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RESEARCH ARTICLE

MINERAL TRIOXIDE AGGREGATE

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ABSTRACT

Metal Trioxide Aggregate (MTA) is a versatile material used in dentistry which finds its uses in an array of clinical procedures both in restorative dentistry as well as in endodontics. Though introduced in **dentistry** in 1990s this product has seen maximum research being conducted on it. This review article talks about MTA, its composition, its properties, its different uses and the recent advances advances till date.

INTRODUCTION

Mineral Trioxide Aggregate (MTA) is an important dental material which was firstly developed by Mahmoud Torabinejad. It is mainly produced from Portland cement combined with bismuth oxide powder. It is considered as bioactive material. It is hard, biocompatible due hydraulic in nature because of which it is recommended for pulp capping, pulpotomy and as tooth filling material [1-7].

Types of MTA: On the basis of color, there are two main types of MTA i.e., Grey MTA and white MTA. These two mainly differ because of the concentration Al_2O_3, MgO and FeO[8].

Composition of MTA: The major component of MTA is Portland (which mainly consists of dicalcium silicate and tricalcium silicates) and bismuth oxide and some traces of SiO_2, CaO, MgO, K_2SO_4 and Na_2SO_4. Portland cement consists of dicalcium silicate, tricalcium silicate, tricalcium aluminate, gypsum, and tetra calciumaluminoferrite[9-11].

Properties of MTA: Chemical, physical, and mechanical properties of MTA include compressive strength, solubility, sealing ability, antibacterial and antifungal property, reaction with other dental materials, biocompatibility etc.

Compressive strength: From previous studies it is revealed that compressive strength of GMTA is greater than WMTA [12].

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Solubility: Solubility of MTA increases on increasing the water content [13].

Sealing ability: Bates et al. found that MTA has very good sealing ability because it expands during setting [14].

Reaction with other dental materials: Nandini S et al. in their studies found that MTA does not react with other dental materials [15].

Biocompatibility: From previous studies it is explored that MTA is a biocompatible material due to which it is highly recommended as filling material [16].

Uses of MTA: MTA is used in pulp capping, pulpotomy, root canal filling, furcation perforation repair, resorption repair etc.[17-20].

Disadvantages of MTA: MTA has some known drawbacks such as a long setting time, high cost, and potential of discoloration. Hydroxyapatite crystals form over MTA when it comes in contact with tissue synthetic fluid. This can act as a nidus for the formation of calcified structures after the use of this material in endodontic treatments[21].

Immunologic effects of MTA for repair and healing: Mineral trioxide aggregate (MTA) would influence healing of periapical tissues by modulating the production of growth factors and cytokines from PDL fibroblast. Many biologic molecules get involved in wound heal process by several mechanisms. Growth factors and cytokines are mediator molecules that have important roles in tissue development and

repair. Among the mediator molecules, transforming growth factor - beta 1, FGF-2 and cytokine interleukin 6 (IL-6) are one of the critical factors. TGF-beta 1 is known to be related to the mitogenesis of cells and remodeling of extracellular matrix while FGF-2 has a potent angiogenic effect. IL-6 is one of the well-known and plentiful inflammatory cytokines. In this regard Koh et al studied the cytokine production from osteoblastic cells in contact with MTA and they found that MTA has up-regulating effect on the expression of IL-1alpha, IL-1beta and IL-6 from osteoblast. Main function of cytokines are the recruitment and activation of immune and inflammatory cells. They activate the defensive mechanisms of host and prepare the basis for tissue regeneration. MTA induces the release of neutrophil chemotactic factor substances from macrophages and mast cells with participation of IL-1beta, MIP-2 (Macrophage inflammatory protein-2) and LTB-4 (Leukotriene B 4).

