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Mineral Trioxide Aggregate: An Overview Unsaid

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Abstract
Mineral Trioxide Aggregate (MTA) is a bioactive 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 biocompatibility as well as its ability to stimulate tissue regeneration. In this article the composition of MTA, setting reaction, manipulation, mechanism of action for mineralization, antimicrobial property, calcific barrier formation in pulp capping and apexification, as well as its disadvantages which include tooth discoloration and post operative pain with MTA has been reviewed.

Key Words
Mineral Trioxide Aggregate, Bioactivity and Tissue regeneration

Introduction

It is estimated that over 24 million endodontic procedures are performed on an annual basis, with up to 5.5% of those procedures involving endodontic apical surgeries, perforation repairs, apexification, apexogenesis and now revascularization treatment. Endodontic surgery is performed to resolve inflammatory processes that cannot be successfully treated by conventional techniques, which may be due to complex canal and/or apical anatomy and external inflammatory processes. Surgical procedures may also be indicated for the resolution of procedural misadventures, to include root perforation that may occur either during canal instrumentation or post-space preparation.[1]

Surgical treatment usually involves achievement of apical seal by the placement of a material designed to seal the root canal contents from the periradicular tissues and repair root defects. An ideal endodontic repair material would adhere to tooth structure, maintain a sufficient seal, be insoluble in tissue fluids, dimensionally stable, non-resorbable, radiopaque, and exhibit biocompatibility if not bioactivity. A number of materials have historically been used for retrograde fillings and perforation repair, such as amalgam, zinc-oxide-eugenol cement, composite resin, and glass-ionomer cement. Unfortunately, none of these materials have been able to satisfy all the requirements of an ideal material.[2]

Mineral trioxide aggregate (MTA) is a biomaterial that has been investigated for endodontic applications since the early 1990s. MTA was first introduced by Mahmoud Torabinejad at Loma Linda University, California, USA and was given approval for endodontic use by the U.S. Food and Drug Administration in 1998. MTA materials are derived from a Portland cement (PC, parent compound), it is interesting that no information has been published regarding any investigations that led to the precise delineation of the present MTA materials.[3]

The aim of this article is to present a systematic review of MTA as a Bioactive Biomaterial.

Composition

According to Torabinejad et al (1993), the main constituents of this material are calcium silicate (CaSiO4), Bismuth oxide (Bi2O3), Calcium carbonate (CaCO3), Calcium sulfate (CaSO4) and Calcium aluminate (CaAl2O4).

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(2005) claim that these oxides are present in less quantity in white MTA while others claim total absence of these oxides in white MTA. White MTA contains smaller particles with a narrower range of size distribution than grey MTA. Portland cement is the active ingredient in white MTA. GMTA(Grey MTA) basically consists of 22.5% dicalcium and 53.1% tricalcium silicate, 21.6% bismuth oxide and small Quantity of tricalcium aluminate and calcium sulphate. Bismuth oxide in MTA provides its radiopacity. Bismuth increases the radiopacity to 8.26mm thickness of Aluminum, which is higher than that recommended by ISO 6876. Bismuth oxide in MTA is not inert. It forms part of the hydrated phase forming a structure composed of calcium silicate-bismuth hydrate and the rest is leached together with calcium hydroxide formed from the hydration of the calcium silicates. The precipitation of calcium hydroxide (CH) in the hydrated paste is reduced in MTA compared to a PC with no addition of bismuth oxide.[4]

Several modifications of MTA are marketed. The original formulation developed at Loma Linda University is manufactured by Dentsply International (ProRoot MTA and Tooth Colored MTA; Dentsply-Tulsa Dental, Tulsa-USA; Dentsply-Johnson City-USA). Other types of MTA are Angelus (AMTA) from Brazil (white and gray: AGMTA, AWMTA; Angelus, Londrina, PR, Brazil), and Egeo (CPM) in white from

Argentina (Egeo, Buenos Aires, Argentina). Many other brands of experimental MTA have been developed and investigated, including MTA Bio, light-cured MTA, and an MTA root canal sealer named CPM sealer (Egeo) and MTA-Obtura (Angelus).

