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Original Article

Tooth discoloration and the effects of internal bleaching on the novel endodontic filling material SavDen® MTA

Wan-Chun Yang [a,b,1], Liang-Yi Tsai [b,1], Yung-Hao Hsu [a,b], Nai-Chia Teng [a], Jen-Chang Yang [c], Sung-Chih Hsieh [a,b,*]

[a] *School of Dentistry, College of Oral Medicine, Taipei Medical University, Taipei, Taiwan*
[b] *Dental Department of Wan-Fang Hospital, Taipei Medical University, Taipei, Taiwan*
[c] *Graduate Institute of Nanomedicine and Medical Engineering, College of Biomedical Engineering, Taipei Medical University, Taipei, Taiwan*

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Background/Purpose: Mineral trioxide aggregate (MTA) was widely used in endodontic therapy as bioceramic material. Although MTA has high biocompatibility, it may lead to tooth discoloration. The aim of this study was to investigate the discoloration of two different bioceramic materials and the effects of internal bleaching.
Methods: Thirty single-canal mandibular premolars were extracted and randomly assigned to three groups (n = 10), white ProRoot® MTA, SavDen® MTA and a control group. Endodontic access opening, cleaning and shaping were performed, then the teeth were obturated using the two bioceramic materials. Tooth color was recorded at baseline, day 1, and 1, 2, 4, 6, 8, 12, 16, and 24 weeks after treatment. At the end of 24 weeks, sodium perborate was used to perform internal bleaching. Tooth color was recorded at 1, 2, and 6 weeks subsequently. Teeth were measured using a DeguDent® spectrophotometer, and data were transformed into Commission Internationale de l'Eclairage (CIE) $L^*a^*b^*$ system.
Results: Teeth treated with white ProRoot® MTA showed significant color change and decrease in L^* value. Internal bleaching leaded to decrease of the ΔE^* value for all three groups and increase in the L^* value. There was no difference in tooth discoloration between SavDen® MTA and the control group after obturation and internal bleaching.
Conclusion: In terms of visual perception, white ProRoot® MTA tends to cause black and blue discoloration. SavDen® MTA, formulated with calcium lactate gluconate, could be used to reduce tooth discoloration in endodontic treatment.

* Corresponding author. School of Dentistry, College of Oral Medicine, Taipei Medical University, 250 Wu-Hsing Street, Taipei, 11031, Taiwan.
E-mail address: endo@tmu.edu.tw (S.-C. Hsieh).
[1] These two authors contributed equally.

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Introduction

Bioceramic material has been widely used in endodontic treatment due to its excellent biocompatibility. ProRoot® MTA (Dentsply Tulsa Dental, Tulsa, OK, USA) was first developed in 1993 and has since been recommended for pulp capping, apexification, perforation repair, and root-end filling. However, MTA's disadvantages include tooth discoloration, a long setting time and poor handling properties.[1–3]

SavDen® MTA (YDS, Taiwan), modified from ProRoot® MTA, was developed from Taipei Medical University in 2012. SavDen® MTA is composed of Portland cement, bismuth oxide as radiopacifier, and 23.1wt% calcium lactate gluconate (CLG). The addition of CLG shortened the setting time to 12.3 ± 2.5 min and improved the handling properties.[4] SavDen® MTA was approved by the US Food and Drug Administration (FDA) in 2017.

For discolored teeth, internal bleaching and crown fabrication can be performed to improve esthetic appearance.[5,6] Internal bleaching is a practical treatment for endodontically treated teeth and could help lighten the discoloration.[7] As a bleaching agent, sodium perborate was proved to inhibit macrophage adhesion, and it may also decrease the chance of external cervical root resorption.[8]

We investigated the discoloration of the teeth after compacting with white ProRoot® MTA and SavDen® MTA containing bismuth oxide, and further compared the improvement in discoloration after internal bleaching.

Materials and methods

Tooth preparation

The present study was approved by the Joint Institutional Review Board (N201805095), Taipei Medical University, Taipei, Taiwan. Teeth used in this study included 30 single-canal mandibular premolars, which had been extracted for periodontal and orthodontic treatment. These teeth were free from decay, restoration, and fracture lines, confirmed under the microscope (Carl Zeiss Microscopy GmbH, Jena, Germany) at 13.6× magnification. The calculus and stain on the surface of each tooth were removed using an ultrasonic scaler, and the teeth were polished with an abrasive paste and brush. Teeth were then randomly assigned into 3 groups (n = 10): group 1: white ProRoot® MTA, group 2: SavDen® MTA and group 3: control group.

