REVIEW ARTICLE

MTA-Based Root Canal Sealers

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ABSTRACT

Mineral trioxide aggregate (MTA) has been recommended for pulp capping, pulpotomy, apical barrier formation in teeth with open apexes, repair of root perforation and root canal obturation. Since, its introduction in 1993 by Torabinejad numerous studies have been published regarding various aspects of this material. The aim of this review was to consider MTA as root canal sealer and various laboratory experiments and clinical studies of MTA-based root canal sealers. An extensive search of the endodontic literature was made to identify publications related to MTA-based root canal sealers. The articles were assessed for the outcome of laboratory and clinical studies on their biological properties and physical characteristics. Comparative studies with other sealers were also considered. Several studies were evaluated covering different properties of MTA-based sealers including physical properties, biocompatibility, leakage, adhesion, solubility, antibacterial properties and periapical healing effect. Comparative studies reveal their mild cytotoxicity, but their antibacterial effects are variable. Further research is required to establish the role of MTA as root canal sealers.

Keywords: Mineral trioxide aggregate sealer, Fillapex, MTA Obtura, CPM sealer, ProRoot Endo Sealer.

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INTRODUCTION

Root canal sealers are used to attain impervious seal between the core material and root canal walls.[1] They can be grouped according to their basic components, such as zinc oxide eugenol, calcium hydroxide, resin, glass ionomer, iodoform or silicon and recently mineral trioxide aggregate (MTA)-based root canal sealers.

A desirable property of root canal sealer is to have good sealing ability.[2] A good sealer must adhere both to dentin and to core material.[3] They must also have cohesive strength to hold the obturation together,[3] should have low viscosity and good wetting properties to flow into the irregularities on the wall of the root canal and fill the space between the gutta-percha cones and surface of the root canal. It should have appropriate biologic and physicochemical properties. It must not irritate the periradicular tissues. Ideally, it would be desirable that it stimulates reparation and biologic sealing by mineralized tissue deposition in the apical foramen.

Every year, new endodontic materials are developed to fulfill the objective of 3-dimensional sealing of root canal system with hopes of revolutionizing the endodontic obturation technique, but none of these materials have presented better results than the association of gutta-percha with conventional sealers.

Most conventional root canal sealers have demonstrated inadequate biological activity and been cytotoxic in cultures especially when freshly mixed.[4-8] The direct contact of sealers with periapical tissues may cause cellular degeneration and delayed wound healing.[4,7] Moreover, clinical practice suggests that fluid and blood contamination in the apical region of root canal and dentin wetness (water into dentinal tubules) may be expected in teeth with apical resorption or immature apices and after poor root canal shaping. So this humid environment and residual moisture may affect the sealing of conventional hydrophobic root canal sealers and the effective bonding to a wet substrate such as root dentine remains a challenge.[9,10]

MTA was developed by Torabinejad in the early 1990's;[11] the first study on this material was published by Lee et al in 1993.[12] The main components of MTA are tricalcium oxide, tricalcium silicate, bismuth oxide, tricalcium aluminate, tricalcium oxide, tetracalcium aluminoferrite and silicate oxide. In addition, there are a few other mineral oxides, which are responsible for the chemical and physical properties of MTA.

Because calcium silicate cements set in the presence of moisture, such as blood and other fluids[13-16] with a great clinical advantage, it appeared interesting to develop endodontic sealers based on calcium silicate hydraulic cements.[17-19]

MTA AS ROOT CANAL SEALER

In 1999 study by Holland et al[20] compared glass ionomer root canal sealer (Ketac Endo) with MTA as a sealer and concluded that MTA induces closure of main canal foramen by new cementum formation with absence of inflammatory cells after 6 months. In 2007 Holland et al[21] examined influence of the extent of obturation on apical and periapical tissue after filling root canal with MTA and concluded that it can be used as root canal sealer. When MTA is used as root canal sealer and is compacted against dentin a dentin MTA interfacial layer forms in the presence of phosphate. This adherent interstitial layer resembles hydroxylapatite in composition and structure when examined under X-ray diffraction and SEM analysis. However, the calcium to phosphorus ratio varies slightly to actual hydroxylapatite. This interface demonstrates superior marginal adaptation. Moreover, particle size of MTA can occlude and penetrate dentinal tubules that might harbor microorganism after cleaning and shaping.

