Prevention of Tooth Discoloration Due to Calcium-Silicate Cements: A Review

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Abstract

Introduction: Mineral trioxide aggregate (MTA) and other calcium silicate cement similar to that are widely used in endodontic treatments. One of the widely emphasized disadvantages of these cements are the induction of tooth discoloration. The purpose of this study was to investigate the mechanisms of tooth discoloration caused by MTA and MTA-like cements and debate different methods suggested for preventing it. **Methods:** An electronic search was performed using databases such as Google Scholar, PubMed, PubMed Central, Science Direct, and Scopus by using keywords such as "mineral trioxide aggregate", "calcium-silicate", "tooth discoloration", and "prevention". **Results:** Several methods for preventing tooth discoloration caused by MTA and MTA-like cements have been proposed including the application of dentin bonding agents on dentinal walls, use of cements containing radiopacifying agents other than bismuth oxide, and addition of zinc oxide to those cements containing bismuth oxide. **Conclusion:** Most studies have shown that none of these methods can completely inhibit tooth discoloration but can decrease it to some length.

Keywords: Calcium silicate cement, discoloration, mineral trioxide aggregate, prevention

Introduction

Mineral trioxide aggregate (MTA) is a type of hydrophilic calcium silicate cement first introduced by Torabinejad *et al.* in 1993[1] and approved by the Food and Drug Administration to be used in the United States in 1997. It is widely used in endodontics and some of this cement's applications include root end filling, repair of root perforations, vital pulp therapy, as an apical barrier, and as a coronal barrier.[2] Various *in vitro* studies have shown this cement to have various advantages and appropriate properties such as good biocompatibility and sealing ability,[3] antibacterial properties,[4] and setting in aqueous environments.[5] Promising clinical outcomes have also been reported for the use of MTA in these clinical applications.[6-8] However, some disadvantages have been reported for this cement including having a long setting time,[9] difficult handling,[10] causing tooth discoloration,[11] and being influenced by environmental conditions.[5,12-14]

To overcome these disadvantages, other calcium silicate cements similar to MTA have been introduced over the years [Table 1].

As the use of these cements in clinical cases have increased overtime, many have encountered the tooth discoloration caused by these cements which is usually associated with patient dissatisfaction. This has caused wide emphasis on this subject in such a way that the American Association of Endodontists[15] and the European Society of Endodontology[16] have discussed this matter in the position statement for regenerative endodontic treatment. Considering that the patient's needs and preferences are one of the three critical important components of an evidence-based approach for clinical treatments,[17] evaluating methods for preventing tooth discoloration in cases requiring the use of calcium silicate cements is of significance. The aim of this review article was to investigate the mechanisms of tooth discoloration caused by calcium silicate cements and discuss different methods suggested for preventing it.

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Table 1: Different types of commercially available calcium-silicate cements available and their composition