Teeth in each of the three groups were endodontically opened from the occlusal surface. The canals were cleaned and shaped with an F5 (50/.05) Protaper® hand file (Dentsply Maillefer, Ballaigues, Switzerland) and were irrigated with 12 mL of 3% sodium hypochlorite solution followed by distilled water. After drying the canals, teeth in the two experimental groups were then filled orthogradely and compacted incrementally with bioceramic materials mixed according to the manufacturers' instructions. Teeth were filled from the apex to 4 mm below the lowest point of the occlusal surface. There was no filling material was obturated in the control group. The coronal seal was not done in order not to affect the color change.

Internal bleaching was performed 24 weeks after obturation of bioceramic materials in the white ProRoot® MTA, SavDen® MTA and control group. Sodium perborate powder was mixed with distilled water in a ratio of 2:1 (g/mL)[9] and compacted into the 4 mm coronal space once weekly. After 2 weeks of application, the bleaching agent was rinsed out with normal saline and the teeth were kept for the following 4 weeks. In the end of the experiment, the teeth were horizontal dissected from the cervical portion of the crown.

During the experimental period, all samples were packed in wet gauze with normal saline solution and stored at 37 ± 1 °C with 100% relative humidity in an incubator.

Tooth shade assessment

A spectrophotometer (Degudent Shadepilot, DeguDent GmbH, Hanau-Wolfgang, Germany) was operated by the same investigator under a constant laboratory condition of darkness. The apical portion of each tooth was fixed within Silagum silicone impression material (DMG, Hamburg, Germany) during the setting procedure to make individual specimen carriers, thus making the specimen 3 mm away and parallel to the spectrophotometer plane of measurement. The same carrier was used for all measurements during the experiment to stabilize the position between the tooth and the spectrophotometer. Before measuring each specimen, the normal saline solution on the tooth surface was removed, and the spectrophotometer was calibrated. The color value was measured on the crown portion of the cervical buccal surface which was below the obturation of bioceramic material. For tooth discoloration period, the shade of each specimen was spectrophotometrically measured 3 times and averaged at 10 time points: after cleaning and shaping, 1 day after bioceramic material obturation, and at 1, 2, 4, 6, 8, 12, 16, 24 weeks following obturation. For internal bleaching, the measurements were performed at 3 time points: 1, 2, and 6 weeks after bleaching procedure was initiated.

For a visual record, the teeth were photographed using a digital camera (Canon 650D; Canon, Tokyo, Japan) with a polarizing filter at each measurement point. The laboratory light environment was stabilized using two dimmable LED lighting devices. The distance and angulation between the tooth and camera were standardized using Zetalabor silicone impression material (Zhermack, Badia Polesine, Italy) covered with matt black paint and acrylic resin mold.

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The color measurements were recorded using the Commission Internationale de l'Eclairage (CIE $L^*a^*b^*$) system. The total color difference (ΔE^*) was calculated by the formula: $\Delta E^*_{ab} = [(\Delta L^*)^2 + (\Delta a^*)^2 + (\Delta b^*)^2]^{1/2}$.[10] The value of L^* is the lightness from black to white, and the values of a^* and b^* are the red-green axis and the yellow-blue axis of the chromaticity parameter, respectively. ΔE^* describes the color difference between the initial time point (after cleaning and shaping) and each subsequent time point measurement after obturation and internal bleaching. If ΔE^* exceeds 3.3 units, which means the color could be differentiated with naked eyes.[11]

Statistical analysis

The data were evaluated using SAS Institute software 9.4 (Cary, CA, USA). Data are presented as mean of ΔE^* values with standard error (SE). The results were analyzed with one-way repeated measures ANOVA and Scheffe's test. Statistical significance is defined as $p < 0.05$.

Results

ΔE^* values

The ΔE^* value for group 1−3 for all time intervals are presented in Fig. 1. Teeth with white ProRoot® MTA and SavDen® MTA exceeded perceptibility threshold (ΔE^* 3.3 units) in week 1 and week 2, respectively. White ProRoot® MTA showed an increase in discoloration of ΔE^* value during the experimental period and was stable at week 12, whereas SavDen® MTA showed a stable ΔE^* value since week 2. The ΔE^* values at week 24 were 9.15 ± 1.05 for white ProRoot® MTA, 4.92 ± 0.48 for SavDen® MTA, and 3.18 ± 0.43 for the control group.

