

Mineral Trioxide Aggregate Use in Pediatric Dentistry: A Literature Review

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Abstract

Mineral trioxide aggregate (MTA), is unique endodontic cement that was initially introduced as a material for root perforation repair. Over the years its use has expanded to include versatile applications in the field of pediatric dentistry. The purpose of this article was to conduct an updated review on mineral trioxide aggregate (MTA) and on its applications in the practice of pediatric dentistry.

Sources and data: Electronic databases, “PubMed”, “Cochrane Database” and “Google Scholar”, were used to identify relevant English-language studies and literature published in the period from 1993 to 2016. The scientific papers were then screened for their relevance to the intended objectives. A combination of the key search terms mineral trioxide aggregate, MTA, pulp therapy, clinical applications, and pediatric dentistry were used.

Study Selection: Abstracts and full text articles were used to identify studies describing the composition, manipulation, properties, types, and clinical features. In addition, controlled clinical trials of clinical applications and relevant laboratory research on its properties and safety were also included.

Conclusions: MTA is a unique material with various advantages. It has been used successfully by pediatric dentists in a variety of clinical applications. However, its drawbacks especially its high cost, discoloration potential, difficulty in handling, and long setting time cannot be overlooked. With the emergence of other novel tricalcium silicate based materials that overcome MTA's key limitations, they are competing to be the next potential dentin substitutes for the various clinical application in which MTA has been used. Nevertheless, with the recent introduction of new improved MTA products, MTA-based materials are likely to yet remain at the heart of good pediatric dental practice for many years to come.

Keywords: Mineral trioxide aggregate; Clinical applications; Pediatric dentistry; Pulp therapy

Introduction

Over the years, various types of dental materials have been developed to serve different purposes and to be applied to multiple scenarios in the field of dentistry. Mineral trioxide aggregate (MTA), is a unique endodontic cement that was initially introduced as a material for root perforation repair by Mahmoud Torabinejad at Loma Linda University in 1993 [1]. It is primarily composed of tricalcium silicate, tricalcium alluminate, tricalcium oxide, and bismuth oxide [2]. It is formulated of fine hydrophilic particles that solidify in the presence of moisture or blood [3]. MTA was approved by the U.S. Food and Drug Administration for endodontic use in 1998 [4].

Further research over the years on MTA resulted in expanding its applications to include its use as a retrograde filling material [5], repair material for internal and external root resorption [6], and as an apexification material [7,8]. Not to mention its other diverse applications in the practice of pediatric dentistry. In addition to apexification, it is used for the management of the coronal part of

fractured roots, in pulpotomies of primary and permanent teeth, and in pulp capping of young permanent teeth [9-12].

In view of the versatile endodontic/restorative applications of this ever-evolving material in pediatric dentistry, an updated review of MTA is encouraged. The aim of this review was to conduct an updated search on the composition, manipulation, types, properties, disadvantages, and clinical applications of MTA in the practice of pediatric dentistry.

Materials and Methods

Electronic databases, “PubMed”, “Cochrane Database” and “Google Scholar”, were used to identify relevant English-language studies and literature published in the period from 1993 to 2016. Abstracts and full text articles were used to identify studies describing the composition, manipulation, properties, types, and clinical features. In addition, controlled clinical trials of clinical applications and relevant laboratory research on its properties and safety were also included. A combination of the key search terms mineral trioxide aggregate, MTA, pulp therapy, clinical applications, and pediatric dentistry were used.

Results

Two hundred and twenty-seven articles together with several references from certain review articles were reviewed. The clinical applications of MTA in pediatric dentistry were illustrated in forty-seven recent studies.

