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ROLE AND PROPERTIES OF MTA IN DECIDUOUS AND CONSTANT TEETH

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Introduction. Mineral trioxide aggregate (MTA) was developed in early 1990s by Dr. Mahmoud Torabinejad and Dentsply Tulsa Dental (Pro-Root MTA, Dentsply Tulsa Dental, Johnson City, TN, USA) and at the Loma Linda University, California, USA, as a root-end filling material in surgical endodontic treatment and was formulated from commercial portland cement with bismuth oxide powder for radiopacity [18, 19]. MTA was originally developed for perforation repair and root end filling and due to its clinical success, MTA has expanded its uses to one visit apexification, pulp-capping and so on. Since its introduction to endodontics, MTA has shown great clinical success due to its good sealing ability and biocompatibility. Over the years, further research on the material has resulted in mineral trioxide aggregate being applied in various clinical situations in addition to its use as a suitable root-end filling material. The diverse application of MTA in the practice of pediatric dentistry is evident in its use as an apical barrier in immature non-vital teeth and in the coronal fragment of fractured roots, as a pulpotomy medicament in deciduous and permanent teeth, a pulp-capping agent in young permanent teeth and as a repair material for perforation and analysis defects. Among many advantages of MTA, main and unique advantage is that the setting of MTA is not adversely affected by presence of water. Indeed, MTA needs water in its setting reaction, thus it is considered hydrophilic and water tolerant. Considering that the traditional root perforation repair materials such as composite resin and glassinomer are sensitive to the existence of water, water tolerance of MTA is believed to be its unique advantage which results in clinical success. However, until now, the setting reaction and the reaction product of hydrated MTA has not been fully investigated and clearly understood, although the setting mechanism and hydration products of MTA have significant effects on the chemical and physical properties of MTA.

Thus, the **aim** of this article is to review the chemical characteristics and the hydration reaction of MTA.

Materials and Methods. An electronic literature search of scientific papers from January 1993 to May 2015 was carried out using the Medline, Embase, Entrez Pubmed, and Scopus databases. These data-bases were used to search for the key words Mineral Trioxide Aggregate, MTA, Gray MTA, Grey MTA, White MTA, GMTA, WMTA, and mineral and trioxide and aggregate.

All papers on MTA, which reported studies carried out *in vitro*, *in vivo*, and *ex vivo* on tissues, animals, and humans were included for reviewing. The search yielded 983 papers, out of which 100 were identified as conforming to the applied criteria. These papers formed the basis of the review and the clinical scenarios presented which demonstrate the application of MTA in the practice of pediatrics dentistry [1, 6].

Chemical and physical properties of MTA.

Structure and composition. Studies analysing the constituents of both white and grey Pro-Root MTA have conclusively shown that both materials are similar to Portland cement, but with bismuth oxide added, presumably to make the materials radiopaque for dental use. Portland cement itself is a mixture of dicalcium silicate, tricalcium silicate, tricalcium aluminate, gypsum and tetracalcium aluminoferrite. It was reported that the amount of gypsum in Pro-Root MTA is approximately half the amount found in Portland cements [4, 17].

Gypsum is an important determinant of setting time and is added by cement manufacturers to retard the setting time of the cement clinker in Port-land cement. Modifying the gypsum content in the MTA mix can result in significant reduction of setting time, thereby reducing the number of treatment visits. Dammaschke *et al.* described the marked differences between Portland cement and Pro-Root MTA, by comparing the same chemical and physical surface, and bulk material characteristics.

They reported that Pro-Root MTA contains lower levels of potentially toxic heavy metals (e.g. manganese and strontium), chromophores (iron oxide), aluminium and potassium. In contrast to Portland cements, Pro-Root MTA contains about 17–18wt% (=2%) bismuth. Portland cements are composed of particles with a wide range of sizes, whereas Pro-Root MTA showed smaller and more uniform particle size. Studies have compared the constituents of grey and white Pro-Root MTA materials. There are contradictory reports with respect to the iron and magnesium oxide phases in the grey and white forms [18, 20].