After internal bleaching, ΔE^* values decreased, with the most obvious change in bleaching effect within week 1. When time just after cleaning and shaping is used as the reference point for comparison with bleaching treatment, the ΔE^* value of SavDen® MTA dropped to 3.55 ± 0.51, whereas the ΔE^* value of white ProRoot® MTA dropped to 7.90 ± 1.01 in the end. However, when compared with week 24, the ΔE^* values of all the experimental groups were lower than threshold. The ΔE^* value on week 6 for white ProRoot® MTA was 1.30 ± 0.13, for SavDen® MTA was 1.77 ± 0.18, and for the control group was 1.61 ± 0.26.

ANOVA showed significant differences between white ProRoot® MTA and the remaining two groups after bioceramic obturation and internal bleaching.

$L^*a^*b^*$ parameter

The mean values of the ΔL^*, Δa^*, and Δb^* parameters with standard error (SE) for group 1−3 for all time intervals are presented in Fig. 2. According to the previous study, human's eyes can differentiate ΔL^*, Δa^*, and Δb^* exceeding 1, 1, 2.6 units.[12] During the 24 weeks, the L^* value decreased in the three groups. White ProRoot® MTA and SavDen® MTA had significant reductions in the first week. White ProRoot® MTA showed a steady decrease during the experimental period. The a^* value decreased in the white ProRoot® MTA group but increased in the SavDen® MTA and control groups. The b^* value decreased in white ProRoot® MTA group, increased in SavDen® MTA and control groups.

During the bleaching period, the L^* value increased, and a^* value decreased in the three groups. The b^* value decreased in the white ProRoot® MTA and the control groups, but remained stable in the SavDen® MTA group.

Discussion

White ProRoot® MTA showed the most significant discoloration starting at the first week of application. With regard to the reduction of L^*, a^*, and b^* values in the white ProRoot® MTA group during the 24 weeks after obturation, the descriptive analysis indicates a tendency toward black, green and blue respectively, in terms of visual perception. Among the parameters, the L^* value changed the most, and the a^* value changed the least.[13] By week 12, the discoloration caused by white ProRoot® MTA stabilized, which corresponds to the release of bioceramic material stimulating mineral deposition in the cement−dentin interface and in the interior of the dentinal tubules within 90 days period.[14] The SavDen® MTA group in the descriptive analysis indicated a tendency toward black, red, and yellow in terms of visual perception, and the discoloration caused by SavDen® MTA stabilized at week 2. The control group, which had only cleaning and shaping, had primarily increased b^* values and secondarily decreased L^* values. Visually, the control group displayed a main tendency toward yellow in discoloration.

According to the previous study, to treat the discolored teeth after the obturation of MTA would need to remove the discolored MTA material in the material−dentin junction with ultrasonic tip or high-speed bur first then with internal bleaching procedure.[7,15] Removing the discolored MTA materials contributed more to improving tooth discoloration than posttreatment bleaching. In other words, a noticeable esthetic improvement could be seen immediately after the removal of discolored material.

In our study, the application of sodium perborate in the control group resulted in increases in L^* and reductions in a^* and b^* values, indicating the visual perception tendency toward white, green, and blue. The bleaching effect of the control group corresponded with the results of a previous study on bleaching with hydrogen peroxide and carbamide peroxide.[10] Also, internal bleaching consistently increased the L^* value in the three experimental groups. The increase in the L^* value caused by internal bleaching compensated for the decrease in the L^* value in the SavDen® MTA group in the previous 24 weeks, thus SavDen® MTA had the lowest ΔE^* value after the bleaching procedure. When the reference point was at week 24, white ProRoot® MTA had a final ΔE^* value of 1.30 ± 0.13, and the ΔL^* was $+1.17 \pm 0.14$. The tendency toward color white could be visually identified, but the overall improvement was not clinically obvious. Based on previous research, white ProRoot® MTA in the canal results in a dark grayish dentinal staining through dentinal tubules.[13,16] There was severe staining in the dentinal walls even