Setting Reaction

When MTA powder is mixed with water, calcium hydroxide (CH) and calcium silicate hydrate are initially formed and eventually transform into a poorly crystallized and porous solid gel. The ratio of calcium silicate drops because of the formation of a calcium precipitate. The precipitated calcium produces CH, which is the cause of MTA's high alkalinity after hydration. Bismuth affects CH precipitation after MTA hydration. Because bismuth oxide dissolves in an acidic environment, it has been suggested that placing MTA in an acidic environment such as inflammatory tissues might result in the release of bismuth oxide. This might decrease MTA's biocompatibility because bismuth oxide does not encourage cell proliferation in cell culture. The amount of sulfur at the surface of set MTA is 3 times higher than the powder forms of MTA, and that this layer protects the cement from further hydration and increases the cement's setting time.[5]

Tricalcium silicate sets by the following reaction:

2Ca3OSiO4 + 6H2Oà3CaO.2SiO 2.3H2O + 3Ca(OH)2

The setting of dicalcium silicate is given by:

2Ca2SiO4 + 4H2Oà3CaO.2SiO 2.3H2O + Ca(OH)2

The principle products are calcium silicate hydrates and calcium hydroxide.[5] During the hydration process, when calcium silicates react to form calcium hydroxide and calcium silicate hydrate gel, producing an alkaline pH. A further reaction forms a high-sulfate calcium sulfoaluminate during the reaction with tricalcium aluminate and calcium phosphate. The release of calcium from setting MTA diffuses through dentinal tubules, and the concentration of the calcium ions increases with time as the material cures.[6]

Manipulation

The MTA paste is obtained by mixing 3 parts of powder with 1 part of distilled water to obtain putty like consistency. Mixing can be done on paper pad or glass slab using a plastic agate spatula. This mix is then placed in the desired location and condensed lightly with a moistened cotton pellet. After mixing, the mix should not be left open on the pad as it undergoes dehydration and dries into a sandy mixture and should be consumed immediately.[7]

Mechanism Of Action For Mineralization

One of the characteristics of a bioactive material is its ability to form an apatite-like layer on its surface when it comes in contact with physiologic fluids. Apatite formation is a common characteristic of calcium silicate - containing biomaterials. MTA is a bioactive material that is mainly composed of calcium and silicate.[8] The mixed MTA primarily undergoes hydration process, as Calcium silicate reacts to form Calcium hydroxide and calcium silicate hydrate gel, producing an alkaline ph of 12.5. Further high sulfate calcium sulfoaluminate formation occurs due to the reaction of tricalcium aluminate with calcium phosphate. The release of calcium ions from the set MTA diffuses through dentinal tubules and the concentration of calcium ions increases with time as the material hardens completely. It appears that, the biocompatibility of the cement might be attributable to the release of hydroxyl ions and formation of calcium hydroxide during the hydration process.[9] When mixed MTA is compacted against dentin, the dentin MTA interfacial layer forms in the presence of phosphate. This adherent interstitial layer resembles hydroxyapatite in composition and structure, which leads to superior marginal adaptation moreover, the particle size and dimensional shape of MTA can occlude and penetrate dentinal tubules that might harbor micro-organisms after cleaning and shaping. MTA not only fulfills the ideal requirement of being bacteriostatic, but it might have potential bactericidal properties also.[10]