Table 1. Chemical compositions of GMTA and WMTA [8]

Chemical compound	GMTA (wt%)	WMTA (wt%)
Calcium oxide	40.45	44.23
Silicon dioxide	17.00	21.20
Bismuth trioxide	15.90	16.13
Aluminum oxide	4.26	1.92
Magnesium oxide	3.10	1.35
Sulfur trioxide	0.51	0.53
Chlorine	0.43	0.43
Ferrous oxide	4.39	0.40
Phosphorus pentoxide	0.18	0.21
Titanium dioxide	0.06	0.11
Carbonic acid	13.72	14.49

MTA AS A SEALER

The aim of this section is considering MTA as root canal sealer and various laboratory experiments and clinical studies of MTA based root canal sealers. Root canal sealers are used to attain impervious seal between the core material and root canal wall. The biomaterial mineral trioxide aggregate was approved for endodontic use by the U.S. food and drug administration in 1998.[22] MTA has been shown to promote favorable tissue reactions characterized by the absence of severe inflammation, the presence of fibrous capsule, and the induction of mineralized repair tissue. [23,24] Bates et al (1996) found that MTA is superior to the other traditional root end filling materials.[25] In 1999 study by Holland et al compared glass ionomer root canal sealer 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. [26]

According to Shipper et al and Torabinejad et al (1995), MTA has excellent sealing ability which may occur because MTA expands during setting reaction. The sealing ability of MTA is enhanced in presence of moist environment due to setting expansion so it has been suggested that a moistened cotton pellet should be placed in contact with MTA before the placement of the permanent restoration.[27] Valois et al (2004) found that about 4 mm thickness of MTA is sufficient to ensure good sealing. [28] In 2007 Holland et al 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. Thisinterface demonstrates superior marginal adaptation.[29]

Grey MTA appears to be a greater sealing agent than White MTA. A recent investigation examined the sealing ability of grey MTA, white MTA and vertically compacted gutta percha against the challenge of human saliva. [30] After 42 days, grey MTA showed leakage in 9.1% of samples, white MTA leaked in 36.4% of samples. MTA has also been shown to provide a superior seal when used as a double scaling intra-coronal material over compacted gutta percha [31]and is equivalent to glass ionomer as an intraorifice or coronal barrier.[32,33] MTA-Angelus scaler consists of tricalcium silicate, dicalcium silicate, tricalcium aluminate, tetra calciumaluminoferrite, bismuth oxide, iron oxide, calcium carbonate, several investigators have evaluated the anti-bacterial effect of MTA angelus. They found that this sealer has an antibacterial effect again Micrococcus Lutes, S Aureus, E Coli, Pseudomonas Aeruginosa and Candida Albicans when compared to Portland cement. [34] An MTA fillapexincorporates most of the proven advantages of MTA in root canal sealant [35]. It is a double paste sealant containing a base and a catalyst that when mixed can be used as a root canal sealant in combination with a single gutta percha master cone [36,37]. It has been shown to promote the formation of new tissue, including cementum at the root apex [35,36] and aid tissue regeneration in sites of bone lesions [35] ,radiopaque[38,39] in agreement with American dental association specification No. 57[40], easily handled [35] with good dentinal tubule, accessory and lateral canal penetration due to the presence of nanoparticles[35,36,41].

Advantage of using MTA as Root Canal sealer

1. Sealers containing MTA are highly biocompatible and stimulate mineralization.
2. Forms calcium hydroxide that releases calcium ion for cell attachment and mineralization.
3. MTA as a sealer provides effective seal against dentin and cementum and promotes biologic repair and regeneration of periodontal ligament.
4. MTA is a non-mutagenic and neurotoxic.
5. It is not sensitive to moisture and blood contamination.
6. It modulates cytokinin production [42].

Disadvantages

1. May cause discoloration due to release of ferrous ions
2. Long setting time about 2 h 45 m
3. Working time is less than 4 min.
4. Compressive strength is inadequate.

