Quantifying Coronal Permanent Tooth Discoloration Caused by Different Pulpotomy Materials

Hanaa Azem*/ Sigalit Blumer **/ Benjamin Peretz ***/Sohad Haj-Yahya ****/ Shlomo Elbahary *****

Introduction: *Bioceramic materials, gray and white mineral trioxide aggregate (GMTA, WMTA), have been shown to have high rates of success in various endodontic applications. A major drawback is their tendency to discolor teeth compared to Biodentine (BD), that has been claimed not to discolor teeth. The aim of this study was to compare tooth discoloration after applying different pulpotomy base materials (BD, GMTA and WMTA).* ***Study design***: *Forty human incisors teeth were used in this study. Coronal access was achieved by a Tungsten Carbide drill, and the pulp chambers were accessed and chemo-mechanically debrided. Each material was placed in the pulp chamber, up to the cervical sectioning level. All specimens were incubated at 37°C and 100% humidity for three months and have been evaluated before the study and weekly. Color was assessed according to the CIE L*a*b* color space system.* ***Results***: *ΔE of all experimental groups (GMTA, WMTA and BD) were significantly different from the control group at all time points (P<0.05). Color changes in the GMTA and WMTA groups, had no statistically significant differences, but showed higher discoloration compared to BD group in the cervical part of the crown, since week 1 (P<0.05). WMTA group showed significant discoloration in the cervical part as of week 1 (P<0.05), and gradually increased over time (Figure 2). BD group showed no significantly discoloration over time. GMTA group showed the significant discoloration at week 1 and week 14 (P<0.05).* ***Conclusions***: *both GMTA and WMTA pulpotomy materials may discolor tooth structure over time in an extracted permanent anterior tooth model. When choosing bioceramic pulpotomy material, BD may be preferable in esthetic area.*

Keywords: *Biodentine, Discoloration, Pulputomy, Mineral Trioxide Aggregate, Pro Root*

INTRODUCTION

Pulpotomy is a procedure for treating immature permanent teeth in order to achieve apexogenesis[1], in this procedure the partial or coronal pulp tissue is removed to eliminate the infected or contaminated pulp and to reach the healthy vital pulp. Several treatment options are available for pulp exposure in traumatized teeth, including pulpotomy, root canal treatment, or extraction. The vitality of the tissue and the time elapsed since the injury dictates the treatment of choice. If the pulp tissue is vital, a cervical pulpotomy has been recommended[2]. Cvek[3] advocated using a partial pulpotomy that involved the excision of 1–2 mm of the pulp tissue adjacent to the exposure site resulting in the removal of the infected pulp. The healthy tissue is covered with a wound dressing agent to promote healing at the amputation site and promote the survival of the underlying pulp tissue[1].

The ideal pulpotomy medicament would be bactericidal, biocompatible, promote the healing of the root pulp, and be compatible with the physiological process of root resorption[1]. Such a medicament or technique with all of those features remains unavailable. Given the lack of clear evidence supporting the superiority of any particular treatment method[4], research has continued to seek alternative

From the Maurice and Gabriela Goldschleger School of Dental Medicine, Tel Aviv University, Tel Aviv, Israel
*Hanaa Azem,, DMD, Department of Pediatric dentistry.
**Sigalit Blumer DMD, Department of Pediatric dentistry.
***Benjamin Peretz, DMD, Department of Pediatric dentistry.
**** Sohad Haj-Yahya, DMD, Department of Endodontology.
***** Shlomo Elbahary, DMD, Department of Endodontology.
School of Dental Medicine, Tel Aviv University, Tel Aviv, Israel.

Corresponding author:
Hanaa Azem
Maurice and Gabriela Goldschleger School of Dental Medicine, Tel Aviv University, Tel Aviv, Israel
E-mail: hanaaazemsh@gmail.com)

pulpotomy agents that can provide better clinical efficacy without secondary effects.