Discussion

Composition

MTA is a tri-mineral aggregate, which is composed of tricalcium silicate, tricalcium aluminate, tricalcium oxide, silicate oxide and bismuth oxide [2]. The material contains calcium oxide (50-75% by weight) and silicon dioxide (15-25%), when they are mixed, they result in the production of tricalcium silicate, dicalcium silicate, tricalcium aluminate and tetracalcium aluminoferrite [13]. When water is added, the cement will hydrate to form a silicate hydrate gel that will eventually solidify to form a hard structure [13]. This hydration reaction was found to result in calcium hydroxide ($\text{Ca}(\text{OH})_2$) as a byproduct [14]. In addition, calcium ions release with a resultant alkaline pH rise was also reported in several studies [15-17]. After mixing MTA, its pH value was found to be 10.2 and rises at 3 hours to 12.5 [18]. This resultant microenvironment with high pH contributes to the particularly appealing antibacterial properties of the material [19].

MTA basically resembles Portland cement in composition with the exception of bismuth oxide which is added to MTA for radioopacity [20,21]. MTA also has more uniform and finer particle size and less gypsum than Portland cement, this decreased gypsum reduces the cement setting time. Additionally, Portland cement has greater level of toxic heavy metals and aluminium compared to MTA [13,22]. Accelerators like sodium phosphate dibasic (Na_2HPO_4), calcium formate ($\text{Ca}(\text{HCO}_2)_2$), and calcium chloride (CaCl_2) are included to reduce the setting time [23,24].

Various studies examined the composition of MTA. They generally revealed some dissimilarity related to the type of MTA, the equipment that was used for examining the composition of the material, or the type of liquid mixed with the MTA powder [14,21,25-32].

Types of MTA

There are two basic forms of MTA based on color, gray (GMTA) and white (WMTA). MTA was initially presented as gray Pro-root MTA, however, the potential for discoloration of GMTA lead to the development of WMTA in 2002 [18,33].

They principally differ in that WMTA was found to have lower quantities of iron, aluminum, and magnesium oxides than GMTA [25-27]. The reduced ferrous oxide (FeO) was suggested by Asgary and colleagues [25-27] to be the likely cause of the lighter color of WMTA. Other differences between WMTA and GMTA were reported in the literature. GMTA's crystal size was found to be about 8 times larger than WMTA's crystal size [27]. GMTA also has significantly longer setting time; less radiopacity; solubility; and pH value than WMTA [34,35]. Concerning the compressive strength, there are conflicting results with one study reporting significantly less compressive strength [35], while two other studies reported more compressive strength of WMTA compared to GMTA [36,37]. Furthermore, regarding their antimicrobial behavior, it was reported that GMTA achieved similar antimicrobial action against particular microorganisms at lower

concentrations than WMTA [38,39]. However, Asgary and Kamran [40], reported similar antibacterial properties for both types of MTA.

Other variations include incorporating resin in the MTA mix to be used as a root canal sealing cement. The purpose was to improve material flow, dentine bonding, and setting time and so to reduce micro-leakage. An example is the MTA Fillapex (Angelus, Londrina, Brazil) [41]. However, it was found that adding resin to the materials results in the reduction of the desired free $\text{Ca}(\text{OH})_2$ (essential for continued root formation in immature permanent teeth) [42,43].

The NeoMTA (NuSmile, Huston, USA), on the other hand, is a pure MTA and does not contain resin. It is marketed as a cost effective MTA intended to be used for pediatric pulp therapy. The powder is provided in a lined vial that is re-sealable which facilitates the use of only the needed amount of MTA in each treatment thereby enhancing cost-effectiveness. The liquid used for mixing is a gel which makes it easier to mix and apply. In addition, it has a non-staining formulation and a fast setting time. All these features are desirable while delivering treatment to the pediatric patient [44]. Another comparable material is the Neo MTA Plus (Avalon Biomed Inc., Bradenton, FL) it also possesses a powder-gel formula and is promoted to be used in pulpotomies because it does not stain the tooth structure by replacing bismuth oxide with tantalum oxide for opacity [42].