Use of MTA as Root end filling Material and Perforation repair: MTA is originally developed for root end filling. There were several different materials such as amalgam, reinforced ZOE, GIC, Composite resins for root end filling after apicoectomy. MTA a reinforced Portland cement, calcium silicate cement was found to be less cytotoxic and better results in biocompatibility and microleakage sealing ability, giving it more success over root end filling materials. MTA is not acceptable as ideal root end filling material because MTA has some drawbacks of toxic heavy metal presence, discoloration., difficult handling, short working time, long setting time washout before setting and washout after set .The long term effects of MTA as a root end filling material compared to other materials is currently inconclusive according to a 2019 Cochrane review. [43] The root end filling material should be easy to manipulate, radiopaque,

dimensionally stable bacteriostatic or bactericidal, non-resorbable and unaffected by the presence of moisture. The cytotoxicity of MTA were tested in vitro cell culture studies and the results showed the satisfactory attachment of osteoblasts and periodontal cells on MTA. The purpose of a root end preparation is to clean and create a space for a root end filling material[44]

MTA as a root end filling material: An in vivo study aim to evaluate clinically and radiographically the periapical healing when MTA was used as retrograde root end filling. MTA was chosen as the root end filling material of choice as it helps in growth of cementoblast like cells . Cementum deposition was essential for the regeneration of periodontal apparatus. Outcomes of MTA as root end filling in endodontic surgery

Aim: To compare clinical outcome outcomes of MTA with other materials to determine which modality offers more favourable outcomes. MTA as root canal fillings is better than and purely gutta percha but similar to IRM. There is a limited number of well-designed clinical trials. Large scale and long term follow up randomised controlled trials are still required to confirm the long-term outcomes of MTA as root end filling.[45] Lateral or furcation perforation, it occurs when an instrument has perforated the root during canal preparation. The perforation can be sealed with a thick mixture of an MTA type product, preventing bacterial ingress. Excess material should be removed from the area while the MTA has not set. Despite of all studies that supported the use of MTA in sealing root and crown preparations sinker et al 2015 reported that biodentin has better sealing ability and least microleakage than retro MTA and pro root MTA when used in furcation repair of mandibular molars using a dye extraction leakage method.[46] Beyram et al, 2015 also reported that bioaggregate showed better perforation repair and biocompatibility than MTA and Portland cement when it was used as root end filling and perforation repair material .[47] MTA is biocompatible with the periradicular tissue thus has a better sealing ability when used for perforation repair. When amalgam, IRM and MTA were tested for repair of experimentally created root perforation, results showed that MTA has significantly less leakage than IRM and amalgam .[48] According to Weldon JK et al, the combination of MTA and super EBA provided a more rapid seal than MTA alone .[49] MTA has been recommended as a repair material for root perforations. The biocompatibility of MTA has been demonstrated in vitro. MTA allows significantly less leakage as compared to amalgam, which is a result of its sealing ability rather than any antimicrobial properties of the material.[50]

MTA as a Pulp Capping agent: Pulp capping has been used as an alternative approach to the maintenance of vital pulp so that many tooth extractions and RCTs could have been avoided through a conservative approach of pulp capping[51,52]. MTA is a new and biocompatible material that has been proven to be an excellent material for direct pulp capping. Two studies have investigated the clinical performance of MTA as pulp capping agent on cariously exposed permanent teeth that reported success rate of 93% and 97% [53]. The relevant literature has been scanned and reviewed under following headings:

1. Clinical evaluation of MTA as a direct pulp capping agent
2. Clinical evaluation of MTA as an indirect pulp capping agent