Tooth discoloration induced by endodontic materials is a common finding and may impair the esthetic outcome of endodontically treated teeth[5]. A major etiological factor for the occurrence of local intrinsic staining, especially in the cervical and middle thirds of the crown, is the presence of root canal filling materials in contact with the coronal dentin of the pulp chamber. Any change to the optical and chromatic properties of the dentinal structure is likely to cause an alteration in the outward appear-ance of the crown caused by its light transmitting and reflecting properties[6]. Mineral trioxide aggregate (MTA) is a biomaterial that has been investigated for endodontic applications since the early 1990s. MTA materials are derived from a Portland cement parent compound; It is a bioactive silicate, contain-ing hydrophilic particles, such as tricalcium silicate, tricalcium aluminate, dicalcium silicate, tricalcium oxide, bismuth and iron[7]. MTA has demonstrated its biocompatible ability to form hydroxyapatite when exposed to physiologic solutions and may provide better microleakage pro-tection[8]. In both animal and human studies, MTA materials have been shown to have excellent potential as pulp-capping and pulpotomy medicaments, However, major drawbacks of MTA are its handling properties, long setting time, and potential for discoloration of the remaining tooth structure. Original MTA was first introduced in grey color, which caused severe discoloration after its application, and concerns were raised about the esthetic competency of this material. The tooth colored formula (WMTA) was then introduced to compensate for this short coming[9,10]. The crystalline structure, as well as the chemical properties and mechanism of action is somewhat unchanged, although higher concentrations of aluminum oxide, magnesium oxide and iron oxide in Grey MTA (GMTA), result in a considerable staining potential[10,11]. To reduce the discoloration potential, the chemical composition of MTA was changed, and an improved formulation was later introduced as White MTA (WMTA). The most significant difference between the two types of MTA is the lack of iron ions in WMTA[12]. However, it has been reported that WMTA may cause discoloration as well[13,14]. Some authors state that the discoloration induced by MTA may be attributed to bismuth oxide, which is added to improve the radiopacity in both grey and white formulations[15]. However, no scientific evidence is available to support this statement. Because MTA is based on industrial Portland cement with bismuth oxide added as an radiopacifier, pure Portland cement was suggested as an alternative[16]. The potential tooth discoloration associated with the use of WMTA and GMTA has led to a search for an alternative endodontic reparative material similar in composition that will not cause tooth discoloration[17],. Various calcium-silicate based products have been launched to the market recently, one among these has been the focus of attention and the topic of a variety of investigations. This material is the Biodentine (BD, Septodont, France), calcium-silicate based product, which became commercially available in 2009. BD indications are similar to MTA, and according to BD manufacturers does not cause tooth discoloration. According to the manufacturer, Biodentine has similar indications for use as MTA along with a faster setting time and does not cause tooth discoloration[18].

Esthetics play an important role in dentistry, and discoloration of a single tooth can significantly impact one's quality of life[19]. The maxillary anterior teeth have a key impact on facial and oral aesthetics [20]. These can severely affect the quality-of-life , causing physical, social and psychological impairment[21,22] . A smile denotes self-esteem, self-confidence and well-being [21,22] and it has been shown that children with concerns about their teeth smile less[23]. Therefore, this study aimed to assess *in vitro* the color alterations of permanent anterior teeth associated with different pulpotomy materials using a reflectance spectrophotometer.

MATERIALS AND METHOD

Prior to the investigation the study was approved by Tel-Aviv university research ethics board. Forty human fully developed permanent incisors teeth were used in this study, recently extracted from male and female patients. The teeth were selected based on dimension, similarity in morphology, and absence of any crack or carious defects and prior discoloration because of intrinsic causes; minimum of two thirds of the original root length was required in order to be included in the study. Debris and soft tissue remnants on the root were removed with a sharp scalpel. All teeth were stored in phosphate-buffered saline until used. In a cervical pulpotomy technique a coronal access was achieved by a tungsten carbide drill HS 330 (Dentsply Maillefer, Tulsa, OK, USA), pulps were extirpated with an excavator, and the internal axial walls of the pulp chambers were chemo-mechanically debrided with Hedström files (Dentsply Maillefer, Tulsa, OK, USA) and 2.5% sodium hypochlorite (10 mL) through the access. After final irrigation, the pulp chambers were washed with sterile saline (5 mL). After mixing the materials according to manufacturers' instructions, the pulpotomy base material was placed on the floor of the pulp chamber and padded against the pulp orifices using a Dovgan carrier (Quality Aspirators, Duncaville, TX, USA) through the access. A slight vertical pressure was applied with finger pluggers to fill the pulp chamber with the material, up to the cervical sectioning level. Ten negative controls were instrumented and kept unfilled.