The moisture (i.e. biological fluids) is essential to allow the setting reaction and to induce bioactivity process with the formation of apatite precipitates.[22-25] Moreover, their hydration forms a sticky/gluey calcium silicate hydrate (CSH) gel that may adhere to a gutta-percha cone in endodontic filling procedure.

Various hydration products form in the hydration reaction, such as porous CSH colloidal gel, portlandite (calcium hydroxide), ettringite (hexacalcium aluminate trisulphate hydrate), and calcium monosulfoaluminate or calcium monocarboaluminate. Porous CSH hardens to form a solid network within 4 to 6 hours and with complete setting after several days.[14,25] This relatively long setting time and the maturation of the cement may explain the improved sealing ability of MTA sealers.

The final irrigation with NaOCl performed at the end of instrumentation acts as antibacterial and tissue-dissolving agent to dissolve collagen and pulpal tissue, leaving an alkaline environment suitable for calcium silicate cement hydration.[26] Precisely, a final treatment with acidic irrigants (such as citric or phosphoric acid) negatively affects MTA cements causing an increase in porosity with deterioration and impairment of the microstructure.[26] Equally, a final irrigation with EDTA negatively interferes with the hydration of MTA.[27]

Advantages of Using MTA as Root Canal Sealer

1. Sealers containing MTA are highly biocompatible and stimulate mineralization.[18]
2. They are bioactive, i.e. hard tissue inductive by encouraging differentiation and migration of hard tissue producing cells.[28]
3. They have antimicrobial activity against *M. luteus*, *S. aureus*, *E. coli*, *P. aeruginosa*, *C. albicans* and *E. faecalis* by its alkaline pH.[29]
4. It modulates cytokinin production.[28]
5. They form a hydroxyapatite (or carbonated apatite) on the MTA surface and provide biologic seal.[22]
6. They also exhibit a higher adhesiveness to dentin than conventional zinc oxide/eugenol-based cements and sealing ability similar to epoxy resin-based cements.
7. Forms calcium hydroxide that releases calcium ions for cell attachment and proliferation.
8. MTA is a nonmutagenic and non-neurotoxic.
9. It does not produce a side effect on microcirculation despite the fact that it can influence vessel contraction.
10. MTA as a sealer provide effective seal against dentin and cementum and promotes biologic repair and regeneration of periodontal ligament.[30]
11. It is radiopaque and nonshrinking.
12. It is not sensitive to moisture and blood contamination.

Disadvantages

1. MTA sealer may cause discoloration due to release of ferrous ions.
2. Long setting time about 2 hours 45 minutes.
3. Working time is less than 4 minutes.
4. Improper handling properties.
5. Compressive strength is inadequate.
6. No known solvent for MTA, Bio Pure MTAD partially dissolve MTA when used it remains in contact with the material for 5 minutes therefore it is difficult to remove from root canal.

Different MTA-based root canal sealers are:

1. ProRoot Endo Sealer (Dentsply Tulsa Dental Specialties, Dentsply/Maillefer, Ballaigues, Switzerland).
2. Fillapex (Angelus).
3. CPM Sealer (EGEO SRL, MTM Argentina SA, Buenos Aires, Argentina).
4. MTA Obtura (Angelus, Angelus Odontologica, Londrina, PR, Brazil).
5. MTAS experimental sealer MTAS (an association between 80% of white Portland cement and 20% of bismuth oxide) with and addition of water soluble polymers.
6. F-doped MTA cements.

