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Review Article

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A versatile agent in Endodontics: A Review

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Introduction

In Endodontics, the preservation of the health of the dental pulp and the periodontium are the main goals. Pathways of communication between the root canal system and the periodontium, such as iatrogenic perforations, must also be sealed with restorative materials that prevent bacterial leakage. As these materials come in contact with vital tissues, they must also be biocompatible and should favours regeneration of the involved tissues to their pre-disease status.

Many materials have been used to seal the pathways of communication between the root canal system and the oral cavity, as well as the periradicular tissues. These include Amalgam, Zinc oxide-eugenol cements such as Super-EBA & IRM, Cavit, Composite resins and Glass ionomer cements. The main disadvantages of these materials include microleakage, varying degrees of toxicity and sensitivity to the presence of moisture[1].

An ideal endodontic repair material should adhere to tooth structure, maintain sufficient seal, be insoluble in tissue fluid, dimensionally stable non resorbable, radio opaque and exhibit bio compatibility if not bioactive. A number of materials have historically been used for retrograde fillings and perforation repair but none of these have been able to satisfy total requirement of an ideal material.

Recently a material called **Mineral Trioxide Aggregate** has been investigated as a potential compound to seal off pathways of communication between the root canal system and the external surface of the tooth.

This material was introduced to dentistry, in the field of endodontics in 1993 by Mahamoud Torbinejad at Loma Linda University, as a material for root end filling and perforation repair.[2]

Since its introduction as a root end filling material in 1993, the use of MTA has expanded to many applications of root repair and bone healing. These applications include direct pulp capping, repair of root and furcation perforations and apexification[3,4]. MTA may be ideal material for use against bone, because it is the only material that consistently allows for the overgrowth of cementum and formation of bone and may facilitate the regeneration of periodontal ligament[5].

Historical background of MTA

At the end of the 1980's, the team of Mahamoud Torbinejad, at the Loma Linda University of California, centered their research on the development of a material which would have various properties:

Sealing, biocompatibility, absence of toxicity; insensitivity to moisture, absence of corrosion, radiopacity etc. The US Food and Drug Administration (FDA) approved MTA in 1998 as a therapeutic endodontic material for human.The material was marketed in the year 1999, under the name of ProRoot MTA (Dentsply, Tulsa, OK).The white colored version of MTA known as - tooth coloured ProRoot MTA was marketed in the year 2002 (Dentsply, Tulsa, OK).

Composition of MTA

MTA consists of 50-75% (wt) calcium oxide is a powder consisting of fine hydrophilic particles of:

- Tricalcium silicate
- Tricalcium aluminate
- Tetracalciumaluminoferrite
- Tricalcium oxide
- Silicate oxide
- Bismuth oxide for radiopacity.

It also contains small amounts of other mineral oxides such as magnesium oxide, calcium sulphate and potassium sulphate. These modify its physical & chemical properties.[4]

Classification

Gray MTA (GMTA) –Marketed as

a) ProRoot MTA (Dentsply, Tulsa, OK)
b) MTA – Angelus (Angelus – Brazil)

Table 1

ProRoot MTA	MTA-Angelus
Portland cement – 75%	Portland cement – 80%
Bismuth oxide – 20%	Bismuth oxide – 20%
Calcium sulfate dehydrate – 5%	

White MTA (WMTA) –Marketed as tooth-colored Pro Root MTA

Difference between Gray and White MTA

The major difference appears to be in the concentrations of Al_2O_3, MgO and especially FeO (Black oxide) which are considerably higher in GMTA as compared to WMTA. The absence of significant FeO (Black oxide) in WMTA is most likely the cause of the change in colour from gray to white. The particle size of WMTA is smaller as compared to GMTA, thus WMTA gives an overall smoother mixture. GMTA contains tetracalciumaluminoferrite, while this substance is absent in WMTA[6].

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Properties of MTA

Setting time: MTA is prepared by mixing its powder with sterile water in a 3:1 powder to liquid ratio. MTA has a setting time of 2 hrs & 45 minutes (+/-5 min) and requires moisture for its complete setting. Setting time is longer than Amalgam- 4 min (+/-30 sec); Super-EBA- 9 min (+/-30 sec); IRM, 6 min (+/-30 sec). Gray MTA exhibits significantly higher setting time than white MTA.

Hydration of MTA powder results in a colloidal gel that solidifies to a hard structure in less than 3 hours.

The characteristics depend on the size of the particles, P:L ratio, temperature, presence of water and entrapped air. The setting time of amalgam is shortest while that of MTA is longest. One of the main disadvantages with using MTA is its extended setting time and difficult handling[7].

Stowe et al (2004) revealed that the MTA/chlorhexidine mixture seemed to set more rapidly (1-2 mins) than the MTA/sterile water mixture (5-6 mins) and take on a more crumbly texture on placement.

Setting expansion: WMTA expands slightly more than GMTA.

Color & Particle size: MTA is available as powder containing fine crystalline hydrophilic particles (already described) and requires water for mixing and setting. It is available as both White and Gray powder. The mean particle size for both powders is 10 µm (Range is 0.1 – 100 µm). WMTA has slightly smaller particle size compared to GMTA.

pH value of MTA: The pH of MTA was measured with pH meter using a temperature compensated electrode. The pH of MTA just after mixing was 10.2 and it rose to 12.5 in 3 hours, thereafter it remained constant because of the constant release of calcium from MTA and the formation of Calcium Hydroxide. Comparing pH values of GMTA with WMTA, the latter material displays a significantly higher pH value 60 minutes after mixing[8].

Solubility of MTA: The solubility of MTA after setting is similar to that of Amalgam & Super EBA, but it is less soluble as compared to Calcium hydroxide. WMTA demonstrates significantly more soluble than GMTA. Fridland et al (2003) the solubility was determined according to ISO 6876 or ADA #30. This study found that calcium hydroxide was the main compound released by MTA in water. Clinically only a very small fraction of MTA would be in contact with the aqueous environment eg. periradicular tissues[9].

The degree of solubility increases with the amount of water used in preparing the mix. 0.33 W: P is considered to be ideal.

Thus the factors affecting solubility of MTA-W:P ratio- Higher the w: p ratio, increased MTA solubility. Using more water would increase calcium release from MTA. Addition of bismuth oxide to MTA, which is insoluble in water, decreases the solubility of MTA.

Compressive strength: The compressive strength of MTA is significantly less than that of amalgam, IRM, and super EBA after 24 hrs. However, after 3 weeks, compressive strength of MTA is slightly higher than IRM. Amalgam showed the highest compressive strength[4]. Because the dicalcium silicate hydration rate is slower than that of tricalcium silicate, the compressive strength of MTA reach their maximum several days after mixing[8]. The compressive strength of Super EBA was significantly greater than that of IRM and MTA after 24h; compressive strength of

IRM was significantly more than MTA at the same time interval. The compressive strength of all cements increased after 3 weeks. The compressive strength of MTA at 24 hr was 40 MPa and at 21 days it increased to 67.3 MPa.

Factors affecting the compressive strength of MTA-

- The liquid that is mixed the material.
- The condensation pressure on the material.
- The pH value of the mixing liquid and the condition of MTA storage.

Compressive strength of WMTA at 3 & 28 days after mixing is less than GMTA.

Radiopacity: MTA was found to be less radiopaque (7.17) than amalgam but more radiopaque than Super EBA & IRM. Its radiopacity is greater than that of dentin and gutta-percha. So it should be easily distinguishable on radiographs when used as root end-filling material or for perforation repair. Bismuth oxide in MTA is responsible for its radiopacity[4].

Marginal adaptation & Microleakage: Most endodontic failures occurs as a result of leakage of irritant from pathologically involved root canals in to the periradicular tissues. Marginal adaptation and microleakage are important factors in success or failure of root end fillings or perforation repair. MTA has got very good marginal adaptation.