The experimental teeth were randomly divided into the following experimental groups:

- GMTA Group (N=10): MTA ANGELUS (GMTA, Angelus, Soluções em Odontologia, Londrina, PR, Brazil) mixed according to the manufacturer instructions was placed inside the root using Dovgan carriers (Quality Aspirators, Duncanville,Texas).
- WMTA Group (N=10): Mineral Trioxide Aggregate (Pro Root; Dentsply-Tulsa Dental, Johnson City, TN, USA) mixed according to the manufacturer instructions was placed inside the root using Dovgan carriers (Quality Aspirators, Duncanville, Texas).
- Biodentine Group (N=10): Biodentin (Septodont, Saint-Maur-des-Fossés, France) mixed according to the manufacturer instructions was placed inside the root using Dovgan carriers (Quality Aspirators, Duncanville,Texas).
- Control Group (N=10): without pulpotomy base material.

The coronal access cavity was then filled with resin modified glass ionomer (EQUIA Forte Fil, GC Europe, Leuven, Belgium). All specimens incubated at 37°C and 100% humidity for 14 weeks and have been evaluated before the study and weekly for three months.

Color Evaluation Procedure

The evaluation procedure was done according to previous suggested model[24]. In brief, all teeth were polished with nonfluoridated and oil-free pumice, rinsed, and dried completely for 10 seconds. The reflectance spectrophotometer SpectroShade (LUA005, MHT Optic Research AG, Zurich, Switzerland; software version, 2.20) was used to evaluate the color alterations. According to a previous investigation, this instrument provides precise measurements during longitudinal evaluation of tooth color in vivo[25]from 22 dental students, were recorded on three separate days (1st, 3rd and 30th.

Color quantification was based on the CIE's L*, a*, and b* color system that uses 3 parameters to define color: the L* coordinate is a measure of lightness similar to value in the Munsell system[26] and ranges from 0 (black) to 100 (white); the a* and b* coordinates represent positions on red/green and yellow/blue axes, respectively. The readings of a* and b* combined provided the same information as hue and chroma in the Munsell system. The spectrophotometer was calibrated before each image-capture session with white and green ceramic tiles supplied by the manufacturer. The calibration process compensated for any deviation in the quantity of illumination output from the internal light source[27]. The spectrophotometric data of each tooth was recorded at 5 consecutive times by positioning, removing, and repositioning the intraoral camera on a black surface to prevent enamel-color alterations[28]. The resulting images were subsequently cross-referenced by using the built-in synchronized image program. Each tooth gone through spectrophotometric analysis of the crown area in its incisal, middle and cervical thirds of its buccal surface (Figure 1). All images were recorded by the same operator (HA).

The CIE color parameters (L*, a*, and b*) were measured and averaged for each material and the resultant color differences (ΔE) between the interval groups was calculated according to the following equation: $\Delta E=[(L * i - L * ii)2 + (a * i - a * ii)2 + (b * i - b * ii)2]1/2$. where i and ii represent the color measurements made before and after the treatment for different time period, respectively.

Statistical Analysis

Color assessment in relation to pulpotomy material, was made with 2-way mixed analysis of variance (ANOVA) for the DE differences and 2-way ANOVA for the time differences. We found it appropriate to analyze the data after applying the log transformation. For each area, we fit the mixed effects 2-way ANOVA nested model. We then performed LRT (likelihood ratio test) to test each of the covariates effects. These statistical analyses were conducted with SPSS software (version 12.0, SPSS, Chicago, Ill., USA). The level of significance was set at $P < 0.05$.