ProRoot Endo Sealer (Dentsply Tulsa Dental Specialities)

ProRoot Endo Sealer is calcium silicate-based endodontic sealer to be used in conjunction with root filling material in either cold lateral warm vertical or carrier-based filling technique. The major components of the powder of ProRoot Endo Sealer are tricalcium silicate and dicalcium silicate, with inclusion of calcium sulfate as setting retardant, bismuth oxide as radiopacifier and a small amount of tricalcium aluminate. The bismuth was incorporated with C-S-H structure. The liquid component consists of viscous aqueous solution of water soluble polymer. The addition of polymer did not seem to affect biocompatibility of material. It is mixed in a liquid in a powder ratio of 1:2.[31]

The water soluble polymer added to MTA to modify properties of MTA had a fluidifying effect and thus increases the flow even at high powder to liquid ratio. It involves adsorption and dispersion in the cement water system. The rapid adsorption of polymer molecule on to cement particles combined with dispersion effect exposes an increase in surface area of cement grains to react with water. It does not alter the hydration characteristics of MTA.[19]

It exhibit biocompatibility when in contact with physiologic solution.[17,32] ProRoot MTA sealer exhibit spherical amorphous calcium phosphate like phase along the sealer dentin interface and within the remnants fractured sealers that transformed into carbonated apatite like phases (Gadaleta et al 1991) after immersion in phosphate containing SBF.

There is also release of calcium and hydroxyl ions from the set sealer liquid.[23,33] Similar to other calcium silicate containing biomaterial, MTA sealer produce calcium hydroxide on reaction with water. These phenomena may account for *in vitro* bioactivity of ProRoot MTA sealer.

Cytotoxicity: According to Bryan et al[31] it possesses favorable cytotoxicity profile that was established under extended time periods after setting. The eluent derived from the sealer has comparatively mild toxic effects on the preosteoblast cells when compared with commercially available sealers under the testing conditions. There is also minimum inhibition of the osteogenic potential of the preosteoblast cells. Thus, it is minimally tissue irritant even when it is inadvertently extruded through the apical constriction.

Pushout bond strength: According to Huffman et al[32] the dislocation resistance of proroot was independent of location of radicular dentin and was more than AH Plus and pulp canal sealer. This may be due to hardness of calcium silicate-based sealer after setting in 100% relative humidity. As natural root canal cannot be completely dehydrated[34,35] due to retention of moisture within dentinal tubules similar hardening should be expected of the set sealer. Continuous maturation of sealer may also have increase dislocation resistance.[32]

An investigation comparing ProRoot sealer with AH Plus and pulp canal sealer reported higher pushout bond strength.[36]

Microleakage studies of ProRoot MTA sealer showed similar sealing ability to epoxy resin-based sealer superior to zinc oxide eugenol-based root canal sealers when evaluated using fluid filtration system.[36]

MTA Fillapex Root Canal Sealer (Angelus)

A MTA endodontic sealer (MTA Fillapex®, Angelus Soluções Odontológicas, Londrina, PR, Brazil) was recently created. According to the manufacturer, its composition after mixture is basically MTA, salicylate resin, natural resin, bismuth and silica.[37]

MTA Fillapex is first paste:paste MTA-based salicylate resin root canal sealer, versatile for every obturation method. It delivers easily and without waste, and exhibits excellent handling properties with an efficient setting time.[37]

Half of MTA Fillapex paste:paste formula contains 13.2% MTA. MTA known for its biocompatibility, yields an impressive, hermetic seal in which the MTA particles expand, preventing microinfiltration. The other half of MTA Fillapex paste:paste formula contains biologically compatible salicylate resin (1,3 butylene glycol disalicylate resin) which is tissue friendly and therefore a better choice over epoxy-based resins, which have been shown to have mutagenic and more cytotoxic effects.