Manipulation and setting reaction

To prepare MTA, its powder is mixed with sterile water in a ratio of 3:1 (powder to liquid) [45]. It was found that using either doxycycline or chlorhexidine (CHX) instead of distilled water, had no effect on MTA's sealing ability [31]. A metal or plastic spatula can be used for a mixing on a glass slab or paper pad to form the consistency of putty like paste [46]. Initial mixing of the material yields a colloidal gel that eventually hardens to form a solid structure [45]. A paper point, plugger, ultrasonic condensation, or carriers with special designs and messing guns can be used to deliver the MTA mix to the desired location [46].

The mean setting time for MTA is 165 ± 5 minutes [18,45]. Moisture from the surrounding tissues or from a moistened cotton pellet will help the setting reaction [18,47]. Nevertheless, excess moisture can lead to 'soupy' mix [48,49]. Using CaCl_2 , $\text{Ca}(\text{HCO}_2)_2$, and Na_2HPO_4 as accelerators was found to significantly lower MTA's setting time, however, it lowers the compressive strength significantly as well [23,24]. On the other hand, using 2% lidocaine anesthetic solution and saline lengthened the setting time without significantly affecting the compressive strength [23].

The mixing time of MTA is very crucial. Prolonged mixing can lead to dehydration of the mix. The mixing time was recommended to be less than 4 minutes [50]. Also, it is preferred to use the mix immediately after mixing to prevent the dehydration and drying into a sandy mixture [51].

Hand instruments or ultrasonic condensation can be used for the placement of MTA into the desired location. Parashos et al. [52] found improved compaction and flow of MTA with ultrasonic, however, it can adversely affect the properties of MTA when used in excess. Two seconds of ultrasonication per increment was the best time to give more desirable values in microhardness, sealing, and absence of radiographic voids. In a recent study, the ultrasonic technique decreased the setting time of MTA [53].

Concerning condensation pressure, it is better to avoid excess pressure while condensing MTA. Increasing the condensation pressure could decrease the MTA's surface hardness because it could lessen the spaces available for water ingress which is necessary for the cement hydration [54].

In one study, it was found that placement of glass ionomer cement (GIC) over WMTA after 45 minutes for one-visit perforation repair had no effect on the calcium salts' formation in the two materials' interface nor on the setting of the WMTA [55]. In addition, the presence of WMTA did not disturb the GIC setting [56].

The addition of GIC powder to the MTA mix has been suggested to improve the setting time and handling characteristics of MTA. One study showed improved setting times but poor compressive strength and pH when compared to MTA powder alone [57]. Another study examined the effect of adding the GIC to the MTA mix (for the purpose of improving the setting time) on the resultant amount of calcium released from the mixture, which is the base for the biological actions of MTA. It was found that adding MTA and GIC at a

proportion of 2:1 by volume did not significantly impact the calcium release from the mixture. However, further clinical evaluation was suggested [58].

Properties of MTA

Chemical and physical properties

Key features of the chemical and physical properties of MTA are summarized in Table 1. MTA's compressive strength was reported to be affected by several factors like, the type of MTA, the type of liquid used to mix the material, the environment's pH value, the condensation pressure on the material, and the condition of MTA storage [36,37,47,54]. Etching WMTA with phosphoric acid (37%) resulted in a significant reduction in the compressive strength of the MTA. Therefore, it was recommended to postpone acid-etch composite restorations after the placement of MTA for a minimum of 96 hours [59].

Property	Features
Compressive strength	It was reported to be 40.0 MPa at 24 hours and it increases up to 67.3 MPa at 21 days in the presence of moisture [2].
Flexural strength	Increase by two sided hydration of MTA [60].
Push-out strength	Increase by moisture [61].
Marginal adaptation and sealing ability	Enhanced in the presence of moisture [62], good sealing of MTA is achieved with a thickness of around 4 mm [62,63].
Solubility	Low or no solubility [2,64-66]. However, increased water: powder ratio in the MTA mix may increase its solubility and porosity [67].
Displacement	The thickness of MTA directly effects its displacement when applied as an apical barrier [18]. An MTA apical barrier with a thickness of 4 mm offers significantly more resistance to displacement compared to a thickness of 1 mm [68].
Retentive Strength	Low, it is not a suitable luting agent [69].
Radiopacity	The mean value of MTA's radiopacity was found to be 7.17 mm of an equivalent thickness of aluminum [2].
Reaction with other dental materials	MTA does not react or interfere with any other restorative material [55,56,70].