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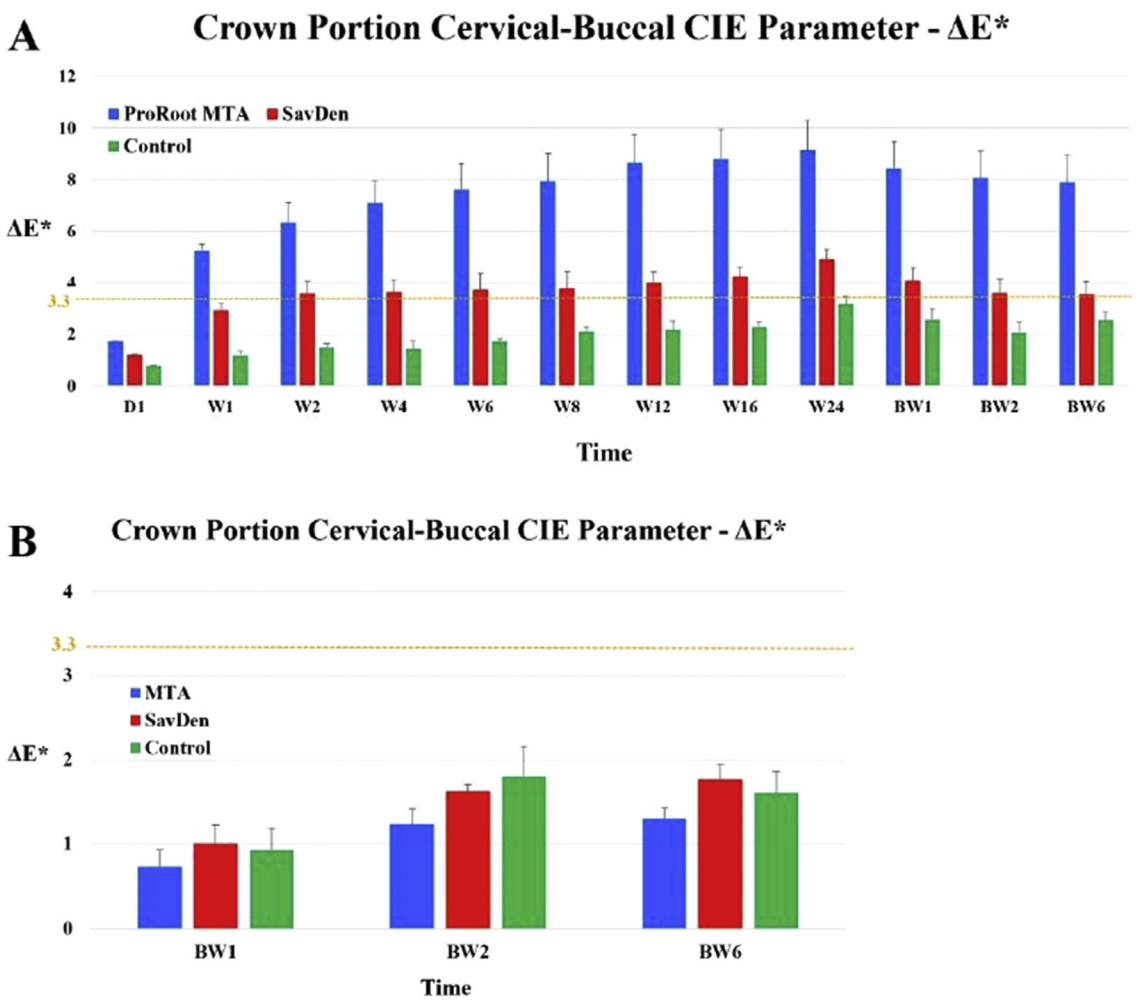

Figure 1 Mean of ΔE* value with standard error (SE) changes at each time interval. Abbreviate day as D, week as W and bleaching as B. For example, W2 means 2 weeks after obturation. BW2 means 2 weeks after bleaching treatment. (A) ΔE* was calculated with the time point as "after cleaning and shaping". (B) ΔE* was calculated with the time point as "24 weeks after Obturation".

after the removal of MTA. In our study, the black substance in the transverse section of the tooth after internal bleaching was thinner than that of the tooth without bleaching (Fig. 3). Removing the discolored MTA and tooth structure after bleaching therapy can minimize the amount of preparation.