Asgary *et al.* reported that white MTA contained significantly less amounts of oxides of iron, aluminium, and magnesium than grey MTA. There have been other studies, which have reported the complete absence of iron oxide in white MTA when compared to grey MTA. When comparing the Pro-Root MTA forms to MTA-Angelus, Song *et al.* also reported that MTA-Angelus had a lower content of bismuth oxide than the Pro-Root MTAs. There are no studies to date comparing the relative radiopacity of MTA-Angelus with the Pro-Root MTAs.

Hardening time. There are few published reports of experimental data relating to the comparative setting times of the different forms of MTA. The setting time of grey Pro-Root MTA was reported by Dr. Torabinejad *et al.* as 2 hours and 45min (±5min).

Islam *et al.* reported final setting times of 140 min (2 hours and 20 min) for white MTA, and 175min (2 hours and 55 min) for grey MTA. Although the manufacturers of MTA-Angelus claim that this material has a setting time of 10min, there appears to be no independent evidence to confirm this [8].

Several studies have compared various modified forms of Portland cement and Pro-Root MTA in an effort to identify a material with all the advantages of MTA and without its extended setting time. The presence of gypsum is reported to be the reason for the extended setting time of MTA.

Therefore, studies have reported modified forms of Portland cement without the gypsum and with added plasticizers, which reportedly do not affect the biocompatibility of MTA. In order to reduce the setting time, the effect of accelerators such as sodium phosphate dibasic (Na_2HPO_4) and calcium chloride ($CaCl_2$) are being investigated currently. MTA Bio is one commercially available product which incorporates an accelerator of this sort, and is promoted as a rapid-setting material [14], 15.

Radiopacity. An ideal restorative material should be more radiopaque than its surrounding structures when placed *in situ*, in order to allow the quality of the restoration or apical seal to be assessed. Several studies have confirmed that MTA is less radiopaque than Super EBA, IRM, amalgam and conventional gutta-percha, but in the same range as zinc oxide eugenol-based root canal sealers.

Compressive strength. Compressive strength is the capacity of a material to withstand axially directed pressure generating compressive stress as a result of compression force.

Torabinejad *et al*. reported comparable mean compressive strength after 21 days for Pro-Root grey MTA, IRM, and Super EBA. The compressive strength of amalgam was higher than these materials after the same time period. Root-end fillings and apical barrier materials do not bear direct pressure during function, hence, their compressive strength is not thought as important as those materials used to repair or restore defects in load-bearing sites. The compressive strength of Pro-Root grey MTA increased with time in the above study [18, 19].

The authors suggest that this increase over a period of time required the presence of moisture. Islam *et al.* reported greater compressive strength for the grey form of Pro-Root MTA in comparison to the white form at 3 days and 28 days in a similar *in vitro* study. Their study also showed that the compressive strength of the grey form of MTA was greater than that of Portland cement [8].

Setting conditions. Studies have reported that an initial period of exposure to moisture or humidity is required for the MTA to achieve optimum flexural strength. These authors recommend the placement of a moistened cotton pellet in the root canal for a period of time before placement of the permanent coronal seal when placing an apical barrier in immature teeth. Currently, there is insufficient literature regarding the implications of the setting conditions on the use of MTA as a pulp capping and pulpotomy medication. The role of moisture drawn in from the pulp or peri-radicular tissues is also unclear.

Solubility. The manufacturer recommends the use of 0.33 g of water with 1g of Pro-Root MTA to achieve an optimum mix of the material. Earlier studies showed no signs of solubility of Pro-Root MTA in water when tested under modified International Organization for Standardization(ISO).

Fridland and Rosado demonstrated that both solubility and porosity of the material show a significantly increasing trend that follows the amount of water used when preparing the mix under ISO specifications. The set or hardened/cured material, on exposure to water, was shown to release calcium as hydroxide, and the authors reported that their finding could explain the basis of the cementogenesis-inducing property of MTA.