Table 1: Summary of the chemical and physical properties of MTA.

The flexural strength is the material's capability to withstand deformation. It is highly recommended to place a wet cotton pellet on top of the placed MTA for the first 24 hours to increase the flexural strength then remove it to avoid the subsequent decrease in the flexural strength 72 hours after MTA receives moisture [18].

The push-out strength is the material's ability to withstand dislodgement. It is a crucial factor for MTA since soon after repair, the material can be dislodged by the tooth function. It was found that the push-out strength of MTA is lower than that of the intermediate restorative material (IRM) or Super ethoxybenzoic acid (EBA) [71].

Both the maximum compressive and push-out strength of MTA was found to be reached several days after mixing [18]. While the sealing ability and marginal adaptation of MTA, was found to be better than the other conventional materials used for root-end filling (attributed to the MTA expansion in its setting reaction) [62,72], the retentive strength of MTA, however, was found to be significantly inferior to GIC or zinc phosphate cement as a luting cement [69]. Additionally,

the adaptation of MTA to dentin may be affected by the presence of residual Ca(OH)₂ in the cavity, reducing the MTA's sealing ability either by reacting chemically with MTA or by becoming a mechanical barrier [12].

Concerning the reaction of MTA with other dental materials, when GIC was placed over MTA it did not affect the setting reaction of the MTA or the GIC [55,56]. In addition, sufficient bond strength was also maintained when a resin composite or a compomer was placed over WMTA using the total-etch one-bottle adhesive [70]. However, acid etching before the first 96 hours after mixing MTA was found to affect the surface micro hardness and compressive strength of MTA [59].

Biologic properties

Concerning the antibacterial and antifungal properties, numerous investigations were conducted with conflicting results. Some studies reported that MTA has limited antimicrobial effect [73-75], while others reported that it has antifungal effects [76,77]. These conflicting

results may be due to variability in the source of the prepared material, the species of the microorganisms that are tested, as well as the type and concentration of the MTA used [18].

An *in vitro* study comparing the antibacterial actions of WMTA and GMTA at different concentrations by the tube dilution test found that increasing the concentration of MTA increases its antibacterial effect. However, higher concentrations of WMTA than GMTA were needed to yield similar antibacterial effects [38]. Likewise, another *in vitro* test found that the antifungal effect of WMTA was enhanced by increasing its concentration [78]. The use of CHX to mix with the MTA powder significantly increased the antimicrobial activity of the material; however, it decreased the compressive strength [36]. In addition, the type of CHX whether liquid or gel was found to have different effects on the setting of MTA [23,36].

With regards to biocompatibility, bacterial and cell culture assay studies showed that MTA was not mutagenic or cytotoxic [79,80]. Studies which have examined MTA samples in the form of intra-osseous and subcutaneous implants in animals found minimal inflammatory responses in the soft tissue and bone [12,81,82]. Lessa et al. [83], however, pointed out that when MTA is applied directly to the pulp tissue in a humid environment it can be solubilized which could permit leaching or dissolution of some of the MTA chemical elements with potential toxic effects. In addition, Balto [84] studied the effect of ProRoot MTA on the morphology of human fibroblasts and found that morphological alterations were observed in some cells. Indicating the potential toxicity of some of the elements released from MTA.

In return, an *in vivo* study that analyzed the effect of a hemostatic agent, which is plant-based, “Ankaferd Blood Stopper” (ABS) on the biocompatibility of MTA during apical surgery with the purpose to control blood contamination in the surgical crypt, it was found that ABS-contaminated MTA did not affect the biocompatibility of MTA [85].

