration was seen at 6 months, reflecting a significant difference compared to other experimental groups.

Lee et al. measured and compared ΔL and ΔE over the course of 8 weeks after treatment with Endoseal MTA and ProRoot MTA, and reported a major increase in the ProRoot MTA group (Lee et al. 2016). However, Endoseal MTA showed no significant differences in either brightness or color change in comparison with the negative control group and the AH Plus group (Lee et al. 2016). Since Endoseal TCS was introduced to the market more recently, no previous studies have investigated tooth discoloration using Endoseal TCS.

According to the results of this study, both calcium silicate–based sealers resulted in significantly less discoloration than ProRoot WMTA. The main mechanism through which discoloration occurs after MTA cement use is the chemical interaction of bismuth oxide, which is added for radiopacity, with other substances with which it comes into contact (Asgary et al. 2005, Berger, Baratz, Gutmann 2014). Endoseal MTA instead uses zirconium oxide as a radiopacifier, with a reduced proportion of bismuth oxide. Recent studies have shown that less discoloration resulted from sealers using zirconium oxide as a radiopacifier (Kang et al. 2015, Yun et al. 2015). Endoseal TCS, which only uses zirconium oxide instead of bismuth oxide as a radiopacifier, also showed less discoloration than Endoseal MTA. In fact, Endoseal TCS showed no significant difference from the negative control group in ΔE or ΔL. In addition to the difference in the components of the radiopacifier, the difference in the original color of these sealers may also contribute to color changes in the tooth. Endoseal MTA has a grayish hue, while Endoseal TCS maintains a white hue after setting. ΔE should be at least 3.7 units in order for changes in color to be noticeable, according to Ioannidis et al. (Ioannidis et al. 2013a, Ioannidis et al. 2013c). Therefore, the ΔE values of Endoseal TCS were not significantly different from the corresponding values of the resin core group. It is also speculated that these color changes are not recognizable by the human eye until the fourth week.

Previous studies investigating the effects of sealer on tooth discoloration reported that the sealer remnants that caused tooth discoloration were left on the cervical or coronal dentin after canal obturation (Davis, Walton, Rivera 2002, Parsons, Walton, Ricks-

Williamson 2001, van der Burgt, Mullaney, Plasschaert 1986, van der Burgt, Plasschaert 1985). The design of this study divided specimens into a delayed core group and an immediate core group, depending on the time point of resin core placement after canal filling. The experiment was conducted to investigate whether the unset residual sealer remaining in the access cavity wall when the resin core was placed in the immediate core groups would affect tooth discoloration. Neither the ΔE nor ΔL values of the two sealers showed significant differences between the immediate core group and the delayed core group. This result was expected, in that the procedure was performed by an experienced third-year resident, meaning that there would not be much sealer remaining in the immediate core group. Therefore, because neither Endoseal MTA nor Endoseal TCS caused severe discoloration, the small amount of remnants did not have a significant impact. Based on the findings in this study, the resin core is recommended to be placed on the same day of canal filling in terms of tooth discoloration concerns.

The thickness of the buccal wall of the tooth after access opening was thought to be likely to affect tooth discoloration, but the Pearson correlation analysis showed no significant results ($p > 0.05$). Although it was expected that less residual buccal thickness would lead to faster and more severe discoloration, buccal thickness did not significantly affect the results of this study.

In the SEM images, the PC group using ProRoot WMTA did not show cement penetration into the dentinal tubules. However, both calcium silicate–based sealers were observed to penetrate into the dentinal tubules. Based on these observation, we speculated that the degree of penetration of filling materials into the dentinal tubules may not affect tooth discoloration.