These studies also suggest that the water to powder ratio recommended by the manufacturer (0.33) would be the ideal proportion.

Santos *et al.* reported that calcium and hydroxyl ions may be released from MTA-Angelus during storage in moist conditions for periods up to 360 hours.

Marginal adaptation and sealing ability. An effective root-end filling material should ideally provide a hermetic apical seal, preventing the movement of tissue fluids into the root canal system and the egress of micro-organisms and their by products from the root canal system. Investigations have been carried out on extracted human teeth which were prepared and restored with the root-end filling materials whose marginal adaptation and sealing ability were investigated by various methods. Historically, investigators have evaluated quality of the apical seal by the degree of dye, radioisotope, or bacterial penetration; electrochemical means; scanning electron microscopy (SEM); or fluid filtration. As a result, the validity of such data is questionable. The results of some studies demonstrate correlation with respect to marginal adaptation with SEM and apical seal dye penetration for different root-end fillings. These studies compared amalgam, Super EBA, IRM and MTA and were the earliest investigations comparing MTA to other traditional root-end filling materials [11].

There are, however, conflicting results in the literature relating to the correlation between marginal adaptation and sealing ability of different root-end filling materials. Several investigators report that the fluid filtration method has the advantage of measuring the cumulative leakage of the entire tooth restoration interface and is therefore quantitative. Bates *et al.* reported that MTA was superior to amalgam and comparable with Super EBA in preventing microleakage when used as a root-end filling by the fluid filtration method on extracted human teeth.

Almost a decade later, Shipper *et al.* compared MTA with amalgam as a root-end filling material with a high and low vacuum SEM study on extracted human teeth. Results showed that MTA demonstrated better marginal adaptation to the root end cavity wall than amalgam. This group of workers purport their findings to be linked to the inherent nature of MTA, and suggested that the expansion of the material during the hydration setting reaction contributed to the superior adaptation to dentine. The authors concluded that this expansion may play a role in the increased incidence of cracks at the interface compared to the amalgam specimens.

Investigators have also compared MTA with amalgam, Super EBA, and IRM with *in vitro* studies using specific bacterial leakage tests [10].

The micro-organisms used in such tests have included *Staphylococcus epidermidis* and *Serratia marcescens*. These studies have been consistent in reporting MTA as showing no or less leakage in comparison to the other three materials, respectively. The peri-radicular environment may have varying pH from a neutral pH of 7.4 to an acidic pH as low as 5.0.

An acidic pH has been shown to inhibit the setting reactions, affect adhesion, and increase solubility of materials placed to effect a root-end seal.

Roy *et al.* compared the sealing ability of materials tested by recording the linear dye leakage with Pelikan Ink. under a surgical microscope, and reported that an acidic environment does not hinder the sealing ability of MTA, amalgam, Geristore, Super-EBA, CPS, and MTA with CPC matrix.

The protein leakage and assay test is claimed to provide the advantage of eliminating the problems involved with radio-isotopes, dye, and bacteria during leakage identification. Valois and Costa studied the influence of the thickness of MTA on the sealing ability of root-end fillings *in vitro* by using a protein-dye complex with Coomassie Blue G dye.

It was shown that 4-mm-thick MTA was significantly more effective than others (1, 2, 3 mm) in preventing apical leakage.

Calcium hydroxide intra-canal medication has been shown to affect the sealing ability of MTA. The *in vitro* sealing efficiency of white and grey Pro-Root MTA as apical barriers was investigated in simulated divergent apices using a dye tracer (basic fuchsine).

A comparable apical seal with both forms of Pro-Root MTA was reported. It was also shown that residual calcium hydroxide intra-canal medication could interfere with the adaptation of MTA to the root canal walls by being a mechanical obstacle, and also by chemically reacting with MTA, thus influencing its surface characteristics. The use of the internal matrix concept to limit the flow of the MTA material (in the root-end and perforation situations) and improve its sealing ability has been investigated. Zou *et al.* reported an *in vitro* study to evaluate internal matrices as barriers to prevent the over-extension of MTA. They reported that calcium sulphate provided a successful barrier against over-extension of MTA, but significantly decreased its sealing ability, and Collaplug (collagen plug) didn't prevent over-extension or improve its sealing ability.