RESULTS

The results relating to the ΔE of the materials over time are presented in Table 1 and Figure 1, 2. The ΔE of all experimental groups (GMTA, WMTA and BD) were significantly different from the control group at all time points ($P<0.05$).

Color changes in the GMTA and WMTA groups, had no statistical significant differences, but showed higher discoloration compared to BD group in the cervical part of the crown, since week 1 ($P<0.05$).

WMTA group showed significant discoloration in the cervical part as of week 1 ($P<0.05$), and gradually increased over time (Figure 2). BD group showed no significantly discoloration over time. GMTA group showed the significant discoloration at week 1 and week 14 ($P<0.05$).

Figure 1: In the figure, central permanent incisor, immediately after the medicament placement(a, d, g and j), one month after placing (b, e, h and k) and three months after placing (c, f, I and l). Dark discoloration was visibly seen mainly in the GMTA group after one month (b) and three months (c). discoloration was also visible in the WMTA group after 3 months (f). In the BD and control group no visibly changes were noticed (g-i and j-l respectively).

Figure 2: The GMTA an WMTA groups showed gradually color change over time. The BD group color change stayed stable over time. Significant difference can be seen between the BD group and all other groups.

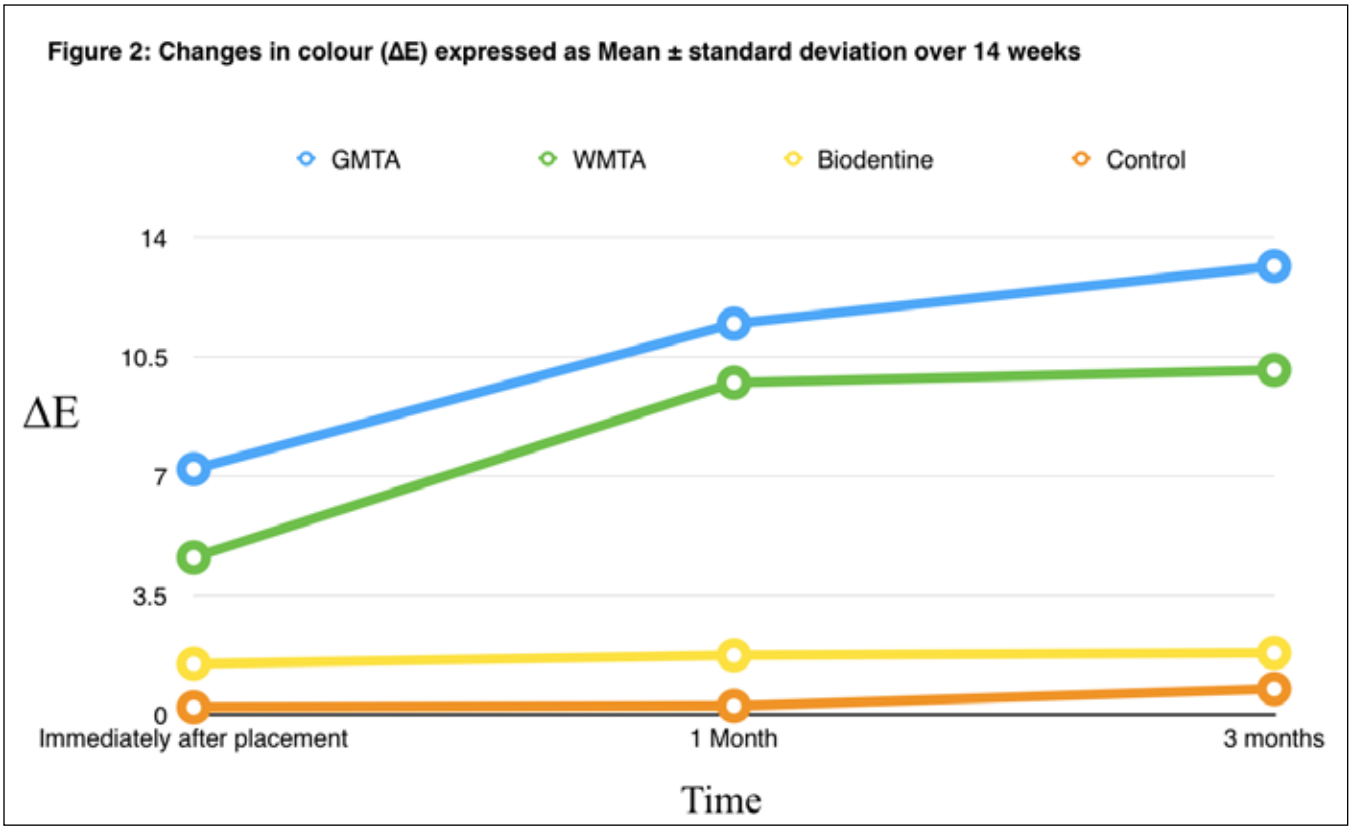

Table 1: Changes in color (∆E) expressed as mean ± standard deviation over 14 weeks.

	N	area	Immediately after placement	One month	3 months
GMTA	10	Cervical	7.2 ± 0.69	11.47 ± 1.72^{c}	13.16 ± 0.57^{c}
		Middle	3.30 ± 1.82	5.79 ± 0.98^{c}	7.43 ± 2.1^{c}
		Incisal	2.11 ± 0.48	6.98 ± 1.54^{c}	8.40 ± 1.63^{c}
WMTA	10	Cervical	4.61 ± 1.91	9.74 ± 2.34^{c}	10.11 ± 2.70
		Middle	2.30 ± 0.98	7.07 ± 1.76^{c}	8.38 ± 1.59
		Incisal	2.31 ± 0.38	6.81 ± 2.80^{c}	8.07 ± 2.06
Biodentine	10	Cervical	1.49 ± 0.05^{b}	1.74 ± 0.39^{b}	1.81 ± 0.20^{b}