In relation to mineralization, Myers et al. [86] established that MTA induces formation of a dentin bridge similar to $\text{Ca}(\text{OH})_2$. It was concluded by Faraco et al. [87] that the dentin bridge formed with MTA is relatively faster and with good structural integrity than with $\text{Ca}(\text{OH})_2$. Also, MTA results in higher mineralization compared to $\text{Ca}(\text{OH})_2$ [88].

MTA has the potential to stimulate the cementoblasts and therefore, to produce cementum [2]. It also allows the periodontal ligament (PDL) fibers to overgrow over its surface. It was also reported that MTA interacts favorably with bone-forming cells that were found to remain viable and release collagen [89]. These properties of MTA indicate the regenerative potential of the material.

Clinical applications in pediatric dentistry

MTA has been used in a wide variety of clinical applications in the pulp therapy of both primary and permanent teeth (Figure 1).

MTA use in primary teeth

Pulp capping: The American academy of pediatric dentistry (AAPD) recommended the use of MTA as a direct pulp capping material to be placed on pinpoint mechanical or traumatic pulp exposures in primary teeth with normal pulps when conditions for a favorable response are optimal [90]. There are few studies that evaluated the use of MTA for pulp capping in primary teeth [91,92]. The results from a case report and a case series showed that MTA can

be successfully used for direct pulp capping of primary molars [91,92]. In a prospective clinical study, Tuna and Olmez [93] reported clinical and radiographic success after 24 months following pulp capping of primary molar teeth with either $\text{Ca}(\text{OH})_2$ or MTA.

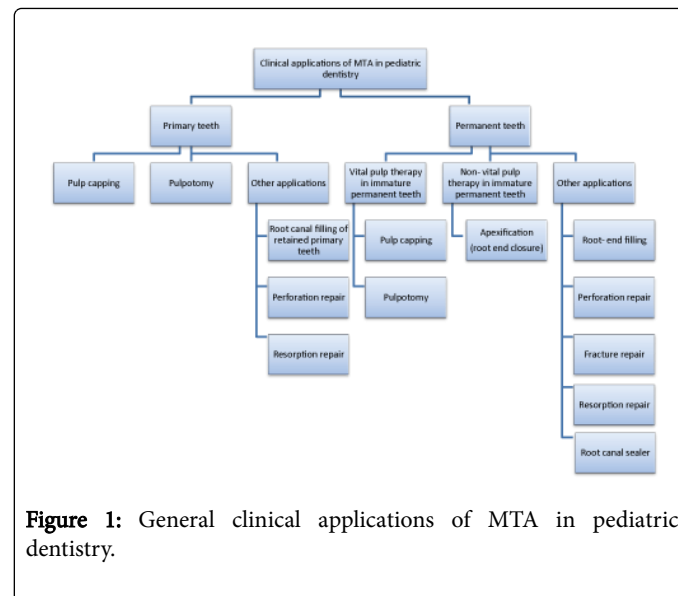


Figure 1: General clinical applications of MTA in pediatric dentistry.

Pulpotomy: The AAPD recommended the use of MTA for pulpotomies of primary teeth with normal pulps or reversible pulpitis when caries removal results in pulp exposure or after a traumatic pulp exposure [90]. Clinical trials have revealed that MTA's performance is equal or superior to formocresol (FC), ferric sulfate, and might be considered as one of the favored pulpotomy materials [9,94-101]. The introduction of MTA for pulpotomy overcame the drawbacks of FC such as its potential toxicity, caustic nature, and tissue irritation and inflammation upon contact with soft tissue [100]. Farsi et al. [9] found that pulpotomized primary molars treated with MTA had significantly more success than those treated with FC. Sushynski et al. [100] conducted a randomized controlled trial and concluded that MTA demonstrated significantly better radiographic outcomes as a pulpotomy medicament compared to diluted FC which also exhibited a higher frequency of internal root resorption in the FC-treated molars. A recent systematic review and meta-analysis comparing MTA and FC used for primary molar pulpotomy, found that MTA was more effective and showed higher success rate than FC at six to 24-months follow-ups [102]. However, Marghalani et al. [103] systematic review and meta-analysis comparing long-term (24 months) clinical and radiographic success of MTA and FC as a pulp-dressing material in pulpotomy treatment in primary molars showed comparable success rates.