The validity of 'leakage studies' has recently been brought into sharp focus by a decision of the *Journal of Endodontics* to place a moratorium on the acceptance of such studies until more is known of their relevance.

Effect of compaction/condensation on mineral trioxide aggregate. Condensation pressure or compaction is an uncontrolled variable when MTA is placed as an apical barrier in an immature tooth, surgical or non-surgical perforation repair, a pulp-capping material, or as a retrograde filling material in a root-end cavity. It is likely that the condensation pressure during the placement of MTA as an apical barrier will be much reduced to prevent the material from being forced into the periodontal ligament or pulp tissue in some of these situations [13].

Nekoofar *et al.* reported no statistically significant effect of condensation pressure on the compressive strength of white Pro-Root MTA, but there was a significant reduction in surface hardness. This group of workers also concluded that greater condensation pressures could limit the space for the ingress of water required to hydrate the material in order to achieve an adequate surface hardness.

Effect of MTA on the strength and hardness of root dentine. Studies using sheep and bovine teeth (*in vitro* and *in vivo*) have shown that teeth with an MTA apical barrier and MTA root filling showed higher fracture resistance in comparison to teeth that had calcium hydroxide placed as an intra-canal medicament. It has been previously suggested that the conventional apexification technique involving the placement of calcium hydroxide in the root canal for a prolonged period of time may be responsible for an increased susceptibility of immature incisors to root fracture. In 2002, Andreasen *et al.* reported that long-term calcium hydroxide dressings weaken the root structure possibly by neutralizing, denaturing, or dissolving the acidic components of dentine. Because these components act as 'bonding agents' between the collagen network and the hydroxyapatite crystals, their destruction may render the tooth more prone to fracture. In light of this evidence, the placement of MTA as a one-step apical barrier after appropriate debridement of the root canal, may be a suitable alternative to traditional apexification or the induced apical barrier technique.

As with any other glassinomer material, inadequate debridement and canal preparation could lead to persistent symptoms even after the apical seal has been placed with MTA. Once the MTA placed as an apical seal has hardened, it becomes extremely difficult to remove, and persistent symptoms can result in the need for surgery or even tooth extraction.

Interface between MTA and dentin. Although the superior sealing ability of MTA was well documented and reported, there has been relatively scarce study on the morphology of MTA-dentin interface. Recently, Reyes-Carmona studied and reported the interfacial layer formed between MTA and dentin.

Reyes-carmona *et al*. and Dreger *et al*. reported that this interfacial layer was formed as a result of biomineralization and some tag-like structures were formed in this process. These were the pioneering reports that the tag-like structures was formed in MTA-dentin interface. Bird *et al*. also reported that the interfacial layer made of hydroxyapatite was formed between MTA and dentin.

Based on these studies, it could be postulated that the superior sealing ability of MTA could be partly attributed to the formation of tag-like structures in MTA-dentin interface. It was interesting that MTA produced more MTA tag-like structures than Portland cement. It was also interesting finding that hydrated MTA immersed in phosphate buffered saline (PBS) produced more mineral precipitation than those immersed in distilled water [7]. These tag-like structures are believed to be the result of ionic dissolution of MTA which resulted in growth and nucleation of the apatite layer. Dreger *et al*. reported that the calcium ions released from the cements diffused through the dentinal tubules and reacted with phosphate ions in the tissue fluids, and yield calcium phosphate and eventually, this calcium phosphate incorporated other ions and matured into carbonated apatite (CDHA). This phenomenon suggested the possibility that the precipitated minerals formed the mineralized layer between MTA and dentin which yielded chemical bonding between MTA and dentin. Han and Okiji demonstrated that