		Middle	0.93 ± 0.18^{b}	1.09 ± 0.42^{b}	1.05 ± 0.92^{b}
		Incisal	0.80 ± 0.66^{b}	0.62 ± 0.28^{b}	0.73 ± 0.26^{b}
Control	10	Cervical	0.21 ± 0.04^{a}	0.25 ± 0.14^{a}	0.75 ± 0.24^{a}
		Middle	0.34 ± 0.16^{a}	0.68 ± 0.13^{a}	0.87 ± 0.45^{a}
		Incisal	0.87 ± 0.67^{a}	0.76 ± 0.34^{a}	0.65 ± 0.35^{a}

Within each time point, groups displaying different superscript letters indicate a significant difference, used by 2 way ANOVA (P<0.05). a - difference between the control to all other groups. b - difference between materials and c - differences within groups in different time stops.

DISCUSSION

Several methods have been proposed for the evaluation or measurement of discoloration, including visual technique and computer analysis of digital photos[6,29,30]longitudinally, coronal discoloration from four sealers. Extracted premolars were sectioned in the coronal third of the root. The chamber contents were removed and instrumentation was via the canal. The following sealers were bulk introduced into the chamber: AH26, Kerr Pulp Canal Sealer, Roths 801 (nonstaining, Inherent objectivity and standardization difficulties may be improved by the use of a spectrophotometer[31]. This study used a spectrophotometer and The CIE L* a* b* color space system that is an arrangement for international standardization on issues of color and is acknowledged by the ISO[32]intact, mandibular third molars were sectioned 1 mm below their cemento-enamel junction (CEJ. Spectrophotometric analysis with the Vita Easy Shade was applied because of the technique's sensitivity to small changes in color, repeatability, and objectivity[33]. The system approximates uniform distances between the color coordinates while covering the visual color space. Seghi *et al*[34] showed that a color change of 2 units of CIE L* a* b* was detected 100% of the time by observers, and 0.5–1 unit was detected 80% of the time, this finding may explain the result in our study, in which gray discoloration could be clearly seen in the GMTA group.