Clinical evaluation of MTA as direct pulp capping agent

- Kierat A et al[54] evaluated that the usefulness of a new product called MTA used in direct pulp capping compared with CaOH, which showed 88.2% of results were positive after a direct coverage of pulp using MTA and 86.7% of positive results were after the application of CaOH. In case of indirect use of both MTA and CaOH 100%. Positive results were obtained and MTA showed significantly lower toxicity compared with CaOH.
- Caliskan MK et al[55] found that 152 out of 172 capped teeth were available for follow-up with an overall recall rate of 87.6% for MTA vs 89.3% for CaOH. The mean period of follow up was (37.3 +_ 17.2) months. Overall success rate of 85.9% a d 77.6% in MTA and CaOH groups were observed respectively. The 24 yr overall pulp survival was 91.4 while 4 and 6 yrs. survival rates are 84 a d 65% respectively.
- Kundzina R et al[56]aimed to compare effectiveness of MTA and a conventional CaOH liners as a direct pulp capping materials in adult molars with carious pulpal exposure. They found that at 36 months the cumulative estimate rate of 85% for the MTA group and 52% for CaOH group. There was no significant association between capping material and postoperative pain.
- Znao Y et [57] tried to evaluate the volume change of rat root following direct pulp capping with MTA and CaOH based paste (Villapex) in randomized control trial that showed the root volume in MTA group was significantly smaller than that in villapex group at 2 and 4 weeks after operation. At 6thweek there was no significant difference between MTA and Villapex.
- Sajid M et[58] found that MTA was proven to be better for direct pulp capping material showed higher success rate clinically and radiographically when compared with CaOH within 3 months follow up period. However both MTA and CaOHwere clinically applicable at the end of 12 month follow up period and there was no significant difference between the protection of tooth vitality and pulp capping agents at 6 and 12 months (P = 0.238, P=0.606) respectively according to vural UK et al[59].
- Nowika A et al[60] involved tomographic evaluations of reparative dentin bridge formation after direct pulp capping with CaOH, MTA, Biodentine (Septodont, Seefeld, Germany) in human teeth. They found that reparative dentin formed in MTA and Biodentine groups was significantly superior to that formed in single bond universal group in terms of thickness and volume. The mean density of dentin bridges was the highest in MTA group and lowest in single bond universal group.
- Swarup SJ et al[61] found the nano HA and MTA produced continuous dentin bridges. Dentin bridge that was formed in MTA group had regular pattern of dentinal tubules but no tubules were seen in nano HA group. Dentin bridges were not observed in Dycal group for 15 days period in majority of sample and by 30 days dentin bridge was observed that were both continuous and interrupted in equal no of samples. The initial inflammatory response and necrosis was more in nano HA and CaOH which reduce with time.

Clinical evaluation pf MTA as an indirect pulp capping agent

- Vural et al[62] found that indirect pulp capping recall rates were 100% at 6 months and 12 months post treatment. Similarly teeth capped with CaOH (6 and 12 months) and capped with MTA (12 and 24 months) received endodontic emergency treatment because of symptoms of irreversible pulpitis, which were clinically or radiographically established.
- George et al[63] (2015) investigated the clinical and radiographic effect of IPC with white MTA and CaOH (Dycal) over 6 months in primary molars. Permanent restoration was then applied in 2nd session. In the study conducted, it was stated that MTA was superior to Dycal both clinically and radiographically in IPC treatment for primary molar teeth. Success rate of MTA was 94.4%, Theracal DC= 87.8% and Dycal = 84.6%.
- Bernoist et al[64] proves the efficacy of MTA in IPC procedure with a significant barrier formation when followed up till 6 months interval. However it was an observational study for a shorter follow up period.

Evolution of Mta (metal trioxide aggregate)

- From dark grey to white and from 2hrs 34 mins setting time to 9-12 mins. Better consistency of MTA has been obtained when mixed with water-based gel.

Nanomodification of MTA for enhanced physiochemical properties

Main aim was to analyze the physiochemical properties of a nano white MTA and compared it with white MTA.[65]

Improvement of bonding properties of mineral trioxide aggregated by elastin like polypeptide (ELP) supplementation

ELP supplementation improved the bond strength of MTA to dentin. MTA supplement by a specific ELP exhibited a less porous structure, higher stickiness and higher flow rates. ELP also decrease the contact angle to dentin.[66]

Caffeic acid -coated nanolayer on MTA(CAMTA) potentiates the host immune responses, angiogenesis and odontogenesis

CAMTA cements were found to have improved physiochemical and biological properties compared their counterpart. In addition, CAMTA cements have enhanced odontogenic, angiogenic and immunosuppressive properties compared with MTA. All results proved that CAMTA cements could be a biomaterial for future clinical application and tissue engineering use.[67]

Conclusion

An ideal endodontic material should adhere to tooth structure, maintain a good seal, be insoluble in tissue fluids, dimensionally stable and non-resorbable, and radiopaque, and exhibit biocompatibility with a certain degree of bioactivity. Among the various available endodontic materials, MTA is currently the biomaterial that possess most of these characteristics. MTA is a miraculous material that has been proved to be outstanding 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. Nevertheless, the extrapolation of results obtained in in-vitro studies should be undertaken with caution when applied to clinical conditions.

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