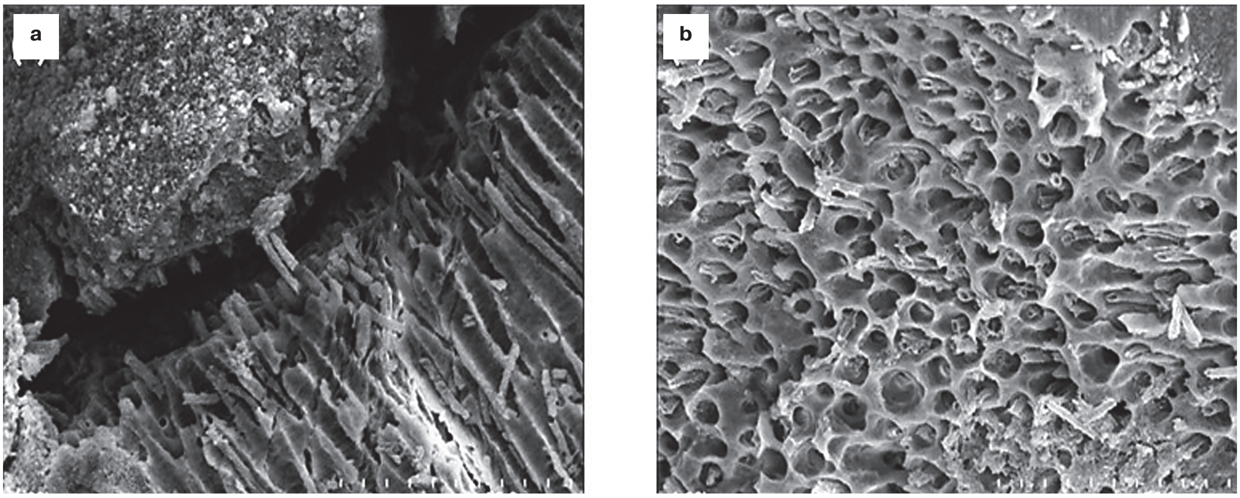

Figure 1. Scanning Electron Microscope (SEM) image which shows the formation of tag-like structures in Ortho MTA-dentin interface and in dentinal tubules. (a) in Ortho MTA-dentin interface (Ч1,000); (b) in dentinal tubules (Ч1,000). Courtesy of Dr. Joon-Sang Yoo.

dentin which was in contact with MTA up took Ca and Si from this calcium silicate based materials. They reported that the Ca and Si uptake of dentin caused chemical and structural modification of it, which might result in higher acid resistance and physical strength (**Figure1**).

Antibacterial and antifungal activity. As micro-organisms are the main aetiological factors in pulpitis and periodontitis, their elimination during treatment is essential. It is likely that even after caries removal and root canal debridement, micro-organisms with the potential to promote disease may persist, or new organisms may enter by coronal leakage. The healing of tissues damaged by pulp or peri-apical pathology depends on the absence of irritating agents originating from microbial metabolic products, or of chemical origin from the sealing materials. For such healing to occur, the materials placed in contact with healthy pulp (pulp-capping, pulpotomy) and peri-apical tissues (apical barrier, root-end filling) should not damage the tissues and should ideally stimulate the deposition of hard tissue, therefore promoting biological sealing. MTA materials fulfill this requirement adequately.

Several studies have been carried out to ascertain the antibacterial and antifungal properties of the MTA cements. Sipert *et al.* reported that MTA-Angelus did not inhibit the growth of *Escherichia coli* in an *in vitro* study. In 2006, Al-Hazaimi *et al*. assessed the anti-bacterial effects of the grey and white MTA materials against *Enterococcus faecalis* and *Streptococcus sanguis in vitro*. They reported that lower concentrations of grey MTA were required than the white MTA to exert the same anti-bacterial effect against each of these micro-organisms. Eldeniz *et al.* also obtained similar results.

Enterococcus faecalis is one of the organisms more likely to be found in cases of failed endodontic therapy than in primary infections, and it is likely that on this basis that all reported literature regarding antibacterial activity of root filling materials is pertaining to this organism [2, 16].