In this study, each tooth was filled up to 4 mm above the CEJ. Usually, in root canal treatment, the sealer or root canal filling material is recommended to be removed at the orifice level in posterior teeth and adjusted to the subgingival line in anterior teeth. Instead, in this study, we filled the cement or sealer to 4 mm above the CEJ level (Ekici et al. 2019). This protocol is not the same as the general procedure, but it is supported by some reasons. First, by filling the coronal aspect with the cement or sealer, it was easy to detect and measure color changes. With regard to the possibility of observing color changes at 2 mm below the CEJ, the concern was raised that such an experiment would not include discoloration of the crown to the enamel layer, thereby presenting a problem for actual clinical practice. It was thought that if the vertical dimensional of the canal filling was too small, it would be possible for errors to occur in the color measurement process, so the choice was made to fill the cement or sealer up to 4 mm above the CEJ to ensure a sufficient range of measurement. Second, despite clinicians' caution, sealer can be placed above the CEJ, as has been found during retreatments.

A limitation of this study is that we did not include other types of sealers. It would have been better to compare the calcium silicate–based sealers with resin-based sealers that are widely used in clinical practice, such as AH Plus (Dentsply, Tulsa Dental, Tulsa, OK, USA), and calcium hydroxide–based sealers such as Sealapex (SybronEndo Corporation, Orange, CA, USA), Apexit, and Apexit Plus (Ivoclar Vivadent, AG, Schaan, Liechtenstein). In addition, it would have been preferable to investigate the EndoSequence BC Sealer (Brasseler, Savannah, GA, USA) or MTA Fillapex (Ângelus Indústria de Produtos Odontológicos Ltda; Londrina, Paraná, Brazil), which are bioceramic sealers that do not contain bismuth oxide. In earlier research on sealer-induced discoloration, Zare Jahromi et al. stated that AH-26 showed more tooth discoloration than a zinc oxide–eugenol (ZOE)-based sealer, and Meincke et al. reported that Sealer 26 (Dentsply) led to more teeth discoloration than AH Plus or a ZOE-based sealer (Meincke et al. 2013, Zare Jahromi, Navabi, Ekhtiari 2011). The considerable variety of sealer types corresponds to differences in the degree of discoloration; therefore, in further studies, comparing the discoloration caused by bioceramic sealers such as Endoseal TCS to that caused by sealers with various components will be more helpful for choosing a sealer to be used in anterior teeth, where discoloration is a major concern.

V. CONCLUSION

Within the limitations of this study, the results suggest the following:

1. Both Endoseal MTA and Endoseal TCS resulted in less discoloration than the original ProRoot WMTA.

2. Endoseal TCS demonstrated significantly less discoloration than Endoseal MTA due to differences in its composition.

3. No significant difference was found according to the timing of core restoration.

4. It is concluded that Endoseal TCS can be used as a sealer with minimal tooth discoloration.

References

Asawaworarit, W., Yachor, P., Kijsamanmith, K., Vongsavan, N. "Comparison of the Apical Sealing Ability of Calcium Silicate-Based Sealer and Resin-Based Sealer Using the Fluid-Filtration Technique." *Med Princ Pract* 25, no. 6 (2016): 561-5. doi:10.1159/000450577.

Asgary, S., Parirokh, M., Eghbal, M. J., Brink, F. "Chemical differences between white and gray mineral trioxide aggregate." *J Endod* 31, no. 2 (2005): 101-3. doi:10.1097/01.don.0000133156.85164.b2.

Berger, T., Baratz, A. Z., Gutmann, J. L. "In vitro investigations into the etiology of mineral trioxide tooth staining." *J Conserv Dent* 17, no. 6 (2014): 526-30. doi:10.4103/0972-0707.144584.

Camilleri, J., Pitt Ford, T. R. "Mineral trioxide aggregate: a review of the constituents and biological properties of the material." *Int Endod J* 39, no. 10 (2006): 747-54. doi:10.1111/j.1365-2591.2006.01135.x.

Davis, M. C., Walton, R. E., Rivera, E. M. "Sealer distribution in coronal dentin." *J Endod* 28, no. 6 (2002): 464-6. doi:10.1097/00004770-200206000-00012.

Ekici, M. A., Ekici, A., Kaskati, T., Helvacioglu Kivanc, B. "Tooth crown discoloration induced by endodontic sealers: a 3-year ex vivo evaluation." *Clin Oral Investig* 23, no. 5 (2019): 2097-102. doi:10.1007/s00784-018-2629-1.