Antimicrobial Property Of MTA

The antimicrobial activity of MTA is related to the release of hydroxyl ions in an aqueous environment. Hydroxyl ions are highly oxidant free radicals that show extreme reactivity with several biomolecules.This reactivity is high and indiscriminate, so these free radicals rarely diffuses away from sites of generation.[11] The lethal effects of hydroxyl ions on bacterial cells are probably due to the anaerobic atmosphere during incubation procedure, since both MTA and Portland cement are rich in oxides. Subsequent to reaction with water on oxygen-rich environments, these compounds might generate reactive oxygen species, such as hydroxyl and hydroperoxyl radicals which exhibit antimicrobial activity.[12] Growth of anaerobes requires an appropriate environment to reduce the intracellular generation of reactive oxygen species; favoring the growth of anaerobic microorganisms in anaerobic environment, the formation of toxic oxygen radicals is likely to be reduced in intracellular location.[13] Moreover, antimicrobial activity of reactive oxygen species is usually impaired by the presence of antioxidants and other reducing molecules such as quinones.[14] MTA has an alkaline ph of 12.5. The pH gradient of the cytoplasmic membrane is altered by the high concentration of hydroxyl ions from calcium hydroxide acting on the proteins of the membrane this phenomenon is known as protein denaturation. The high pH of MTA alters the integrity of the cytoplasmic membrane through chemical injury to the organic components and transport of nutrients by means of the destruction of phospholipids or unsaturated fatty acids of the cytoplasmic membrane, observed in the peroxidation process, which is a saponi@257;cation reaction.[6] Saad Al-Nazhan et al (2003),conducted an in vitro study to investigate the antifungal effect of MTA using a tube-dilution test. The tested MTA was incubated with C.albicans for 1 hour, 24 hours & 3 days. They concluded that MTA was effective against C.albicans even after 3 days.[15]

Calcific barrier formation with MTA in pulp capping procedure

Pulp capping is an operative procedure designed to preserve the vitality of a potentially infected dental pulp.Main goal of pulp capping is to form a barrier at the site of pulp exposure. Difference between barrier formation stated by various authors. Maria de Lourdes et al (2008)[16] evaluated Mineral Trioxide Aggregate and Calcium Hydroxide Cement as Pulp-capping agents in Human Teeth. Pulpal exposures were performed on the occlusal floor of 40 human permanent premolars and the pulp was capped either with CH or MTA and

restored with composite resin. After 30 and 60 days, teeth were extracted and processed for histologic exam and categorized in a histologic score system. All groups performed well in terms of hard tissue bridge formation, inflammatory response, and other pulpal findings. However, a lower response of CH after 30 days was observed for the dentin bridge formation, when compared with MTA after 30 days and MTA after 60 days groups. Eduardo Galia Reston and Carlos Alberto de Souza Costa (2009)[17], carried out a SEM electron microscopy study for evaluation of the hard tissue barrier after pulp capping with Mineral Trioxide Aggregate (MTA) in 29 specimens and showed that in seven specimens (29.2%), the deposition of mineralized tissue occurred in the centroperipheral area, characterizing the complete hard tissue barrier formation. In the remaining 17 specimens (70.8%), the hard tissue barrier was formed only in the peripheral area. Five specimens did not present formation of a hard tissue repair barrier and were therefore not included in the statistical analysis because they did not produce any morphology or localization data.[18] MTA induces the formation of a hard tissue barrier without a significant local inflammatory response. It has been reported that, although MTA and calcium hydroxide have a similar mechanism of action on the exposed pulp tissue, the inflammatory pulp response to MTA seems to be less intense. This might be attributed to the fact that, immediately after preparation for use, MTA has a significantly lower pH (approximately 10.2) than calcium hydroxide (nearly 11.2).[19] At the end of the follow-up period after pulpotomy (90 days), the tested MTA cements presents a limited diffusion of their components from the pulp-capping site to the interior of the pulp tissue. Perhaps, it might be an important factor that contributed to presence of a complete (centroperipheral) hard tissue barrier in several specimens in MTA and to the small number of this type of barriers in the roots in which pulp remnant was capped with calcium hydroxide. With MTA, thicker bridges are formed and the presence of an odontoblastic layer is a frequent finding. In addition, only in few cases capped with MTA shows hyperaemia, whereas hyperaemia is seen in every sample capped with calcium hydroxide, and virtually no odontoblastic layer was formed in case of calcium hydroxide.After 6 months of pulp capping with MTA, 0.43 mm-thick dentin bridge and a nearly regular odontoblastic layer was observed.[20]