Calcium silicate cements	Composition
Angelus MTA[18]	Tricalcium silicate, dicalcium silicate, bismuth oxide, tricalcium aluminate, calcium oxide, aluminum oxide, and silicon dioxide. Liquid: distilled water.
Aureoseal MTA[7]	The powder consists of Portland cement, bismuth oxide, setting-time controllers, plastifying agents, and radiopaque substances. Liquid: distilled water.
BioAggregate[13]	Tricalcium silicate, dicalcium silicate, calcium phosphate monobasic, amorphous silicon oxide, and tantalum pentoxides. Liquid: deionized water.
Biodentine[5]	Tricalcium silicate, dicalcium silicate, calcium carbonate, zirconium oxide, calcium oxide, and iron oxide. Liquid: calcium chloride, a hydrosoluble polymer and water.
Calcium-enriched mixture (CEM) cement[5]	Calcium oxide, silicon dioxide, Al_2O_3, MgO, SO_3, P_2O_5, Na_2O, Cl. Liquid: water-based solution.
EndoBinder[19]	Al_2O_3, CaO, SiO_2, MgO, and Fe_2O_3
Endocem MTA[20]	CaO, Al_2O_3, SiO_2, MgO, Fe_2O_3, SO_3, TiO_2, H_2O/CO_2, bismuth oxide
Endocem Zr[21]	Calcium oxide, silicon dioxide, aluminum oxide, magnesium oxide, ferrous oxide, and zirconium oxide
EndoSequence, RRM, RRP[12]	Zirconium oxide, calcium silicates, tantalum oxide, calcium phosphate monobasic, and filling and thickening agents
iRoot BP[7]	Zirconium oxide, calcium silicates, tantalum oxide, calcium phosphate monobasic, and filler and thickening agents
iRoot BP Plus[7]	Calcium silicate, calcium phosphate, tantalum, and zirconium oxide
iRoot FS[7]	Calcium silicates, zirconium oxide, tantalum oxide, and calcium phosphate monobasic
MicroMega MTA[21]	Tricalcium silicate, dicalcium silicate, tricalcium aluminate, bismuth oxide, calcium sulfate dehydrate, and magnesium oxide
MTA Bio[7]	Portland cement and bismuth oxide
MTA Plus (White)[7]	Tricalcium silicate, $2CaOSiO_2$, Bi_2O_3, $3CaOAl_2O_3$, and $CaSO_4$
MTA Repair HP[22]	Tricalcium silicate (Ca_3SiO_5), dicalcium silicate (Ca_2SiO_4), tricalcium aluminate ($3CaO.Al_2O_3$), calcium oxide (CaO), calcium tungstate ($CaWO_4$), water, and polymer plasticizer
MTA Plus (White)[7]	Tricalcium silicate, dicalcium silicate, bismuth oxide, tricalcium aluminum oxide, and calcium sulfate
MTA Plus (Grey)[7]	Tricalcium silicate, dicalcium silicate, bismuth oxide, tricalcium aluminum oxide, calcium sulfate, and $Ca_2(Al,Fe)_2O_5$
NeoMTA Plus[23]	Tricalcium silicate, dicalcium silicate, tantalite, calcium sulfate, and silica
Odontocem[21]	Powder contains triamcinolone acetonide, 0.2%, in a calcium cement base; liquid contains a solution of ammonium phosphate and ammonium sulfate
OrthoMTA[24]	Tricalcium silicate, dicalcium silicate, tricalcium aluminate, tetracalcium aluminoferrite, free calcium oxide, and bismuth oxide
ProRoot MTA (Grey)[10]	Tricalcium silicate, dicalcium silicate, bismuth oxide, tricalcium aluminate, calcium sulphate dihydrate (gypsum), and calcium aluminoferrite. Liquid: distilled water.
ProRoot MTA (Tooth-colored/White) [5]	Tricalcium silicate, dicalcium silicate, bismuth oxide, tricalcium aluminate, calcium sulfate dehydrate, or gypsum. Liquid: distilled water.
Quick-Set[23]	Monocalcium aluminate powder that contains bismuth oxide (as a radiopacifier) and hydroxyapatite
RetroMTA[5]	Calcium carbonate, silicon oxide, aluminum oxide and hydraulic calcium zirconia complex. Liquid: water.
Tech Biosealer Capping, Tech Biosealer Root End, Tech Biosealer Apex[7]	Mixture of white CEM, calcium sulfate, calcium chloride, bismuth oxide, and montmorillonite
TheraCal LC[25]	CaO, Sr glass, fumed silica, barium sulfate, barium zirconate, Portland cement type III, and resin-containing Bis-GMA and PEGDMA

MTA, mineral trioxide aggregate.

Methods

An electronic search was performed using databases such as Google Scholar, PubMed, PubMed Central, Science Direct, and Scopus by using keywords such as (“mineral trioxide aggregate” OR “calcium-silicate” OR the name of all calcium silicate cements available) AND (“discoloration” OR “staining potential” OR “color” OR “colour”) AND (“tooth” OR “teeth”) AND/OR “prevention”. The last search was performed on March 2019.

The inclusion criteria were all *in vitro*, *ex vivo*, clinical studies, case reports or series, and review articles that evaluated tooth discoloration induced by different calcium silicate-based cements and/or its prevention in peer-reviewed journals published in English. Exclusion criteria included studies published in a language other than English, abstracts from congress.

The articles were selected to address the following research question: How can the discoloration due to calcium silicate-based cements be prevented?