Biodentine is a novel calcium-silicate based bioactive material that is similar to MTA. It has been introduced as a “dentine replacement” material, its mechanical properties resemble those of natural dentine. It has been used in a variety of clinical applications similar to those in which MTA is used [104,105]. In a study that compared the clinical and radiographic success of MTA, Biodentine, and Laser when used as pulpotomy agents in primary molar teeth, it was found that all three showed similar clinical and radiographic success at their three and six months' evaluations [105].

Other applications: MTA was also reported to be used as a root canal filling of retained primary teeth [106] and in furcation perforation repair and resorption repair of primary teeth [46,107].

Vital pulp therapy in immature permanent teeth

The objective of apexogenesis in vital immature young permanent teeth is to allow the continued physiologic root development and apex formation by placing an appropriate dressing medicament in the appropriate vital pulp therapy procedure such as indirect or direct pulp capping, and partial pulpotomy for carious exposures and traumatic exposures (Cvek pulpotomy) [90]. Various studies have investigated the use of MTA as a dressing material for vital pulp therapy in permanent teeth.

Pulp capping: Regarding the use of MTA for indirect pulp capping in permanent teeth. Leye Benoist et al. [108] conducted a randomized controlled trial to compare between MTA and Ca(OH)₂ when used as an indirect pulp-capping material, at three months, a significantly higher success rate was observed in the MTA group, though, at six months there was no statistically significant difference in the dentine thickness between the two groups. They recommended that further histological studies are required for supporting these results.

AAPD recommended the use of MTA (or Ca(OH)₂) for direct pulp capping in permanent teeth for small carious or mechanical exposures in teeth with normal pulps [90]. There are numerous prospective studies that were conducted to compare MTA to Ca(OH)₂ in healthy teeth capped after mechanical pulp exposures and subsequently validated by histopathological examination and they demonstrated that MTA resulted in a thicker dentinal bridge, less pulpal inflammation and more favorable pulpal condition than Ca(OH)₂ [109,110]. However, Iwamoto et al. [111] found no significant difference between MTA and Ca(OH)₂, while Accorinte et al. [112] reported that initial healing was better with MTA, but, subsequent healing was similar in both.

In a study comparing between direct pulp capping using either MTA or Biodentine in healthy permanent molars which were planned to be extracted for orthodontic purposes, no significant difference was found between MTA and Biodentine upon histopathological examination of the pulp-dentin complex after 6 weeks [113].

Observational studies in which MTA was placed over carious exposures in permanent teeth showed promising results [10,114]. In a nine year follow up of an observational study in which MTA was placed over carious exposures in permanent teeth, showed favorable outcomes of 97.6% of the treated teeth with complete root formation in all of the treated immature teeth with open apices [114].

In a retrospective study comparing MTA with Ca(OH)₂ when used for direct pulp capping over carious exposures in permanent teeth, it was found that the Ca(OH)₂ treated teeth had significantly higher failure risks than those treated with MTA [115].

Pulpotomy: The use of MTA as a pulpotomy dressing material in permanent teeth have been widely investigated. In a study that examined the use of MTA versus Ca(OH)₂ for the pulpotomy of premolar teeth that were scheduled for extraction after four and eight weeks for orthodontic treatment, MTA showed a more homogenous dentin bridge formation and less pulpal inflammation than Ca(OH)₂ [116]. El-Meligy and Avery [11] conducted a prospective study using either MTA or Ca(OH)₂ for the pulpotomy of immature permanent teeth, the results showed that there was no statistically significant difference neither clinically nor radiographically between the two

groups. Similar results were seen in other studies where pulpotomy was done in cariously exposed permanent molars using MTA or Ca(OH)₂, both demonstrating comparable success for two to three years follow up periods [117,118].