Reactions with other dental materials. In an effort to offset the extended setting time of MTA, researchers have reported various alternatives to the placement of a moist cotton pellet over the setting MTA material. An *in vitro* study conducted by Nandini *et al.* reported that conventional glassinomer cement can be layered over partially set MTA for a single-visit procedure and that the setting of MTA proceeds unhindered underneath the layer of glassinomer.

In such a procedure, Ballal *et al.* reported their observations on a glassinomer cement layered upon partially set MTA. The setting of both materials was unaffected, and the glassinomer cement showed no signs of dehydration [3]. Tunc *et al*. evaluated the bond strength of a composite and a compomer to white MTA using different bonding systems. They concluded that the total-etch one bottle system mediated a stronger bond to white MTA than the self-etch one-step system. The conclusions from these studies bear relevance to the use of MTA as a pulp-capping and pulpotomy wound-dressing material [5].

Biocompatibility. The biocompatibility of MTA has been reported widely over the past decade by researchers involved in *ex vivo* cell culture studies and *in vivo* studies in humans and animals:

Subcutaneous and intra-osseous evaluation: Studies in the late 1990s reported bacterial and cell culture assays, respectively, to conclude that MTA was not mutagenic or cytotoxic. There have been several studies since then, which have tested samples of MTA as subcutaneous and intra-osseous implants in rats, guinea pigs, and rabbits. These studies reported minimal inflammatory responses in the soft tissue and bone, and confirmed MTA to be capable of inducing osteogenesis.

Animal studies: The biocompatibility of MTA has also been studied in vivo as root-end fillings in dogs and monkeys. These studies reported satisfactory peri-apical tissue responses and healing with MTA. Animal studies have also reported MTA as a favourable pulp-capping material following traumatic exposures in monkeys and dogs. MTA has been evaluated *in vivo* in rats as a pulpotomy medicament in comparison to formocresol and ferric sulphate, and reported to perform ideally as a pulpotomy agent, causing dentine bridge formation and simultaneously maintaining normal pulpal histology.

Cost implications and storage. Important barriers to the widespread use of MTA in pediatric dentistry include its perceived cost, difficulties with storage, and the need for appropriate training.

The list prices of some commercial products are as follows:

- ProRoot MTA (White) 5 Dose Pack (ProRoot MTA) – J302.00
- ProRoot MTA (White) 2 Dose Pack (ProRoot MTA) – J133.00
- MTA-White 1G Pack 7 Applications (MTA-Angelus) – J46.50
- MTA-Grey 1G Pack 7 Applications (MTA-Angelus) – J46.50
- MTA-Grey 2G 14 Applications (MTA-Angelus) – J85.00

Pro-Root products are supplied in single-dose sachets, whereas Angelus products are supplied in double-sealed glass vials. The composition of MTA is not unlike that of the cement used in the building industry to make concrete. Such a material should be kept dry during storage because moist air leads to the phenomenon of air setting, which reduces the strength of the mix. The presentation of Pro-Root products as a 1g sachet for single use, would result in considerable wastage of material, and the transfer of this material to a sealed container such as an Eppendorf tube (Eppendorf UK Ltd, Cambridge, UK) would extend the life of the material and allow more than one treatment to be completed from a single ‘dose’. The Angelus vials of material are marketed with guidance that 1g may allow up to seven treatments, depending of course on the volume of material to be used.

Clinical applications of MTA in constant and deciduous teeth.

There is a paucity of *in vivo* human studies on the performance of MTA in its various clinical applications. This section will review these studies.

Pulp treatment in permanent (constatnt) teeth. Pulp-capping: There have been few studies to date on MTA as a pulp capping agent in human permanent molars. Four prospective human clinical studies have compared MTA and calcium hydroxide as pulp-capping medicaments in third permanent molars following the *mechanical exposure* of healthy pulps [11].