Result

A total of 427 articles were identified after elimination of duplicates by our search strategy. After evaluation of the titles, abstracts, and full texts, 71 references were included for review and evaluation. Among these articles, nine were review articles regarding discoloration caused by calcium silicate cement, three were clinical trials, and five were case reports/series. Only seven articles were related to tooth discoloration prevention.

Discussion

Tooth discoloration caused by calcium silicate cements

The first type of MTA introduced was gray MTA. This formulation caused obvious tooth discoloration. As the color of this cement was gray, tooth discoloration was initially considered resultant of its color which was due to the presence of FeO, MgO, and Al_2O_3 in its composition.[1] Therefore, these metallic oxides were eliminated from its formulation and tooth colored/white MTA (WMTA) was introduced; however, this formulation also caused some degrees of tooth discoloration.[26,27]

Overall, reasons for the tooth discoloration caused by WMTA are as follows:

(1) Presence of 9% iron oxide in WMTA[28] attributed to the calcium aluminoferrite phase of its powder.

(2) Presence of bismuth oxide as a radiopacifier in its composition[29,30] that can interact with strong oxidizing agents,[31] that is, sodium hypochlorite commonly used as an irrigating solution, during endodontic treatments resulting in the production of carbonate bismuth[29,30] or interact with collagen in tooth dentin, forming a black precipitate.[29]

(3) Penetration of erythrocytes from environmental blood into porosities of unset MTA and consequently tooth discoloration due to both discoloration of the MTA bulk and accumulation of hemoglobin or other forms of hematin molecules in dentin.[24,32]

Preventing tooth discoloration caused by calcium silicate cements

Based on these mechanisms for causing tooth discoloration, several strategies have been introduced to prevent this discoloration, which are as follows:

(1) Using calcium silicate cements containing alternative radiopacifying agents such as zirconium oxide and calcium tungstate.[33,34]

(2) Sealing the dentinal tubules of pulp chamber prior to the application of calcium silicate cements using dentin bonding agents.[35]

(3) Placing MTA below the cementoenamel junction.[36]

(4) Adding zinc oxide (ZnO)[37] or aluminum fluoride (AlF_3)[38] to the powder of WMTA.

Studies have shown that the methods described above cannot completely inhibit tooth discoloration but can decrease it to some extent [Table 2].

In the case of using calcium silicate cements containing alternative radiopacifying agents, studies have shown different outcomes. For instance, most studies reported less tooth discoloration when Biodentine, a calcium silicate cement lacking bismuth oxide and containing zirconium oxide as its radiopacifying agent, was applied.[18,33,39] However, Ramos *et al.*[40] showed significantly higher levels of tooth discoloration 12 months after the application of this cement. These levels were similar to the levels reported for WMTA in other studies.[19,20] BioAggregate is another calcium silicate cement lacking bismuth oxide. This cement contains tantalum peroxide as the radiopacifying agent. Yoldaş *et al.*[34] have shown that this cement causes lower levels of tooth discoloration compared to ProRoot MTA; however, it caused higher levels of tooth discoloration compared to Biodentine. This was attributed to higher porosity and higher fluid uptake in BioAggregate. Marconyak *et al.*[39] showed that Endo Sequence Root Repair, a calcium silicate cement containing zirconium oxide and tantalum oxide, and Biodentine did not cause significant tooth discoloration.

Although the use of cements with radiopacifying agents other than bismuth oxide may cause less tooth discoloration, these cement are less radiopaque.[41] Increasing the amount of radiopacifying agents in their formulation causes adverse effects on physical and chemical properties of these cement.[29]

Regarding the use of dentin bonding agents prior to the application of calcium silicate cements, the few available studies performed up to now have shown that this approach can decrease tooth discoloration caused by these cements.[35,42] The dentin bonding acts as barrier preventing cement accumulation in the access cavity and its contact with dentin collagen. The use of multiple layers of dentin bonding have been suggested for better coverage.