This study evaluated the discoloration potential of 3 bioceramics materials (GMTA, WMTA, and BD) to determine which might be best suited for use in esthetic areas . The results indicate that GMTA and WMTA, discolor tooth structure to a perceptible degree. BD though, showed no discoloration over time. Both GMTA and WMTA groups had significant discoloration in the first week and more overall color change over time. However, only GMTA showed another significate difference over time (at week 14).

Many studies testing coronal discoloration are accomplished by removing tooth structure below the cementoenamel junction, removing the pulp tissue, and placing the experimental material via a retrograde approach[17,32]wMTA + blood (n = 18. In this study, in an attempt to more closely simulate a clinical procedure, an ideal coronal access preparation was made, and reparative materials were placed in an orthograde manner. The teeth were then restored with a glass ionomer cement restoration.

The irrigation protocol in this study during canal preparation was NaOCl and a final irrigation with sterile saline to remove the smear layer. This protocol was chosen to facilitate the maximum penetration of the materials into the dentinal tubules. According to Davis et al[35], discoloration is less evident or takes longer when the smear layer is not removed, and materials in the canal penetrate more readily when the smear layer is removed. Irrigating with NaOCl has been shown to react with bismuth-containing materials causing a dark-brown discoloration[36], hence final saline rinse was made before pulpotomy material was placed in the chamber.

Despite the harmonious color of WMTA with dental tissues, tooth discoloration was observed in the findings of this study, which was in accordance with the results of some other studies[5,10]. These findings limit applications of MTA in endodontic treatments such as pulp capping and pulpotomy in the esthetic zones[11]

Variable amounts and durations of color change was reported with the same formulation of MTA, which would be the result of different thickness of the remaining tooth structure, colorimetric method of color measurement and material application methods[10,14,35]. The mentioned metal oxides, are present in the tooth-colored formula (WMTA) although to a very low degree, and can induce tooth discoloration[10]. Elements such as Fe, Mn and Cu, with d-electrons, are well known to have strong colors in oxide form. The d-electrons are readily excited by a visible spectrum light. Other oxides without such electrons (Ca, Si, Al, Mg and S) tend to be colorless or white, but the heavy ones such as bismuth has a yellow oxide[37]. Some authors state that the yellow oxide of bismuth used in both formulations of MTA for radiopacity, is the significant factor for tooth discoloration[15].

Research indicates that the most pronounced staining from dental materials occurs in the cervical third of the crown[17,38], which is why the area of measurement for this study was confined to the cervical third. During the experiments, it was observed that the WMTA and GMTA groups showed gray discoloration of the cervical root dentin, whereas the BD group had no discernible color change in the corresponding region. This finding is more in alignment with the current body of research that has shown MTA to cause gray discoloration of tooth structure[10,17,39]wMTA + blood (n = 18. The findings in this study contest to our previous study, which compared the same materials in primary teeth[40].

Many of the clinical applications of bioceramics involve proximity to and incorporation of blood. Studies have shown that the presence of blood compounds the staining propensity of WMTA and GMTA[5,17], and blood alone also has potent staining ability[41,42]. This study lacks in this matter, because no blood contamination was tested which may not reflect the clinical procedure in vivo. To evaluate the intrinsic staining potential of the materials with blood contamination, future studies are required.

CONCLUSION

Within the limitation of this in vitro study ,GMTA and WMTA pulpotomy material may discolor tooth structure over time in an extracted permanent anterior tooth model. It could be suggested that, in terms of aesthetics, the use of BD appears to be favorable. Clinical studies are needed to further confirm these finding .