Aeinehchi *et al.* reported a 0.28-mm-thick dentine bridge in teeth pulp capped with grey MTA at 2 months, and 0.43 thickness at 6 months in contrast to a 0.15-mm-thick dentine bridge noted with calcium hydroxide at 6 months. This study also reported tissue inflammation and adjacent pulp tissue necrosis with calcium hydroxide at 6 months, and no pulp tissue inflammation adjacent to MTA with a near regular odontoblastic layer for the same duration. These results were not significant due to the small sample size. A similar study by Iwamoto *et al.* compared white MTA with calcium hydroxide at 30 days and 136 days post-treatment.

At these evaluation periods, no significant difference was found between the groups with regard to the clinical presentation and the histological status. Initial results indicate that both grey and white MTA may perform as well as calcium hydroxide in non-carious mechanical pulp exposures in permanent teeth with normal pulp tissue. In contrast, Nair *et al.* reported that MTA resulted in less pulpal inflammation and more predictable hard tissue barrier formation in permanent teeth in comparison to hard-setting calcium hydroxide.

Accorinte Mde *et al.* also reported their support of the safety of MTA for pulp capping in human teeth. Their study reported that MTA seemed to heal the pulp tissue at a faster rate than calcium hydroxide cement, although after 60 days both materials reached similar and excellent results for pulp capping in human teeth. Bogen *et al.* have reported an [3]tional study where MTA was placed over *carious exposures* in permanent teeth with reversible pulpitis, over a 9 year period. They followed 49 teeth over this period and reported favourable outcomes of 97.6% of the sample based on radiographic appearance, subjective symptoms, and cold testing. All teeth in younger patients that initially had open immature apices showed complete root formation (apexogenesis) (**Figure 2**).

Pulpotomy: At the time three studies had been reported on the outcome of MTA as a wound dressing following pulpotomy in permanent teeth [18].

Two of these were observational studies reporting a small sample of 28 and 23 teeth, respectively. Barrieshi-Nusair and Qudeimat evaluated the success of grey MTA for partial pulpotomy in 28 cariously exposed young permanent first molars. This was an observational study

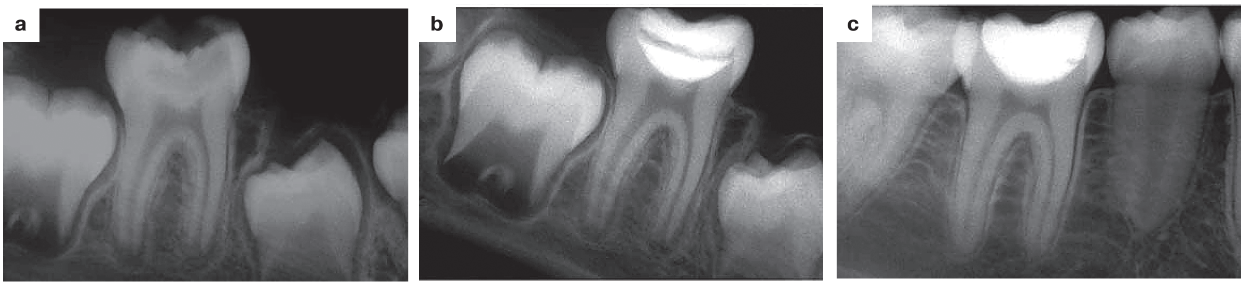

Figure 2.
(a) Radiographic image prior to treatment in a mandibular molar with deep caries and immature apices in a 9-year-old patient (Bogen G., Kim J.S., Bakland L.K. Direct pulp capping with mineral trioxide aggregate).
(b) Radiographic image of the tooth with mineral trioxide aggregate as a pulp-capping agent. (Bogen G., Kim J.S., Bakland L.K.. Direct pulp capping with mineral trioxide aggregate).
(c) Radiographic image of the tooth at 5.5-year recall showing a permanent restoration and evidence of complete root formation. The tooth exhibited a normal response to cold testing (Bogen G., Kim J.S., