Mineral Trioxide Aggregate—A Review

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Mineral Trioxide Aggregate (MTA) is a new material with numerous exciting clinical applications. MTA promises to be one of the most versatile materials of this century in the field of dentistry. Some of the appreciable properties of MTA include its good physical properties and its ability to stimulate tissue regeneration as well as good pulp response. In this article the availability, composition, manipulation, setting reaction, properties and clinical applications of MTA in pediatric practice has been reviewed.

Key Words: *Mineral Trioxide Aggregate, MTA, Review*
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INTRODUCTION

Quest for newer materials are never ending especially in the field of dental science. Various materials have been formulated, tested and standardized to obtain maximum benefit for good clinical performance. One such new material is Mineral Trioxide Aggregate (MTA), which was introduced by Mahmoud Torabinejad at Loma Linda University, California, USA and the first literature about the material appeared in 1993.1 Mineral Trioxide Aggregate (MTA) was originally formulated to provide the physical properties,[2] setting requirements[3] and characteristics necessary for an ideal repair and medicament material.[1,4,5] Studies on MTA reveal that it not only exhibits good sealing ability, excellent long term prognosis, relative ease of manipulation and good biocompatibility but favors tissue regeneration as well.[1,2.6,7,8,9,10,11]

MTA has been approved by the U.S. Food and Drug Administration in the year 1998.[9] With its numerous exciting clinical applications, MTA promises to be one of the most versatile materials of this century in the field of dentistry. Some of the appreciable properties of MTA include its good physical properties and its ability to stimulate tissue regeneration as well as good pulp response. In this article we shall review the availability, composition, manipulation, setting reaction, properties and clinical applications of MTA in pediatric dental practice.

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Availability of Mineral Trioxide Aggregate

Mineral trioxide aggregate (MTA) is a fine hydrophilic powder available is single use sachets of 1 gram. Some companies also provide premeasured water sachets for ease of use.[4,5,12]

Some of the commercially available MTA are ProRoot MTA (Dentsply), White ProRoot MTA (Dentsply), MTA- Angelus (Solucoes Odontologicas), MTA- Angelus Blanco (Solucoes Odontologicas), MTA Bio (Solucoes Odontologicas).[12]

The important barriers to the widespread use of MTA are its cost and difficulty in storage. The cost of MTA (single use) is approximately 60-75 USD.[12]

Composition of Mineral Trioxide Aggregate

MTA consists of tricalcium silicate, tricalicum aluminate, tricalcium oxide, silicate oxide and bismuth oxide.[2] Its composition is said to be similar to Portland cement except for the absence of bismuth oxide in Portland cement. Bismuth oxide is added (17-18 wt%) to improve the properties and the radioopacity.[2] The MTA particles are smaller and uniform in size[13] whereas the particle size of Portland cement vary in size. Though Bismuth oxide is said to improve the radio opacity, MTA-Angelus that contain less bismuth oxide compared to ProRoot MTA, is more radio opaque than ProRoot MTA.[14]

MTA are of two types- grey and white. The white and grey MTA differs mainly in their content of iron, aluminium and magnesium oxides. Asgary et al claim that these oxides are present in less quantity in white MTA[15] while others[14,16] claim total absence of these oxides in white MTA**.**

White MTA contains smaller particles with a narrower range of size distribution than grey MTA.[17] The chemical analysis and X-ray diffraction have demonstrated that 18.8% of the material is insoluble in water and its crystallinity is close to 80%.[18]

Manipulation and Setting Reaction of Mineral Trioxide Aggregate

The MTA paste is obtained by mixing 3 parts of powder with 1 part of water to obtain putty like consistency. Mixing can be done on paper or on a glass slab using a plastic or metal spatula. This mix is then placed in the desired location and condensed lightly with a moistened cotton pellet.[3, 4, 19]

MTA has a pH of 10.2 immediately after mixing and increases to 12.5 after 3 hours of setting which is almost similar to calcium hydroxide.[2]

MTA powder should be stored carefully in closed sealed containers away from moisture. The mixing time of MTA is crucial. If the mixing of MTA is prolonged, it results in dehydration of the mix. Sluyk et al[3] in their study reported that the mixing time should be less than 4 minutes.