Similarly, in a recent systematic review of pulp capping and partial pulpotomy by Fransson et al. [119], it was concluded that Ca(OH)₂ or MTA frequently result in the formation of a hard tissue barrier when applied on an exposed pulp, however, the scientific evidence is insufficient in that MTA promotes more frequent hard tissue formation than Ca(OH)₂.

Non vital pulp treatment in immature permanent teeth / Apexification (root end closure)

The objective of apexification is to induce root end closure in an incompletely formed non-vital permanent tooth. Root end closure can be achieved by the use of an apical barrier such as MTA and the remaining canal space can then be filled with Gutta percha. In cases with a thin canal wall, the canal can be filled with MTA or composite resin to support the tooth against fracture [90].

Ca(OH)₂ has been widely used for apexification. But then again, this method requires the placement of Ca(OH)₂ for a long time in the root canal to accomplish the apical hard tissue barrier formation [120]. The use of MTA as an apical barrier was introduced in 1999 [51] and has subsequently become the material of choice for this procedure mainly because of its shorter treatment time as a one visit procedure [121,122]. Many studies have reported the clinical success of MTA in the apexification of non-vital immature permanent teeth [8,123,124]. El-Meligy and Avery [7] compared the apexification with either Ca(OH)₂ or MTA, and found that there was no statistically significant difference between the 2 groups, clinically or radiographically. Similarly, a systematic review and meta-analysis on the apexification of immature teeth with Ca(OH)₂ or MTA, showed that there was no significant discrepancy between them in the rate of clinical success and apical barrier formation [120].

In a recent study comparing MTA and Ca(OH)₂ for the treatment of immature non-vital permanent incisors by either ultrasonic or hand filing of the canal, it was found that ultrasonic filing plus MTA placement needed the shortest mean time for the formation of the apical hard tissue barrier, however, Ca(OH)₂ was better in the elongation of the apical root length regardless of the method of filing used [125].

Other applications in permanent teeth

Root- end filling: Efficiently filling the root canal to secure good sealing and leakage prevention is the key element for the success of periapical endodontic surgery. In a review by Kim and Kratchman [5] on the practice and materials used in modern endodontic surgery, they stated that MTA was the most biocompatible root-end filling material and that it can be used in endodontic surgery with predictable outcomes. In a meta-analysis on the materials used as fillers in periapical surgery, it was found that MTA offers the best seal with superior biocompatibility and high clinical success rates, and that it is the only root-end filling material that stimulates tissue regeneration in comparison to IRM, amalgam, and Super EBA [126].

Perforation repair: Perforation repair with various dental materials, such as amalgam, gutta-percha, GIC, zinc EBA cement, and IRM, have been researched over the years with varying degrees of success [127]. With the introduction of MTA, promising results were believed to be

accomplished with its use for perforation repairs [128]. In a systematic review and meta-analysis by Siew et al. [127] on the treatment outcome of non-surgically repaired root perforation it was reported that the overall pooled success rate was 72.5%, and the success rate was enhanced to 80.9% by the use of MTA but the difference was not statistically significant.

A comparable success rate was seen by Mente et al. [129] who investigated the outcome of 64 teeth that were managed with MTA for the repair of root perforations with a long term follow up period of 12–107 months. It was found that 86% of the teeth healed and that MTA demonstrated good long-term root perforation sealing ability regardless of the perforation location.

Fracture repair: Following root fracture of permanent teeth, the coronal non-vital portion of the fractured tooth can be sealed with MTA [12]. Many case reports demonstrated the use of MTA mainly for horizontal root fractures' repair without any problems or symptoms. [130-134].