Calcific barrier formation with MTA in Apexification Procedure

Apexification is a procedure to promote the formation of an apical barrier to close the open apex of an immature tooth with a non-vital pulp such that the filling materials can be contained within the root canal space (Rafter 2005). Shabahang S (1999), placed MTA for apexification procedure into the root canal space and histologically observed three types of tissue formation. Firstly, their was dentin formation along the dentinal walls resulting in the thickening of the root canal dentin wall, secondly, the presence of bone-like tissue and thirdly, periodontal ligament like tissues were observed at the apical root end. The formation of calcific bridge at various levels of the root canal space was possibly the result of the osteo-inductive activity of the MTA. Aeinehchi M (2003)[21], also observed the histologic evaluation of calcific barrier formation with MTA & Calcium Hydroxide. He demonstrated less inflammation, hyperaemia and necrosis alongwith thicker dentinal bridge formation. The odontoblastic layer formation was observed with the MTA which was consistently more uniform & thicker than Calcium Hydroxide. Lidia Postek et al (2009)[22] and Anil Kumar G et al(2010)[23] reported that the primary advantage of MTA is early apical barrier formation, proper development of apical seal, excellent biocompatibility and reduction of number of appointments. Simon et al (2007)[24] stated that one step apexification using apical plug of MTA can be considered as predictable treatment and successful alternative to Calcium hydroxide

Tooth discoloration with MTA

Discoloration after placement of MTA has been one of the biggest problems related to its use in anterior teeth. Saeed Asgary (2005)[25] compared the composition of Grey and White MTA and observed that the concentration of aluminum oxide, magnesium oxide and ferric oxide in gray MTA is more than white MTA and is responsible for tooth discoloration. Watts J.D (2007)[26] and Boutsioukis C (2009)[27] repotted that both external and internal coronal discoloration are associated with white MTA. But still grey MTA causes grayish staining because of infiltration of ferric ion into the dentinal tubules near the CEJ which increases the discoloration with time.

Post operative pain when MTA placed in root end surgery

Chong BS & Pit Ford TR (2004), conducted a study to evaluate the post operative pain after surgical root end resection & then filling the root end cavity with MTA. A standardized surgical technique was employed. Post operative instruction along with pain questionnaire & visual analogues scale was given to each patient. All the patients were instructed to record the intensity of pain in the intervals of 5, 24 & 48 hours. They reported that there was no significant difference in the pain experienced by the patients. However, the reported post operative pain was of relatively of short duration at its maximum intensity early in the post operative period but it was progressively decreased with time.[28] Researchers are working in this field to overcome this. Jessyca Leal Moura FE et al (2014)[29] associated use of Mineral trioxide aggregate (MTA) with Aloe vera to verify the coadjutant action of that medicinal plant in the bone neoformation process in tibia of rats. The association of MTA and Aloe vera showed potential to reduce the effects of the inflammatory cascade and promote bone neoformation making it to a promising proposal for future use in endodontic therapy.

Conclusion

The present available literature is an important tool for rationalizing correct clinical decisions. This is why the scientific efforts to improve do not stop and include new concepts and treatment strategies in order to reduce the incidence of adverse effects and increase their biocompatibility. It may be concluded from this review that MTA appears to be a promising successor to Calcium hydroxide for variety of applications. That is because MTA is an excellent material with innumerable qualities required of an ideal material. There is, however, presently a definitive lack of long-term clinical studies to demonstrate the safety and effectiveness of this new material. MTA need to be explored by clinicians so that its more and more beneficial properties can be extracted.

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