Biocompatibility: Biocompatibility is defined as the ability of a material to perform with an appropriate host response in a specific application. This means that the tissue of the patient that comes into contact with the materials does not suffer from any toxic, irritating, inflammatory, allergic, genotoxic or carcinogenic action[10]. Torabinejad and colleagues performed a series biocompatibility studies with MTA. They were found it to be non-mutagenic and less cytotoxic than Super EBA and amalgam. In animal studies MTA was the only material among the various material studied, that allowed cementum overgrowth. In vitro studies of human osteoblasts showed that MTA stimulated cytokine release and interleukin products IL-Ia, IL-Ib, IL-6 & M-CSF. These studies suggest that MTA is not just an inert material but may actively promote hard tissue formation.[11]

Antibacterial properties: Several independent studies have shown that certain microorganisms are repeatedly recovered from previously root-filled teeth that have become infected. These are chiefly *Enterococcus*, *Actinomyces*, *Propionibacterium*, *yeasts* and *Streptococcus*, with occasional reports of other types. Thus material used for root end filling should be bactericidal or bacteriostatic. The MTA/water mixture was inhibitory to *S. aureus*, *E. faecalis*, and all of the anaerobes tested including *F. nucleatum.* Estrela et al (2000) reported that antifungal action of Gray MTA against C. *albicans* was limited during 48 hour period.[12]

Hydration: On hydration both MTA and PC would be expected to produce calcium silicate hydrate gel and calcium hydroxide. This would explain the similar mode of action of MTA and calcium hydroxide. It is assumed that the hydration mechanism of MTA is similar to that of PC. However, there is a lack of precise knowledge of the hydration mechanism of MTA.

Mixing of MTA

MTA powder must be kept in containers with tight lids and away from moisture. According to manufacturer of PROROOT^{TM} (Dentsply. Tulsa Dental, Tulsa OK 74136) MTA powder should be mixed with sterile water at a ratio of 3:1 on a glass or paper slab with the aid of plastic or metal spatula. The mixture can be carried in a plastic or metal carrier to the intended site of the operation. If the area of application is very wet, the extra moisture can be removed with a piece of dry gauze or foam.

Placement of MTA

MTA has a consistency that is unlike any other dental material that are currently in use and it has correctly been described as "difficult to handle" in many circumstances. When properly mixed it resembles wet sand and therefore is not easily condensable. It is used similar to loose, wet cement in that it must be teased into place and should not be "packed" with a plugger. Removal of too much of the moisture can adversely affect the set. Several devices can be used to apply it. A messing gun or specially designed Dovgan Carriers are best. When using it as a canal filling material or in apexification, low powered ultrasonics can often be helpful in getting rid of voids and helping the material flow in to place.

Mechanism of action of MTA

MTA is a bioactive material. It has got ability to form an apatite-like layer on its surface when it comes in contact with physiologic fluids or with simulated tissue fluids. The inductively coupled plasma atomic spectroscopy data presented above indicate that MTA undergoes dissolution, releasing all of its major cationic constituents and triggers the precipitation of hydroxyapatite i.e. MTA undergoes dissolution in tissue fluids releasing Ca, Si, Bi, Al, and Mg. Of all the ions released, calcium is the most dominant, because it is sparingly soluble in biologic fluids, it leads to the precipitation of hydroxyapatite (HA). Production of HA is a very desirable phenomenon and a sign of biocompatibility. After the placement of MTA in root canals and its gradual dissolution, HA crystals nucleate and grow, filling the microscopic space between MTA and the dentinal wall. Initially, this seal is mechanical. With time, we conjecture that a diffusion-controlled reaction between the apatite layer and dentin leads to their chemical bonding. The result is the creation of a seal at the MTA dentine interface. Histologically, this layer has been described as dentinal bridge, osteotypic matrix, osteodentin, and reparative dentin in various animal and human studies. MTA is a bioactive material and has the ability to create an ideal environment for healing. From the time that MTA is placed in direct contact with human tissues, it appears that the material does the following:

1. Forms Calcium Hydroxide (CH) that releases calcium ions for cell attachment and proliferation.
2. Creates an antibacterial environment by its alkaline pH.
3. Modulates cytokine production.
4. Encourages differentiation and migration of hard tissue producing cells.
5. Forms HA (or carbonated apatite) on the MTA.[3]

Indications of MTA

The various indications of MTA are:-

1. Root-end filling - MTA has a higher sealing and lesser sensitivity to moisture than the materials usually used for root-end filling (Amalgam, IRM or Super EBA).[13]
2. Apical stopper in the procedures of apexification.
3. Pulp capping and pulpotomy - MTA allows the formation of a thick dentinal bridge, composed of tubular dentine in a pulp free from irritation in a manner more reproducible than with calcium hydroxide.
4. Sealing of perforations.
5. Furcation repair.
6. As an intracoronal barrier during internal bleaching of endodontically treated teeth.
7. Prophylactic treatment of dens-in-dente and dens evaginatus.
8. To repair Internal and external root resorption.
9. To repair a vertical and horizontal root fracture.
10. As obturating material.
11. As a coronal plug.
12. For the retention of post.
13. As root canal sealer.

Advantages

1. The advantage of using a material to form an immediate apical barrier over the conventional apexification treatment is that endodontic treatment can be achieved in a single appointment.

2. MTA can be used as a one stepobturation material in an open apex.
3. 70% of the failures in study of perforation repair were associated with extrusion of repair material. But MTA does not have to be compacted as firmly as amalgam to adapt adequately to the tooth surface.
4. The setting ability of MTA is uninhibited by blood or water. This is an important request of a material which has to be used normally in presence of blood & water and also in teeth with necrotic pulps and inflamed periapical lesions because one of problems in these cases is presence of exudates at the root apex.
5. The slow setting time of MTA is an advantage in that it reduces the amount of setting shrinkage which may help explain MTA's low micro leakage.
6. A major problem in performing endodontics in immature teeth with necrotic pulp and wide open apices is obtaining an adequate seal of the root canal system. MTA has been proposed as a potential material to create an apical plug at the end of the root – canal system, thus preventing the extrusion of filling materials.
7. MTA has an antibacterial effect on few of the facultative bacteria, when comparatively none other test materials had all of antibacterial effects desired.
8. MTA has low solubility and a radiopacity slightly more than that of dentin.

Drawbacks of MTA

The main drawbacks of MTA includes-[14]

1. Presence of toxic elements (arsenic)in the material composition.
2. Difficult handling characteristics.
3. Difficulty in obturation of curved root canals.
4. Long setting time.
5. Absence of a known solvent for this material, and the difficulty of its removal after curing.
6. High material cost.
7. Discoloration potential of teeth treated with GMTA.

Comparison between MTA and portland cement

The first research paper on the chemistry of Portland cement that had potential for dental use demonstrating the similarity of grey MTA to Portland cement was published in 2000(Estrela et al. 2000)[15]. A study comparing the white MTA to the white Portland cement showed the cements to have similar constituents elements except, Bismuth oxide was not present in the Portland cement (Asgary et al. 2004)[16].

Other findings included a higher level of toxic heavy metals and aluminium in Portland cement and difference in particle size distribution. Portland cement exhibited a wide range of sizes whereas MTA showed a uniform and smaller particle size.

Abdullah D, Pittford TR[16] in their study concluded that Mineral Trioxide Aggregate in comparison to Portland cement has:

Smaller mean particle size.
Lesser toxic heavy metals.
Longer working time.
Undergoes additional processing/ purification.

Pulpal reactions: MTA used for pulp capping or partial pulpotomy stimulates reparative dentine formation. MTA-capped pulps showed complete bridge formation with no signs of inflammation (Pitt Ford et al. 1996, Tziafas et al. 2002, Andelin et al. 2003, Faraco& Holland 2004). The same results were obtained when MTA (Loma Linda University) was placed over pulp stumps following pulpotomy (Holland et al. 2001b). This hard tissue bridge formed over the pulp was documented after using ProRoot MTA and MTA Angelus and both grey and white Portland cement (Menezes et al. 2004). The incidence of dentine bridge formation was higher with MTA (Loma Linda University) than with calcium hydroxide (Faraco& Holland 2001).

Periradicular tissue reactions:

When MTA (Loma Linda University) has been used for root-end filling in vivo, less periradicular inflammation was reported compared with amalgam (Torabinejad et al. 1995d). In addition, the presence of cementum on the surface of MTA (Loma Linda University) was a frequent finding (Torabinejad et al. 1997). It induced apical hard tissue formation with significantly greater consistency, but not quantity, in a study of three materials, although the degree of inflammation was not significantly different between the groups (Shabahang et al. 1999).

Again, MTA (ProRoot) supported almost complete regeneration of the periradicular periodontium when used as a root end filling material on non infected teeth (Regan et al.2002). The most characteristic tissue

reaction to MTA was the presence of organizing connective tissue with occasional signs of inflammation after the first postoperative week (Economides et al. 2003). Early tissue healing events after MTA root-end filling were characterized by hard tissue formation, activated progressively from the peripheral root walls along the MTA–soft tissue interface (Economides et al. 2003). Both fresh and set MTA (ProRoot) caused cementum deposition when used after apical surgery (Apaydin et al. 2004). In addition, MTA (ProRoot) showed the most favourable periapical tissue response of three materials tested, with formation of cemental coverage over MTA (Baek et al. 2005). Use of MTA (ProRoot) in combination with calcium hydroxide in one study has shown that the periodontium may regenerate more quickly than either material used on its own in apexification procedures (Ham et al. 2005). All these studies in vivo have shown a favourable tissue response to MTA.

Subcutaneous and intra-osseous implantation

Histological evaluation of tissue reaction to MTA has been evaluated by subcutaneous and intra-osseous implantation of the materials in test animals. Subcutaneous implantation in rats showed that MTA (ProRoot) initially elicited severe reactions with coagulation necrosis and dystrophic calcification (Moretton et al. 2000, Yaltirik et al. 2004). The reactions, however, subsided with time. Osteogenesis was not observed with MTA (Loma Linda University) upon subcutaneous implantation indicating that the material was not osteo-inductive in this tissue.

Implantation of MTA in rat connective tissue (Holland et al. 2001a, 2002) and dog (Holland et al. 1999b, 2001b) produced granulations that were birefringent to polarized light and an irregular structure like a bridge was observed next to the material. Reactions to intraosseous implants of MTA (ProRoot) were less intense than with subcutaneous implantation. Osteogenesis occurred in association with these implants (Moretton et al. 2000). With intra-osseous implantation the tissue reactions to the material subsided with time over a period of 12 weeks (Sousa et al. 2004). MTA (ProRoot) implantation in the mandible of guinea pigs resulted in bone healing and minimal inflammatory reactions (Saidon et al. 2003). The tissue reaction to MTA (Loma Linda University) implantation was the most favourable reaction observed in both tibia and mandible of test animals, as in every specimen, it was free of inflammation. In the tibia, MTA (Loma Linda University) was the material most often observed with direct bone apposition (Torabinejad et al. 1995c, 1998). In another study MTA (ProRoot,) was shown to be biocompatible and did not produce any adverse effect on microcirculation of the connective tissue (Masuda et al. 2005)

Comparison between proroot MTA & MTA Angelus

According to the manufacturer's material safety data sheet**,** Pro-Root MTA is composed of 75% Portland cement, 20% bismuth oxide and 5% dehydrated calcium sulfate. MTA Angelus is composed of 80% Portland cement and 20% bismuth oxide, with no calcium sulfate. MTA Angelus has greater release of calcium in the first 24 hours of activation and a lower concentration of bismuth (grey version only). ProRoot MTA has significant lower solubility than Angelus MTA and the mixture of Angelus MTA and distilled water showed the highest solubility after 28 days and in another words the solubility of both materials increases over time.[18]

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