REFERENCES

1. Vargas KG, Fuks AB, Peretz B. Pulpotomy Techniques: Cervical (Traditional) and Partial. In: Pediatric Endodontics. Springer International Publishing; 2016:51-70.
2. Holan, G. Introduction to dental trauma : Managing traumatic injuries in the primary dentition. Pediatr Dent Infancy Through Adolesc. Published online 2005:236-256. Accessed September 23, 2018.
3. Cvek M. A clinical report on partial pulpotomy and capping with calcium hydroxide in permanent incisors with complicated crown fracture. J Endod. 1978;4(8):232-237.
4. Smaïl-Faugeron V, Courson F, Durieux P, Muller-Bolla M, Glenny A-M, Fron Chabouis H. Pulp treatment for extensive decay in primary teeth. Cochrane Database Syst Rev. 2014;(8):CD003220.
5. Lenherr P, Allgayer N, Weiger R, Filippi A, Attin T, Krastl G. Tooth discoloration induced by endodontic materials: a laboratory study. Int Endod J. 2012;45(10):942-949.
6. van der Burgt TP, Mullaney TP, Plasschaert AJM. Tooth discoloration induced by endodontic sealers. Oral Surgery, Oral Med Oral Pathol. 1986;61(1):84-89.
7. Camilleri J, Montesin FE, Brady K, Sweeney R, Curtis R V., Ford TRP. The constitution of mineral trioxide aggregate. Dent Mater. 2005;21(4):297-303.
8. Torabinejad M, Hong CU, McDonald F, Pitt Ford TR. Physical and chemical properties of a new root-end filling material. J Endod. 1995;21(7):349-353.
9. Belobrov I, Parashos P. Treatment of Tooth Discoloration after the Use of White Mineral Trioxide Aggregate. J Endod. 2011;37(7):1017-1020.
10. Ioannidis K, Mistakidis I, Beltes P, Karagiannis V. Spectrophotometric analysis of coronal discolouration induced by grey and white MTA. Int Endod J. 2013;46(2):137-144.
11. 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;2012:563203.
12. Song J-S, Mante FK, Romanow WJ, Kim S. Chemical analysis of powder and set forms of Portland cement, gray ProRoot MTA, white ProRoot MTA, and gray MTA-Angelus. Oral Surgery, Oral Med Oral Pathol Oral Radiol Endodontology. 2006;102(6):809-815.
13. Maroto M, Barberia E, Planells P, Vera V. Treatment of a non-vital immature incisor with mineral trioxide aggregate (MTA). Dent Traumatol. 2003;19(3):165-169.
14. Watts JD, Holt DM, Beeson TJ, Kirkpatrick TC, Rutledge RE. Effects of pH and Mixing Agents on the Temporal Setting of Tooth-colored and Gray Mineral Trioxide Aggregate. J Endod. 2007;33(8):970-973.
15. Steffen R, van Waes H. Understanding mineral trioxide aggregate/Portland-cement: A review of literature and background factors. Eur Arch Paediatr Dent. 2009;10(2):93-97.
16. Hwang Y-C, Kim D-H, Hwang I-N, et al. Chemical Constitution, Physical Properties, and Biocompatibility of Experimentally Manufactured Portland Cement. J Endod. 2011;37(1):58-62.
17. Felman D, Parashos P. Coronal Tooth Discoloration and White Mineral Trioxide Aggregate. J Endod. 2013;39(4):484-487.
18. Rajasekharan S, Martens LC, Cauwels RGEC, Verbeeck RMH. Biodentine material characteristics and clinical applications: a review of the literature. Eur Arch Paediatr Dent. 2014;15(3):147-158.
19. Dugas N, Lawrence H, Teplitsky P, Friedman S. Quality of Life and Satisfaction Outcomes of Endodontic Treatment. J Endod. 2002;28(12):819-827.
20. Flores-Mir C, Silva E, Barriga MI, Lagravère MO, Major PW. Lay person's perception of smile aesthetics in dental and facial views. J Orthod. 2004;31(3):204-209.
21. Cortes MI de S, Marcenes W, Sheiham A. Impact of traumatic injuries to the permanent teeth on the oral health-related quality of life in 12-14-year-old children. Community Dent Oral Epidemiol. 2002;30(3):193-198.