MTA Fillapex two pastes combine in a homogenous mix to form a rigid, but semipermeable structure with excess MTA dispersed throughout. The MTA activity is possible because of its permeability.[37]

Physical Properties

- *Flow:* MTA Fillapex has a high flow rate (27 mm) and a low film thickness, so it easily penetrates the lateral and accessory canals. Regardless of the obturation technique, MTA Fillapex confidently delivers high sealing capability that, unlike other sealers, is not adversely affected by heat.
- *Ideal work time:* 35 minutes perfect for cases with multiple roots canals.
- *Antibacterial properties:* It has excellent antibacterial properties, as solubility is extremely low (0.1%), thus, it does not erode with time like the other sealers making the root susceptible to microgaps that allow bacteria to re-enter the canal. Furthermore, it exhibits a high pH for extended antibacterial action and tendency toward maintaining the calcium releasing relatively constant until 14 days.
- MTA's radiopacity exceeds recommended ISO values, so radiographic diagnosis will never be a question mark. And, should retreatment be necessary, it is easily removed.[38]

It should be only used as endodontic sealer, mainly in endodontic accidents of difficult access, since its physicochemical characteristics differ from gray and white MTA. Notwithstanding, the material presents an alkaline pH similar to that of the clinically and scientifically well-established sealers.[29]

CPM Sealer (EGEO SRL, MTM Argentina SA, Buenos Aires, Argentina)

In 2004, CPM sealer was developed in Argentina (EGEO SRL, Buenos Aires, Argentina), in an attempt to combine the sealing and physiochemical properties of root canal sealer with biological properties of MTA. Considering that MTA is composed basically of Portland cement (Estrela et al 2000) additives used in civil engineering may be considered to improve its clinical deficiency. Powder consists of fine hydrophilic particles that form a colloidal gel in presence of moisture. The main components are tricalcium silicate, tricalcium oxide, tricalcium aluminate and other oxides. The liquid solution consists of saline solution and calcium chloride (Schware T Ley Joe 20028 749). It becomes solid and forms a hard sealer in 1 hour.[39]

The composition after mixing is reported to be 50% MTA (SiO_2, K_2O, $A1_2O_3$, SO_3, CaO and Bi_2O_3), 7% SiO_2, 10% $CaCO_3$, 10% Bi_2O_3, 10% $BaSO_4$, 1% propylene glycol alginate, 1% propylene glycol, 1% sodium citrate and 10% calcium chloride.[19]

Presented as a white modified Portland cement-based material, its most significant difference is the presence of large amount of calcium carbonate, which intends to increase the release of calcium ions and offer good sealing properties, adhesion to dentinal walls adequate flow rate, and biocompatibility. Addition of calcium carbonate reduces pH from 12.5 to 10 after setting. This way surface necrosis in contact with material is restricted which allows action of alkaline phosphatase. According to Vasconselos et al,[40] Endo CPM sealer has an alkaline pH and an ability to release calcium ions.

Studies have demonstrated that addition of calcium chloride to MTA reduces setting time,[41] improve its sealing ability and facilitate insertion into cavities without interfering with its biocompatibility.[14]

When analyzing the Endo CPM sealer regarding its sealing ability on apical plugs, it was observed that there is no difference between grey MTA Angelus (Angelus Solucoes Odontologicas, Londrina, PR, Brazil) and Endo CPM sealer.[36]

It has good antimicrobial activity (Tanomaru 2008) and satisfactory radiopacity.[29] Moreover, culture with fibroblast revealed that it is not cytotoxic.[29] CPM sealer is able to release calcium and hydroxyl ions and is therefore biocompatible.

The study of Bramante et al (2006)[42] allows comparison between the results obtained with CPM sealers and those of the present results. According to those authors, CPM sealers have dimensional adhesion stability through time, among other properties. However, the results observed for this material with regard to sealing ability were not so good, with a mean overall leakage of 4.00 ± 1.00 mm. No significant difference between CPM sealer, AGMTA and MBP sealer in leakage was shown.[27,43]

CPM sealer show higher ratio of leakage as compare to AH Plus and Sealapex. Conversely, in a recent study by Silva Neto and Moraes (2003),[44] MTA was not considered as a good sealer.