Another approach for preventing tooth discoloration was proposed by Marciano *et al.*[37,38] They suggested adding ZnO or AlF_3 to white MTA Angelus. They reported that Zn and AlF_3 molecules interact with the bismuth oxide, stabilizing it and preventing the interact of bismuth oxide with strong oxidizing agents.[37,38] They concluded that addition of 5% ZnO to white MTA Angelus inhibited tooth discoloration and increased calcium release from this cement, not affecting its other properties,[37] whereas addition of 5% and 15% AlF_3 increased the pH and calcium ion release of the cement.[38] More research is required.

Overall, the majority of articles on this topic of tooth discoloration caused by calcium silicate cements are *in vitro* or *ex vivo* studies. These *in vitro* or *ex vivo* cannot completely simulate all clinical conditions such as the effect

Table 2: Tooth discoloration caused by various calcium-silicate cements in different studies

Author	Materials	Model	Time interval evaluated	Results	
				$\Delta E < 3.3$	$\Delta E > 3.3$
Arman *et al.*[27]	Control (blood and empty) A-WMTA CEM cement	Tooth model	1 week; 1, 6 months	Control+ (1 week) Control− (1 week; 1, 6 months) A-WMTA (1 week) CEM cement (1 week)	Controls (1, 6 months) A-WMTA (1, 6 months) CEM cement (1, 6 months)
Dettwiler *et al.*[18]	Control Ledermix MTA MM-MTA Biodentine Odontocem PC PC BiOx PC ZrO	Dentin disk	12 months	–	Control Ledermix MTA MM-MTA Biodentine Odontocem PC PC BiOx PC ZrO
Ioannidis *et al.*[26]	Control A-WMTA A-GMTA	Tooth model	1 week; 1, 2, 3 months	Control A-WMTA (1 week; 1, 2 months)	A-GMTA A-WMTA (after 3 months)
Jang *et al.*[20]	Control, ProRoot, MTA, Angelus MTA, Endocem	Tooth model	1, 2, 4, 8, and 12 weeks		Control, ProRoot, MTA, Angelus MTA, Endocem
Marciano *et al.*[37]	A-WMTA A-WMTA + 5% ZnO A-WMTA+ 15% ZnO A-WMTA + 45% ZnO	Tooth model for human teeth and Dentin disk for bovine teeth	3 months	–	A-WMTA A-WMTA + 5% ZnO A-WMTA + 15% ZnO A-WMTA + 45% ZnO
Marciano *et al.*[38]	A-WMTA A-WMTA + 5% AlF_3 A-WMTA+ 15% AlF_3 A-WMTA +45% AlF_3	Tooth model for human teeth and Dentin disk for bovine teeth	3 months	–	A-WMTA A-WMTA + 5% AlF_3 A-WMTA + 15% AlF_3 A-WMTA + 45% AlF_3
Ramos *et al.*[40]	Control ProRoot WMTA Biodentine	Tooth model	6 weeks 12 months	–	Control ProRoot WMTA Biodentine
Shokouhinejad *et al.*[24]	Control ProRoot MTA Biodentine Ortho MTA ERRM	Tooth model	1 day 1, 6 months	–	Control ProRoot MTA Biodentine Ortho MTA ERRM
Vallés *et al.*[33]	Control ProRoot WMTA Biodentine	Tooth model	1 week, 1, 3, 4 months	Biodentine (1 week)	Control (after 1 month) ProRoot WMTA Biodentine (after 1 month)
Yoldaş *et al.*[34]	Control (Blood) BioAggregate Biodentine A-WMTA	Tooth model	1 day 1 week 1, 3, 12 months	–	Control (Blood) BioAggregate Biodentine A-WMTA

AlF_3, aluminum fluoride; ERRM, Endo Sequence Root Repair; GMTA, gray MTA; MTA, mineral trioxide aggregate; ZnO, zinc oxide.

of temperature changes in the oral environment on discoloration and its prevention. Among the few clinical studies including clinical trials and case reports/series, all only reported the occurrence of discoloration and none quantified and compared its intensity. Very few articles have evaluated methods for prevention of tooth discoloration. It seems that although prevention is always better than treatment, this topic requires more attention and research.

Conclusion

Although strategies have been proposed to prevent tooth discoloration caused by calcium silicate cement, up to now, none were able to completely inhibit it.

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Conflicts of interest

There are no conflicts of interest.

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