White ProRoot® MTA and SavDen® MTA have the same bismuth oxide composition, however they are prone to different changes after material placement and internal bleaching. The L^* value in the experimental period showed a similar tendency for both white ProRoot® MTA and SavDen® MTA, and the only difference was that the magnitude of the decline was lower in the SavDen® MTA group. In the white ProRoot® MTA group, a^* value decreased in the 24 weeks. On the contrary, the SavDen® MTA group showed an increase. The b^* value in the white ProRoot® MTA group remained stable in week 4, but the b^* value of the SavDen® MTA group dropped within week 1 and then rose to the level of the control group at week 24. During the 24 weeks after material placement, white ProRoot® MTA and SavDen® MTA group showed quite an opposite change in a^* and b^* value. For the six weeks of bleaching effect, the b^* value in the white ProRoot® MTA group showed a decrease, whereas that of the SavDen® MTA group remained stable. These results demonstrate that bismuth oxide is not the only factor to affect the tooth discoloration.

Previous theory of the tooth discoloration included oxidation of metal oxides, such as aluminum oxide (Al_2O_3) and ferric oxide (Fe_2O_3).[17] Nowadays, bismuth oxide is believed to be the reason for the discoloration, but the mechanism is still unclear. Bismuth oxide may react with sodium hypochlorite, amino acids in collagen, carbon dioxide in the air, or the blood in the dentinal tubules, and the oxygen and lighting condition is also a concern.[18–24] Sodium hypochlorite (NaOCl), an irrigant used in endodontic therapy, can penetrate into dentin to a depth of 77–300 μm and is difficult to remove from root canals.[25] Blood could lead to discoloration by the accumulation of hemoglobin and hematin molecules.[26] Under curing light and anaerobic condition, the products containing bismuth oxide will exhibit dark discoloration.[23] Bismuth oxide may eventually result in metallic bismuth or bismuth carbonate.[21,23] To counter the effect of tooth discoloration, final irrigation with water or application of two layers of dentin bonding agent before obturation are recommended.[27,28]

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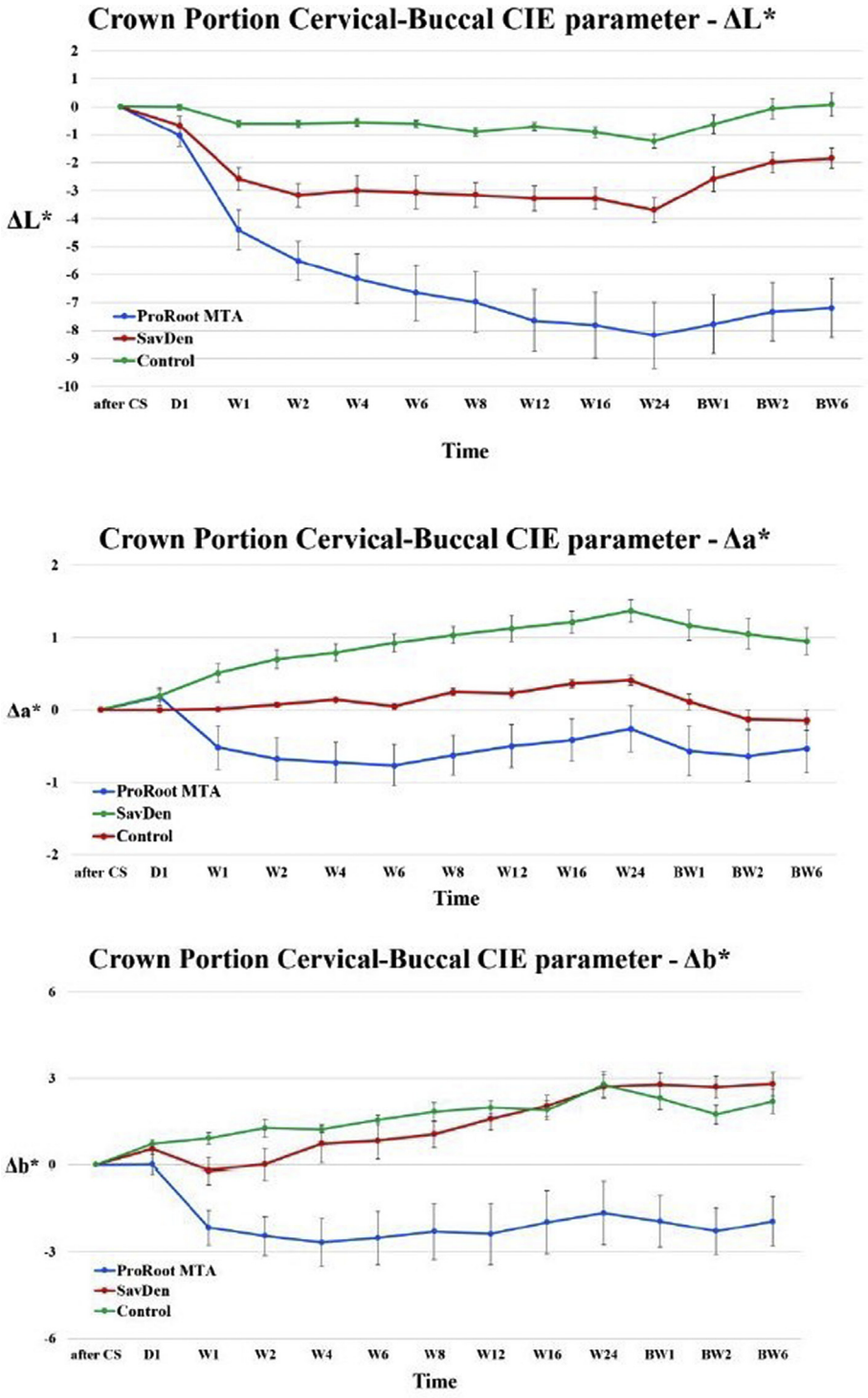