MTA Obtura

This sealer was developed by replacing saline with a liquid resin as cure initiator. The composition of the powder in this cement is similar to gray MTA Angelus, consisting of Portland cement clinker and bismuth oxide. The development of MTA Obtura aimed at the achievement of an endodontic sealer combining the biological and sealing properties of MTA. This sealer presented very stable leakage values at 15 and 30 days, as expected for an MTA-based material. Its performance reproduced the good sealing ability of MTA as repair material 26, 27. However, at 60 days MTA Obtura exhibited a considerable increase in leakage.

Study, conducted by Bernardes et al,[45] MTA Obtura presented the lower flow rate (27.65 mm). Because of this property, MTA Obtura will probably penetrate with more difficulty in ramifications and irregularities of root canal walls than the other sealers tested. However, it was superior to the minimum demanded by ADA specification no. 57.[38,46,47]

MTAS Experimental Sealer

It was developed by the authors at discipline of Endo Araraquara Dental School UNESP, University of Estadual Paulista, Sao Paulo, Brazil. It is composed of 80% white Portland cement, zirconium oxide as radio opacifying agent, calcium chloride as additive, and resinous vehicle. It is prepared using powder to liquid ratio of 5:3 by weight which was determined in previous pilot studies. It has similar initial and final setting time to those of AH Plus sealer. According to Tanomaru et al (2011) MTAS showed higher calcium release than MTA and Portland cement except for 14 days period. This may be due to incorporation of calcium chloride to the sealer. This also favors calcium ion release. The pH of MTAS sealer was significantly higher up to 48-hour period and was statistically similar to MTA and Portland cement. This indicates that MTAS has strong capacity of release of hydroxyl ions.

F-doped MTA Cements

Powder-White Portland cement, bismuth oxide, anhydrite, sodium fluoride (Carlo Erba, Italy).

Liquid consist of Alphacaine SP solution. Sodium fluoride was included in FMTA as an expansive and retardant agent. It has been recently demonstrated (Gandolfi et al 2009) that Portland-based cement containing fluorine had a significant expansion in water and in PBS. The expansion of Portland-based cements is a water-dependent mechanism because of water uptake because when immersed in hexadecane oil, no expansion occurred.[16] Moreover, the formation of ettringite, which is responsible for expansion, is accelerated in fluorine-doped cements. Older sodium fluoride was included in the experimental cement.[48] FMTA for its expansive properties and prolonged setting time and its activity on bone and dental pulp cells.[16] Osteoconductive activity is an important property in a sealer for biological response and new bone tissue formation and repair because the extrusion of sealer from the apex is a frequent occurrence in clinical practice. So the fluoride-containing cement revealed a better sealing ability likely because of greater expansion.[48] Moreover, fluorine ions from the cement may penetrate into the dentine and enhance the mineralization of dentine and may also plug and close dentinal tubules. The setting reaction of the cement involves the continuous formation of hydration products that contribute to reducing the microchannels in the cement bulk.[25] The hydration products may react with dentinal ions (Ca and P)[23] and reduce marginal gaps, improving the seal of the apical third by calcium phosphate precipitate formation. The hydration products may also provide the mechanical interlock of the dentine interface and the obliteration of dentinal tubules in absence of smear layer, previously removed by EDTA irrigation.[49]

The large amount of portlandite formed during the hydration of tricalcium silicate causes the early increase in pH up to 12 that may play a protective role in preventing bacteria recontamination of a filled root canal. The formation of calcium hydroxide during the hydration process increases the potential for their clinical use as sealers in orthograde endodontic therapy.

CONCLUSION

This review of MTA -based root canal sealers shows that these materials do not fulfil all the criteria described by Grossman. Most studies are laboratory based or in animal models, which may differ from the clinical situation. The antibacterial effects of MTA based sealers are variable. Cytotoxicity appears to be milder than for other groups of sealers. Thus, MTA based Sealers are favorable alternative as compare to other sealers.

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