Felman, D., Parashos, P. "Coronal tooth discoloration and white mineral trioxide aggregate." *J Endod* 39, no. 4 (2013): 484-7. doi:10.1016/j.joen.2012.11.053.

Hwang, J. H., Chung, J., Na, H. S., Park, E., Kwak, S., Kim, H. C. "Comparison of bacterial leakage resistance of various root canal filling materials and methods: Confocal laser-scanning microscope study." *Scanning* 37, no. 6 (2015): 422-8. doi:10.1002/sca.21231.

Ioannidis, K., Beltes, P., Lambrianidis, T., Kapagiannidis, D., Karagiannis, V. "Validation and spectrophotometric analysis of crown discoloration induced by root canal sealers." *Clin Oral Investig* 17, no. 6 (2013a): 1525-33. doi:10.1007/s00784-012-0850-x.

Ioannidis, K., Mistakidis, I., Beltes, P., Karagiannis, V. "Spectrophotometric analysis of coronal discolouration induced by grey and white MTA." *Int Endod J* 46, no. 2 (2013b): 137-44. doi:10.1111/j.1365-2591.2012.02098.x.

———. "Spectrophotometric analysis of crown discoloration induced by MTA- and ZnOE-based sealers." *J Appl Oral Sci* 21, no. 2 (2013c): 138-44. doi:10.1590/1678-7757201302254.

Jang, J. H., Kang, M., Ahn, S., Kim, S., Kim, W., Kim, Y., Kim, E. "Tooth discoloration after the use of new pozzolan cement (Endocem) and mineral trioxide aggregate and the effects of internal bleaching." *J Endod* 39, no. 12 (2013): 1598-602. doi:10.1016/j.joen.2013.08.035.

Joiner, A. "Tooth colour: a review of the literature." *J Dent* 32 Suppl 1 (2004): 3-12. doi:10.1016/j.jdent.2003.10.013.

Kang, S. H., Shin, Y. S., Lee, H. S., Kim, S. O., Shin, Y., Jung, I. Y., Song, J. S. "Color changes of teeth after treatment with various mineral trioxide aggregate-based materials: an ex vivo study." *J Endod* 41, no. 5 (2015): 737-41. doi:10.1016/j.joen.2015.01.019.

Krastl, G., Allgayer, N., Lenherr, P., Filippi, A., Taneja, P., Weiger, R. "Tooth discoloration induced by endodontic materials: a literature review." *Dent Traumatol* 29, no. 1 (2013): 2-7. doi:10.1111/j.1600-9657.2012.01141.x.

Lee, D. S., Lim, M. J., Choi, Y., Rosa, V., Hong, C. U., Min, K. S. "Tooth discoloration induced by a novel mineral trioxide aggregate-based root canal sealer." *Eur J Dent* 10, no. 3 (2016): 403-7. doi:10.4103/1305-7456.184165.

Lee, J. K., Kim, S., Lee, S., Kim, H. C., Kim, E. "In Vitro Comparison of Biocompatibility of Calcium Silicate-Based Root Canal Sealers." *Materials (Basel)* 12, no. 15 (2019). doi:10.3390/ma12152411.

Lim, E. S., Park, Y. B., Kwon, Y. S., Shon, W. J., Lee, K. W., Min, K. S. "Physical properties and biocompatibility of an injectable calcium-silicate-based root canal sealer: in vitro and in vivo study." *BMC Oral Health* 15, no. 1 (2015): 129. doi:10.1186/s12903-015-0112-9.

Marciano, M. A., Costa, R. M., Camilleri, J., Mondelli, R. F., Guimaraes, B. M., Duarte, M. A. "Assessment of color stability of white mineral trioxide aggregate angelus and bismuth oxide in contact with tooth structure." *J Endod* 40, no. 8 (2014):

1235-40. doi:10.1016/j.joen.2014.01.044.