Resorption repair: Several case reports have described successful treatment of external root resorption using MTA as the material to fill the resorbed area of the tooth surface with surgical, nonsurgical methods, or by a combination of these approaches [135-137].

Concerning the treatment of internal resorption, successful use of MTA for the repair of the resorption defects by surgical and nonsurgical procedures in the management of such cases has been reported in some case reports [138-140].

Root canal sealer: In a review by Parirokh and Torabinejad [141] it was suggested that MTA can be used as a root canal sealer, it induces closure of the foramen of the canal by the deposition of new cementum but cautions should be taken from overfilling as it might have adverse effects on periapical tissues. Thakur et al. [142], in 2013, compared the clinical and radiological outcome of MTA or epoxy resin as a root canal sealer with ZOE sealer and found no significant difference between them at six months. Further studies are needed to test MTA as a root canal sealer.

Disadvantages of MTA

The main disadvantages of MTA include its high cost, which has been one of its major limitation, its discoloration potential, difficulties in handling the material, prolonged setting time, presence of toxic elements in its composition, difficulty to remove after setting, and it does not have a solvent [12,141].

Unfortunately, the use of MTA as a dressing for pulpotomies in molars [143], for filling pulp chambers of immature teeth [144], and as an apical barrier [145], has resulted in the discoloration of the crown. The reason of discoloration is debatable, but it has been linked mainly to the interaction between bismuth oxide and the collagen of the tooth tissue [146] and sodium hypochlorite, which is usually used in root canal therapy [147].

In concern of the toxic elements in MTA, mainly in its arsenic content several investigations were conducted and found that the amount of arsenic released is very low [148,149]. In addition, other factors further minimize the arsenic release from the material into the tissue, such as the small amounts of the MTA that are actually used clinically, as insoluble nature [64], and the FeO present in its composition with its subsequent stabilizing effect on the arsenic content [25,150].

In an effort to overcome these disadvantages other tricalcium silicate based materials have been introduced to the market [147]. Bioaggregate (Verio Dental, Vancouver, Canada) and Biodentine (Septodont, Saint-Maur-des-Foss es, France) are tricalcium silicate based materials that have been developed to overcome the drawbacks of MTA while maintaining its desired characteristics and clinical applications [147,151]. Compared to MTA, Biodentine is a cost effective material that is easier to handle, has a faster setting time (set at about 10-12 minutes), is less soluble, and results in a better seal. It also has alternative radiopacifiers to overcome the discoloration related to bismuth oxide present in MTA [101,151].

In a study to assess the color stability of MTA Plus compared to Neo MTA plus and Biodentine when used in pulpotomies in immature permanent teeth in the presence of sodium hypochlorite solution, it was found that MTA Plus showed discoloration while Neo MTA Plus and Biodentine did not show discoloration [42].

In addition, recently other cements have been developed, such as calcium aluminate alfa-aluminate cement (CAAC), calcium aluminate alfa-aluminate plus cement (CAAC Plus), and wollastonite (a naturally occurring calcium silicate) and CAAC cement mixture (WOLCA) (Torabinejad Dental Research Center, Isfahan University of Medical Sciences (IUMS), Isfahan, Iran).

An animal study by Aminozarbian et al. [152], in 2012, found that CAAC Plus was not biocompatible while the biocompatibility of CAAC and WOLCA was comparable with that of MTA. Further studies are necessary to determine the biocompatibility of these materials.

Conclusion

MTA is a unique material with various advantages. It has been used successfully by pediatric dentists in a variety of clinical applications. Despite the many advantages of MTA, its drawbacks especially its high cost, discoloration potential, difficulty in handling, and long setting time cannot be overlooked. With the emergence of other novel tricalcium silicate based materials in the market, such as Biodentine, that overcome MTA's key limitations, they are competing to be the next potential dentin substitute for the various clinical application in which MTA has been used. However, with the recent introduction of new improved MTA products, MTA-based materials are likely to remain at the heart of good pediatric dental practice for many years to come.

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