MTA takes longer time to set compared to any other material. The exact time taken to set varies between different studies. According to Torabinejad and colleagues[2] the setting time of grey MTA is about 2 hours and 45 minutes ($\pm$5minutes), whereas Islam et al[20] reported 2 hours and 55 minutes for grey MTA and 2 hours and 20 minutes for white MTA. Extended setting period of MTA is one of its main drawbacks. It is suggested by many investigators that the incorporation of accelerators such as sodium phosphate dibasic (Na_2HPO_4) and calcium chloride ($CaCl_2$) may reduce the setting time.[20,21]

MTA being hydrophilic requires moisture to set, making absolute dryness not only unnecessary but contraindicated. Presence of moisture during setting improves the flexural strength of the set cement. Therefore it is advised to place a wet cotton pellet over the MTA in the first visit followed by replacement by a permanent restoration at the second visit.22,23,24 Hydration of the powder results in a colloidal gel composed of calcium oxide crystals in an amorphous structure (33 percent calcium, 49 percent phosphate, 6 percent silica, 3 percent chloride and 2 percent carbon).[19,25,26] Though moisture is needed for MTA to set, excess moisture results in a mix that is 'soupy' and difficult to use.[9,27]

After mixing, the mix should not be left open on the slab as it undergoes dehydration and dries into a sandy mixture.[19] It should be used immediately after it is prepared.

MTA may be placed into the desired location using hand instruments or ultrasonic condensation. Hand condensation is done with the help of a plugger, paper point or messing gun.[19] Ultrasonic condensation is done by first placing a hand instrument such as a condenser in direct contact with the MTA. Then an ultrasonic instrument is placed touching the shaft of the hand instrument and activated for several seconds.[28] In a study by Aminoshariae et al[29] comparison was made between hand condensation and ultrasonic condensation. They found that hand condensation resulted in a better adaptation of MTA to the walls with less voids compared to the ultrasonic method. MTA is often pressed into place and not condensed with excess pressure.[9] Nekoofar et al[30] reported that although the method of condensation and the amount of condensation pressure did not affect the compressive strength of MTA, an increase in condensation pressure might reduce the surface hardness. The explanation given was that, increasing the condensation pressure probably reduces the space required for the ingress of water which is required to hydrate the cement.

Properties of Mineral Trioxide Aggregate (Figure 1)

1. **Compressive strength:** It takes an average of three to four hours for the MTA material to completely solidify. It has been shown that once it is set, it has a compressive strength equal to IRM and Super EBA but less than amalgam.[31] Compressive strength of MTA within 24 hours of mixing was about 40.0 MPa and increases to 67.3 MPa after 21 days.[2] In comparison grey MTA exhibited greater compressive strength than white MTA.[32]
2. **Radio-opacity:** MTA is less radio opaque than IRM, Super EBA , amalgam or gutta-percha and has similar radiodensity as Zinc Oxide Eugenol.[33,34] The mean radio opacity of MTA is 7.17 mm of equivalent thickness of aluminium, which is sufficient to make it easy to visualize radiographically.[2]
3. **Solubility:** Although the set MTA shows no signs of solubility, the solubility might increase if more water is used during mixing. The set MTA when exposed to water releases calcium hydroxide which might be responsible for its cementogenesis inducing property.[35] An acidic environment does not interfere with the setting of the MTA.[36]
4. **Marginal adaptation and sealing ability:** This property is most vital for any restorative material especially when used for root end filling, repair of perforations, pulpcapping or pulpotomy procedures. Bates et al[37] found MTA superior to the other traditional root-end filling materials. MTA expands during setting which may be the reason for its excellent sealing ability.[38] According to Torabinejad et al[32] MTA seals very superiorly and no gaps were found in any of the experimental specimen. However, amalgam, Super EBA and IRM exhibited gaps ranging from 3.8 to 14.9 microns. MTA has also proved itself to be superior in the bacterial leakage test by not allowing the entry of bacteria at the interface.[39] MTA thickness of about 4 mm is sufficient to provide a good seal.[40] Residual calcium hydroxide may interfere with the adaptation of MTA to dentin thereby reducing its sealing ability either by acting as a mechanical obstacle or by chemically reacting with MTA.[12] This may be important when calcium hydroxide is placed in the cavity in between the appointments prior to the placement of MTA.
5. **Antibacterial and antifungal property:** By virtue of providing a good seal and preventing micro leakage, it can be proclaimed as an antibacterial agent especially against Enterococcus *faecalis* and Streptococcus *sanguis* in vitro.[41] But Torabinejad et al[42] reported that MTA shows no antimicrobial activity against any of the anaerobes but did have some effect on five