Meincke, D. K., Prado, M., Gomes, B. P., Bona, A. D., Sousa, E. L. "Effect of endodontic sealers on tooth color." *J Dent* 41 Suppl 3 (2013): e93-6. doi:10.1016/j.jdent.2012.10.011.

Parirokh, M., Torabinejad, M. "Mineral trioxide aggregate: a comprehensive literature review--Part I: chemical, physical, and antibacterial properties." *J Endod* 36, no. 1 (2010a): 16-27. doi:10.1016/j.joen.2009.09.006.

———. "Mineral trioxide aggregate: a comprehensive literature review--Part III: Clinical applications, drawbacks, and mechanism of action." *J Endod* 36, no. 3 (2010b): 400-13. doi:10.1016/j.joen.2009.09.009.

Parsons, J. R., Walton, R. E., Ricks-Williamson, L. "In vitro longitudinal assessment of coronal discoloration from endodontic sealers." *J Endod* 27, no. 11 (2001): 699-702. doi:10.1097/00004770-200111000-00012.

Ramos, J. C., Palma, P. J., Nascimento, R., Caramelo, F., Messias, A., Vinagre, A., Santos, J. M. "1-year In Vitro Evaluation of Tooth Discoloration Induced by 2 Calcium Silicate-based Cements." *J Endod* 42, no. 9 (2016): 1403-7. doi:10.1016/j.joen.2016.06.012.

Sarkar, N. K., Caicedo, R., Ritwik, P., Moiseyeva, R., Kawashima, I. "Physicochemical basis of the biologic properties of mineral trioxide aggregate." *J Endod* 31, no. 2 (2005): 97-100. doi:10.1097/01.don.0000133155.04468.41.

Seo, D. G., Lee, D., Kim, Y. M., Song, D., Kim, S. Y. "Biocompatibility and Mineralization Activity of Three Calcium Silicate-Based Root Canal Sealers Compared to Conventional Resin-Based Sealer in Human Dental Pulp Stem Cells." *Materials (Basel)* 12, no. 15 (2019). doi:10.3390/ma12152482.

Steffen, R., van Waes, H. "Understanding mineral trioxide aggregate/Portland-cement: a review of literature and background factors." *Eur Arch Paediatr Dent* 10, no. 2 (2009): 93-7. doi:10.1007/bf03321608.

Thomson, A. D., Athanassiadis, B., Kahler, B., Walsh, L. "Tooth discolouration: staining effects of various sealers and medicaments." *Aust Endod J* 38, no. 1 (2012): 2-9. doi:10.1111/j.1747-4477.2011.00339.x.

Torabinejad, M., Hong, C. U., Lee, S. J., Monsef, M., Pitt Ford, T. R. "Investigation of mineral trioxide aggregate for root-end filling in dogs." *J Endod* 21, no. 12 (1995): 603-8. doi:10.1016/S0099-2399(06)81112-X.

Torabinejad, M., Parirokh, M. "Mineral trioxide aggregate: a comprehensive literature review--part II: leakage and biocompatibility investigations." *J Endod* 36, no. 2 (2010): 190-202. doi:10.1016/j.joen.2009.09.010.

Valles, M., Mercade, M., Duran-Sindreu, F., Bourdelande, J. L., Roig, M. "Influence of light and oxygen on the color stability of five calcium silicate-based materials." *J Endod* 39, no. 4 (2013): 525-8. doi:10.1016/j.joen.2012.12.021.

Valles, M., Roig, M., Duran-Sindreu, F., Martinez, S., Mercade, M. "Color Stability of Teeth Restored with Biodentine: A 6-month In Vitro Study." *J Endod* 41, no. 7 (2015): 1157-60. doi:10.1016/j.joen.2015.03.014.

van der Burgt, T. P., Mullaney, T. P., Plasschaert, A. J. "Tooth discoloration induced by endodontic sealers." *Oral Surg Oral Med Oral Pathol* 61, no. 1 (1986): 84-9. doi:10.1016/0030-4220(86)90208-2.

van der Burgt, T. P., Plasschaert, A. J. "Tooth discoloration induced by dental materials." *Oral Surg Oral Med Oral Pathol* 60, no. 6 (1985): 666-9. doi:10.1016/0030-4220(85)90373-1.