22. Holan G, Needleman HL. Premature loss of primary anterior teeth due to trauma–potential short- and long-term sequelae. Dent Traumatol. 2014;30(2):100-106.
23. Gherunpong S, Tsakos G, Sheiham A. The prevalence and severity of oral impacts on daily performances in Thai primary school children. Health Qual Life Outcomes. 2004;2(1):57.
24. Karamouzos A, Athanasiou AE, Papadopoulos MA, Kolokithas G. Tooth-color assessment after orthodontic treatment: A prospective clinical trial. Am J Orthod Dentofac Orthop. 2010;138(5):537.e1-537.e8.
25. KARAMOUZOS A, PAPADOPOULOS MA, KOLOKITHAS G, ATHANASIOU AE. Precision of in vivo spectrophotometric colour evaluation of natural teeth. J Oral Rehabil. 2007;34(8):613-621.
26. Nickerson D. Munsell Color System, Company, and Foundation.; 1976. Accessed September 23, 2018. https://munsell.com/wp-content/uploads/2011/03/munsell-color-history-dorothy-nickerson.pdf
27. Chu SJ. Use of a reflectance spectrophotometer in evaluating shade change resulting from tooth-whitening products. J Esthet Restor Dent. 2003;15 Suppl 1:S42-8.
28. Russell MD, Gulfraz M, Moss BW. In vivo measurement of colour changes in natural teeth. J Oral Rehabil. 2000;27(9):786-792.
29. Parsons J, Walton R, Ricks Williamson L. In Vitro Longitudinal Assessment of Coronal Discoloration from Endodontic Sealers. J Endod. 2001;27(11):699-702.
30. Partovi M, Al-Havvaz AH, Soleimani B. In vitro computer analysis of crown discolouration from commonly used endodontic sealers. Aust Endod J. 2006;32(3):116-119.
31. Guan YH, Lath DL, Lilley TH, Willmot DR, Marlow I, Brook AH. The measurement of tooth whiteness by image analysis and spectrophotometry: a comparison. J Oral Rehabil. 2005;32(1):7-15.
32. Ioannidis K, Mistakidis I, Beltes P, Karagiannis V. Spectrophotometric analysis of coronal discolouration induced by grey and white MTA. Int Endod J. Published online 2013.
33. AlGhazali N, Burnside G, Smith RW, Preston AJ, Jarad FD. Performance assessment of Vita Easy Shade spectrophotometer on colour measurement of aesthetic dental materials. Eur J Prosthodont Restor Dent. 2011;19(4):168-174.
34. Seghi RR, Hewlett ER, Kim J. Visual and Instrumental Colorimetric Assessments of Small Color Differences on Translucent Dental Porcelain. J Dent Res. 1989;68(12):1760-1764.
35. Davis MC, Walton RE, Rivera EM. Sealer Distribution in Coronal Dentin. J Endod. 2002;28(6):464-466.
36. Camilleri J. Color Stability of White Mineral Trioxide Aggregate in Contact with Hypochlorite Solution. J Endod. 2014;40(3):436-440.
37. Asgary S, Eghbal MJ, Parirokh M, Ghoddusi J, Kheirieh S, Brink F. Comparison of Mineral Trioxide Aggregate's Composition with Portland Cements and a New Endodontic Cement. J Endod. 2009;35(2):243-250.
38. Karabucak B, Li D, Lim J, Iqbal M. Vital pulp therapy with mineral trioxide aggregate. Dent Traumatol. 2005;21(4):240-243.
39. Jang J-H, Kang M, Ahn S, 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(12):1598-1602.
40. Elbahary S, Bercovich R, Flaisher-Salem N, Azem H. Quantifying Coronal Primary Tooth Discoloration Caused by Different Pulpotomy Materials. J Clin Pediatr Dent. 2020;44(3):142-147.
41. Freccia WF, Peters DD. A technique for staining extracted teeth: a research and teaching aid for bleaching. J Endod. 1982;8(2):67-69.
42. Marin PD, Bartold PM, Heithersay GS. Tooth discoloration by blood: an in vitro histochemical study. Dent Traumatol. 1997;13(3):132-138.