Figure 2 Mean values with standard error (SE) of Commission Internationale de l'Eclairage (CIE) change in the ΔL*, Δa* and Δb* chromatic parameters. Abbreviate day as D, week as W and bleaching as B. For example, W2 means 2 weeks after obturation. BW2 means 2 weeks after bleaching treatment.

According to the previous study, the discoloration of white ProRoot® MTA would lead to a thick stained tooth structure. However, in our study, the horizontal section of white ProRoot® MTA after bleaching revealed a thin layer of black substance and a relatively thicker layer of white substance in the outer area (Fig. 3). Under the action of sodium perborate, it may represent that the two layers may have different compositions form the grayish product. Reaction with sodium perborate can act on the outer black substance and turn into white product, but not the inner portion. In the SavDen® MTA group, the same white substance was observed on the outer area, but the black

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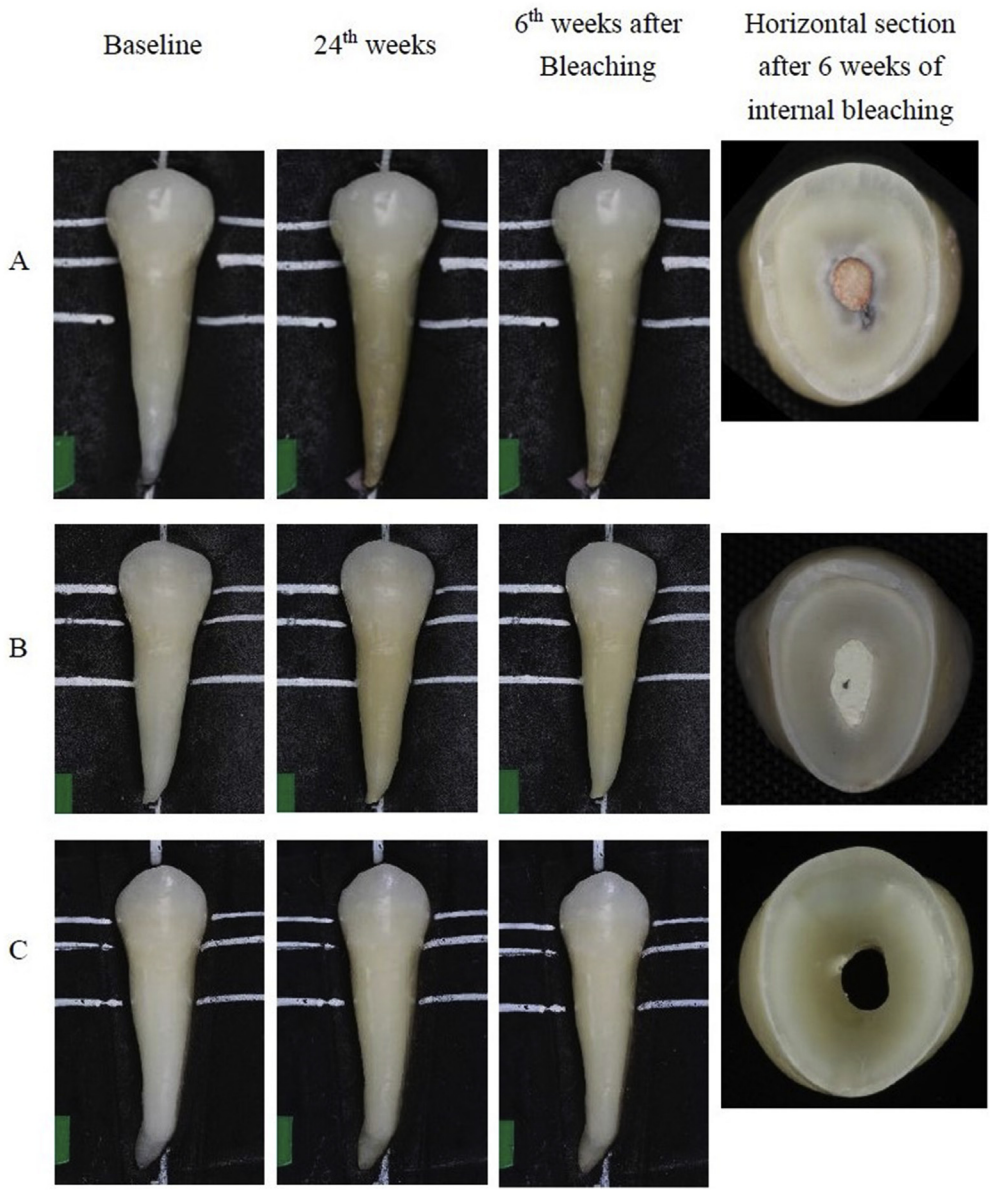