(S.*mitis*, S.*mutans*, S.*salivarius*, Lactobacillus and S.*epidermidis*) of the nine facultative bacteria. Since most of the flora in the root canal are strict anaerobic bacteria with few facultative anaerobes, MTA may not be beneficial as a direct antibacterial in endodontic practice.

6. **Reaction with other dental materials:** MTA does not react or interfere with any other restorative material. Glass Ionomer cements or composite resins, used as permanent filling material do not affect the setting of MTA when placed over it.[43]
7. **Biocompatibility:** Any material that is identified to be used in humans or animals should be biocompatible without having toxic or injurious effects on biologic tissues and its function. Kettering and Torabinejad studied MTA in detail and found that it is not mutagenic and is much less cytotoxic compared to Super EBA and IRM.10 This supports the superiority of MTA over formocresol as a pulpotomy medicament.

   Genotoxicity tests of cells after treatment of peripheral lymphocytes with MTA showed no DNA damage.[44] On direct contact they produce minimal or no inflammatory reaction in soft tissues and in fact are capable of inducing tissue regeneration.[45] In animal studies, MTA produced cementum growth which was very unique compared to other root-end filling materials.[11] Arens and Torabinejad[8] reported osseous repair of furcation perforations treated with MTA. MTA showed good interaction with bone-forming cells: cells remained viable and released collagen even after 72 hours with good adherence.[46]

   Investigations by Koh et al[47] revealed that MTA offers a biologically active substrate for bone cells and stimulates interleukin production. MTA is also said to stimulate cytokine production in human osteoblasts.
8. **Tissue regeneration:** MTA is capable of activation of cementoblasts and production of cementum.[11] It consistently allows for the overgrowth of cementum and also facilitates regeneration of the periodontal ligament. MTA allows bone healing and eliminates clinical symptoms in many cases.[9]
9. **Mineralization:** MTA, just like calcium hydroxide, induces dentin bridge formation.[5] Many investigators believe that the hard tissue bridge deposited next to MTA is because of the sealing property, biocompatibility, alkalinity and other properties associated with this material.[19,32,48] Holland et al[49] found calcite crystals nearest to the opening of the dentinal tubules close to MTA. They theorized that the tricalcium oxide in MTA reacts with tissue fluids to form calcium hydroxide, resulting in hard-tissue formation in a manner similar to that of calcium hydroxide. But the dentin bridge that is formed with MTA is faster, with good structural integrity and more complete than with calcium hydroxide.[50] MTA also proves to be better at stimulating reparative dentin formation and maintaining the integrity of the pulp.[51,52] MTA consistently demonstrated less inflammation, hyperemia and necrosis, as well as a thicker dentinal bridge with more frequent odontoblastic layer formation, than that seen with calcium hydroxide.[53]

Clinical Applications of MTA in Pediatric Dentistry

Mineral trioxide aggregate (MTA) resists bacterial leakage and may provide protection for the pulp, allowing repair and continued pulp vitality in teeth when used in combination with a sealed restoration. Due to all these vital properties, MTA finds application in many clinical procedures.

Following are the Clinical Applications of MTA in Pediatric Dentistry:

1. **Pulp Capping:** MTA has been proposed as a potential medicament for capping of pulps with reversible pulpitis because of its excellent tissue compatibility.[5,9,54] It is much superior to the routinely used calcium hydroxide based on the tissue reaction and the amount and type of dentin bridge formed.[55] Although both MTA and calcium hydroxide are alkaline, there is a wide difference in tissue reaction between these materials. Calcium hydroxide is associated with tissue necrosis and inflammation during the initial period of placement but no such inflammation or necrosis was seen in the pulp tissue adjacent to MTA.[53] With MTA, dentin bridge after pulp capping was seen at about 1 week which steadily increased in length and thickness within 3 months of capping whereas following pulp capping with calcium hydroxide, the dentin bridge was less consistent and had numerous tunnel defects.56

   Since there is no pulpal necrosis, pulp tissue heals faster with MTA.[57] Aeinehchi et al[53] reported a 0.28 mm thick dentin bridge by 2 months which increased to 0.43 mm by 6 months. The dentin bridge formed with calcium hydroxide was only 0.15 mm by 6 months. But follow up studies indicate that there are no significant differences between MTA and Calcium hydroxide with regard to clinical and histological changes.[58] Bogen et al[54] did a study using MTA as the pulp capping agent for cariously exposed young permanent teeth with reversible pulpitis and followed up the cases for 9 years. They reported a success rate of 97.6% based on thermal test, clinical examination and radiographic assessment. All the teeth showed complete root formation.

2. **Pulpotomy**: Formacresol has been routinely used as a pulpotomy agent for deciduous teeth. But this material has been criticized for its tissue irritating, cytotoxic and mutagenic effects. MTA was tested and found to be an ideal material with low toxic effects, increased tissue regenerating properties and good clinical results.[59,60] In a histological study by Jabbarifar et al[61] MTA was found to be a better choice as pulpotomy

material along with bioactive glass when compared to hydroxyappatite and formacresol. Furthermore, the presence of blood has little impact on the setting or degree of leakage when a 2-millimeter-thick layer of MTA was placed over the pulp during pulpotomy.[62,63] Discoloration of teeth was observed in 60% of the deciduous molars treated with MTA. But this was not of significance since the tooth was later restored with a stainless steel crown.[27]

Steps Involved in the Placement of a Pulp Capping or Pulpotomy Agent[19]

- Bleeding is controlled with a cotton moistened with Sodium Hypochlorite (NaOCl).
- MTA is placed over the exposed pulp using a large amalgam carrier
- The material is padded into place with a moist cotton pellet
- The moist cotton pellet is placed on the MTA and the material is allowed to set. The rest of the cavity is filled with temporary filling material
- In the next visit the temporary material is removed along with the cotton pellet and the tooth is restored with a permanent restoration
- The entire cavity can also be filled with MTA, instead of temporary material. A wet piece of gauze is placed between the treated tooth and the opposing tooth for 3-4 hours. This can be done only in compliant patients. After 1 week, about 3-4 mm of the material from the occlusal surface is removed and final restoration placed over the set MTA.

3. **Root-End Filling of Immature Permanent Teeth:** Endodontic surgery followed by root-end filling may at times be necessary for certain teeth where routine endodontic treatment is not possible. This procedure involves surgical exposure of the root apex, root resection and plugging the apical foramen with a suitable material that provides complete apical seal, is non toxic, non resorbable, dimensionally stable and radio opaque.[42] Many materials have been used as root-end filling agents but the main disadvantage is their failure to prevent leakage and the lack of biocompatibility. Amalgam, although routinely used as a root-end filling material, proved to be much inferior when tested with MTA. MTA treated teeth exhibited significantly less inflammation, more cementum formation and regeneration of periradicular tissues.[11,64]

Steps Involved in Root-End Filling[19]:

- Flap is raised under local anesthesia. This is followed by ostectomy, root-end resection and hemorrhage control
- MTA is placed into the prepared root end cavity with a small carrier and mildly patted into place with a plugger
- Since placement of wet cotton over the setting MTA is not possible, moist environment can be created by inducing mild bleeding from adjacent tissues and bringing the blood over the MTA
- The area should not be rinsed after the placement of MTA
- Flap is then sutured back into place.

4. **Apical Plug**: Conventional management of an immature non vital permanent tooth is apexification with calcium hydroxide.[65] The purpose of apexification is to obtain an apical barrier so as to prevent the extrusion of the obturating material. But the disadvantage of using calcium hydroxide is the extended time taken for the completion of the procedure which may range anywhere between 3 to 54 months.[66] Other disadvantage of calcium hydroxide as noted by Andreasen et al[67] is that the tooth with calcium hydroxide placed for more than 100 days showed a significant reduction in fracture resistance. This problem is solved with the use of MTA. An MTA plug of 4mm thickness placed at the apical region is adequate to form a barrier, sealing the canal from the periapical area.[68,69]

Steps Involved in Apical Plug Placement [19]:

- Access opening is done under local anesthesia and rubber dam
- The root canal is cleaned with intracanal irrigants
- Calcium hydroxide paste can be placed in the canal to disinfect for about 1 week
- Calcium hydroxide is removed by rinsing. Excess moisture is removed from the canal
- Mixed MTA is placed in the cavity using a large amalgam carrier. The material is pushed towards the apical foramen with a plugger or paper points
- The apical plug should be at least 3-4 mm thick and this should be checked radiographically
- If the apical plug could not be placed adequately, the entire material is rinsed from the canal with sterile water and the procedure repeated
- A moist cotton pellet is placed in the canal and the tooth is temporarily restored.
- After 3 hours, the remaining canal is obturated with gutta percha and a permanent restoration is then placed.

5. **Obturation of the Canal:** Mineral Trioxide Aggregate can be used to obturate the root canal of a retained primary tooth where the succedaneous permanent tooth is absent. One such application on a retained primary mandibular second molar was reported by O'Sullivan and Hartwell.[70] This technique is not recommended for obturation of primary teeth that are expected to exfoliate since it is anticipated that Mineral Trioxide Aggregate would be absorbed slowly, if at all.

6. **Repair of Perforation:** Root perforation can be iatrogenic or due to severe extension of internal resorption leading to a communication between the root canal and the periodontium. There may be severe inflammation and granulation tissue formation with extensive hemorrhage. Repairing such a communication requires a material that should be biocompatible, should withstand moisture without dissolving and should have good sealing ability. Lee and associates[1] found that MTA had significantly less leakage and less tendency for overfilling or underfilling, when compared with amalgam and IRM.

Steps involved in the repair of perforation[19]:

- Procedure is done under anesthesia and rubber dam
- After performing access opening, the canals are irrigated with NaOCl.
- Calcium hydroxide can be placed in the canal in between appointments which will help control hemorrhage.
- Before placing MTA, calcium hydroxide should be completely removed.
- The apical portion of the canal is obturated with sectional cone technique using gutta percha and root canal sealer.
- MTA is placed into the defect and moist cotton pellet is placed over it. The access cavity is closed with a temporary restoration.
- The remaining portion of the canal is restored with a permanent filling material after at least 3-4 hours.

7. **Repair of fracture**:
   a) **Horizontal Root Fracture:** Schwartz et al[9] described a case of upper central incisor with Cl-III mobility and horizontal root fracture. The apical portion in which the pulp was vital was left intact. The pulp from the coronal fragment was removed, calcium hydroxide placed in the canal and the tooth splinted. After six weeks, calcium hydroxide was removed from the canal. The canals were dried and MTA was placed at the fracture site as a barrier. The canals were then obturated with gutta percha. At the six month recall, the tooth was asymptomatic.
   b) **Vertical Root Fracture:** Torabinejad and Chivian[19] have suggested the use of MTA for sealing vertical root fractures. The tooth canal is first filled with composite resin. The fracture line is assessed by reflecting a flap. A groove is then made with a small bur along the fracture line using continuous waterspray. MTA is placed in the prepared groove, covered with a resorbable membrane and the flap sutured back into place. They have also suggested that the tooth can be intentionally extracted to repair the fracture if the fracture line cannot be assessed by flap surgery followed by reimplanting it back into the socket. The patient should be strictly told to maintain oral hygiene.

8. **To Obtain Coronal Seal Before Bleaching:** MTA can be used to provide coronal seal in a tooth that requires internal bleaching. A thickness of 3-4 mm of MTA placed over the condensed gutta percha in the access cavity prevents the ingress of bleaching agents. Wet cotton is placed over the MTA and the remaining cavity filled with temporary restoration. Later the temporary material is removed and after completion of bleaching a permanent restoration is given as indicated.

CONCLUSION

MTA is an excellent material with innumerable qualities required of an ideal material. One of the important applications of MTA in Pediatric Dentistry is in the management of non vital immature teeth. Apexification with calcium hydroxide is comparatively unpredictable and also makes the tooth less resistant to fracture. Single visit MTA apical plug placement has proved to be a successful alternative in such cases. MTA is also successful in the formation of a dentin bridge that is thicker with lesser defects and side effects. MTA need to be explored by clinicians so that its beneficial properties can be extracted.

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