Vitti, R. P., Prati, C., Silva, E. J., Sinhoreti, M. A., Zanchi, C. H., de Souza e Silva, M. G., Ogliari, F. A., Piva, E., Gandolfi, M. G. "Physical properties of MTA Fillapex sealer." *J Endod* 39, no. 7 (2013): 915-8. doi:10.1016/j.joen.2013.04.015.

Yun, D. A., Park, S. J., Lee, S. R., Min, K. S. "Tooth discoloration induced by calcium-silicate-based pulp-capping materials." *Eur J Dent* 9, no. 2 (2015): 165-70. doi:10.4103/1305-7456.156789.

Zare Jahromi, M., Navabi, A. A., Ekhtiari, M. "Comparing Coronal Discoloration Between AH26 and ZOE Sealers." *Iran Endod J* 6, no. 4 (2011): 146-9.

Abstract (IN KOREAN)

두 가지 다른 규산 칼슘계 실러에 의한 치아 변색 평가

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(지도교수 신 수 정)

본 연구는 새로 개발된 규산 칼슘계 실러에 의해 발생되는 치아 변색의 정도를 mineral trioxide aggregate(MTA)와 비교하여 평가하는 것을 목적으로 한다.

52 개의 사람의 소구치를 백악법랑경계부의 하방 2 mm 에서 절단하였으며, 각 치아는 아래와 같이 실러의 종류와 코어 시기에 따라 6개의 그룹으로 나누었다. (1) 양성 대조군: ProRoot WMTA (Dentsply, Tulsa, OK, USA) + 즉

시 코어; (2) 음성 대조군: 복합레진 충전; (3) Endoseal MTA (Maruchi, Wonju, Korea) + 즉시 코어; (4) Endoseal MTA + 지연 코어; (5) Endoseal TCS (Maruchi) + 즉시 코어, 그리고 (6) Endoseal TCS + 지연 코어. 교합면에서 근관 와동을 형성한 후 백악법랑경계부 상방 1 mm의 중앙부의 협측 치질 두께를 측정한다. 실러와 MTA는 백악법랑경계부 상방 4mm까지 충전한 후 즉시 코어 그룹은 충전재의 초기경화 이후 잔여 근관 충전재를 제거한 뒤 복합레진 (Filtek Z350 XT; 3M ESPE, St. Paul, MN, USA) 과 상아질 접착제 (Adper Single Bond 2; 3M ESPE) 를 이용하여 와동을 충전한다. 지연 코어 그룹은 충전 후 1주일 보관한 뒤 현미경을 이용하여 잔여 근관 충전재를 제거한 뒤 복합 레진을 이용하여 와동을 충전한다. 시편들은 37° C, 100% 상대습도 환경에서 보관한다. 시편의 상은 분광광도계 Spectroshade; MHT) 를 이용하여 와동 형성 전, 충전 1, 2, 4, 8, 그리고 24주 후 측정한다.

색조와 명도는 충전 재료에 따라 유의한 차이를 보였다. ProRoot WMTA는 다른 재료에 비해 유의하게 높은 변색을 보였고 ($p < 0.05$), Endoseal MTA 그룹은 복합 레진 그룹에 비해 유의하게 더 많은 변색을 보였다 ($p < 0.05$). 반면 Endoseal TCS 그룹은 복합 레진 그룹과 비교했을 때 지연 코어 그룹의 명도변화량을 제외 하고는 유의한 차이를 보이지 않았다 ($p > 0.05$).

Endoseal TCS는 Endoseal MTA와 비교하였을 때 유의하게 낮은 변색을 보

였다. 이 연구에 한계가 있지만, Endoseal TCS는 치아에 매우 적은 변색을 유발하는 재료라고 볼 수 있다.

핵심되는 말 : 치아 변색, 분광광도계, 규산 칼슘계 실러, Endoseal MTA, Endoseal TCS