Figure 3 Photographs in each time interval of each group. (A) ProRoot® MTA, (B) SavDen® MTA, (C) control group.

layer was not present. The chemical ingredient of SavDen® MTA is almost the same as that of white ProRoot® MTA; the only difference is the addition of calcium lactate gluconate (CLG). CLG is characterized by high solubility in water (400 g/L water). It was speculated that when SavDen® MTA was applied into root canal, CLG may react first with moisture that contains sodium hypochlorite, so the discoloration was less prominent than white ProRoot® MTA. In other words, the black material in the inner layer may be the product of the reaction by bismuth oxide and sodium hypochlorite. Further research is needed to clarify the mechanism of tooth discoloration. In clinical application, SavDen® MTA had a reduced degree of tooth discoloration. Even after internal bleaching treatment for esthetic consideration, lesser staining composition would need to be removed and more tooth structure could be preserved.

Declaration of Competing Interest

The authors, Sung-Chih Hsieh, Nai-Chia Teng and Jen-Chang Yang are the inventors of the SavDen® MTA.

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References

1. Parirokh M, Torabinejad M. Mineral trioxide aggregate (MTA). A comprehensive literature review—part I: chemical, physical & antibacterial properties. *J Endod* 2010;**36**:16—27.

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2. Torabinejad M, Parirokh M. Mineral trioxide aggregate: a comprehensive literature review—part II: leakage and biocompatibility investigations. *J Endod* 2010;**36**:190–202.
3. Parirokh M, Torabinejad M. Mineral trioxide aggregate: a comprehensive literature review—part III: clinical applications, drawbacks, and mechanism of action. *J Endod* 2010;**36**:400–13.
4. Hsieh SC, Teng NC, Lin YC, Lee PY, Ji DY, Chen CC, et al. A novel accelerator for improving the handling properties of dental filling materials. *J Endod* 2009;**35**:1292–5.
5. Ahmed HM, Abbott PV. Discolouration potential of endodontic procedures and materials: a review. *Int Endod J* 2012;**45**:883–97.
6. Kaneko J, Inoue S, Kawakami S, Sano H. Bleaching effect of sodium percarbonate on discolored pulpless teeth in vitro. *J Endod* 2000;**26**:25–8.
7. Belobrov I, Parashos P. Treatment of tooth discoloration after the use of white mineral trioxide aggregate. *J Endod* 2011;**37**:1017–20.
8. Jiménez-Rubio A, Segura JJ. The effect of the bleaching agent sodium perborate on macrophage adhesion in vitro: implications in external cervical root resorption. *J Endod* 1998;**24**:229–32.
9. Valera MC, Camargo CH, Carvalho CA, de Oliveira LD, Camargo SE, Rodrigues CM. Effectiveness of carbamide peroxide and sodium perborate in non-vital discolored teeth. *J Appl Oral Sci* 2009;**7**:254–61.
10. da Costa JB, McPharlin R, Paravina RD, Ferracane JL. Comparison of at-home and in-office tooth whitening using a novel shade guide. *Operat Dent* 2010;**35**:381–8.
11. Ruyter IE, Nilner K, Moller B. Color stability of dental composite resin materials for crown and bridge veneers. *Dent Mater* 1987;**3**:246–51.
12. Lindsey DT, Wee AG. Perceptibility and acceptability of CIELAB color differences in computer-simulated teeth. *J Dent* 2007;**35**:593–9.
13. Ioannidis K, Mistakidis I, Beltes P, Karagiannis V. Spectrophotometric analysis of coronal discolouration induced by grey and white MTA. *Int Endod J* 2013;**46**:137–44.
14. Dreger LA, Felippe WT, Reyes-Carmona JF, Felippe GS, Bortoluzzi EA, Felippe MC. Mineral trioxide aggregate and portland cement promote biomineralization in vivo. *J Endod* 2012;**38**:324–9.
15. Jang JH, Kang M, Ahn S, Kim S, Kim W, Kim Y, et al. Tooth discoloration after the use of new pozzolan cement (Endocem) and mineral trioxide aggregate and the effects of internal bleaching. *J Endod* 2013;**39**:1598–602.
16. Alsubait S, Al-Haidar S, Al-Sharyan N. A comparison of the discoloration potential for EndoSequence bioceramic root repair material fast set putty and ProRoot MTA in human teeth: an in vitro study. *J Esthetic Restor Dent* 2017;**29**:59–67.
17. Asgary S, Parirokh M, Eghbal MJ, Brink F. Chemical differences between white and gray mineral trioxide aggregate. *J Endod* 2005;**31**:101–3.
18. Marciano MA, Duarte MA, Camilleri J. Dental discoloration caused by bismuth oxide in MTA in the presence of sodium hypochlorite. *Clin Oral Invest* 2015;**19**:2201–9.
19. Keskin C, Demiryurek EO, Ozyurek T. Color stabilities of calcium silicate-based materials in contact with different irrigation solutions. *J Endod* 2015;**41**:409–11.
20. Marciano MA, Costa RM, Camilleri J, Mondelli RF, Guimarães BM, Duarte MA. Assessment of color stability of white mineral trioxide aggregate angelus and bismuth oxide in contact with tooth structure. *J Endod* 2014;**40**:1235–40.
21. Kang SH, Shin YS, Lee HS, Kim SO, Shin Y, Jung IY, et al. Color changes of teeth after treatment with various mineral trioxide aggregate-based materials: an ex vivo study. *J Endod* 2015;**41**:737–41.
22. Felman D, Parashos P. Coronal tooth discoloration and white mineral trioxide aggregate. *J Endod* 2013;**39**:484–7.
23. Vallés M, Mercadé M, Duran-Sindreu F, Bourdelande JL, Roig M. Influence of light and oxygen on the color stability of five calcium silicate–based materials. *J Endod* 2013;**39**:525–8.
24. Sanz O, Haro-Poniatowski E, Gonzalo J, Navarro JF. Influence of the melting conditions of heavy metal oxide glasses containing bismuth oxide on their optical absorption. *J Non-Cryst Solids* 2006;**352**:761–8.
25. Zou L, Shen Y, Li W, Haapasalo M. Penetration of sodium hypochlorite into dentin. *J Endod* 2010;**36**:793–6.
26. Marin PD, Heithersay GS, Bridges TE. A quantitative comparison of traditional and non-peroxide bleaching agents. *Endod Dent Traumatol* 1998;**14**:64–7.
27. Voveraityte V, Gleizniene S, Lodiene G, Grabliauskiene Z, Machiulskiene V. Spectrophotometric analysis of tooth discolouration induced by mineral trioxide aggregate after final irrigation with sodium hypochlorite: an in vitro study. *Aust Endod J* 2017;**43**:11–5.
28. Akbari M, Rouhani A, Samiee S, Jafarzadeh H. Effect of dentin bonding agent on the prevention of tooth discoloration produced by mineral trioxide aggregate. *Int J Dent* 2012:563203.

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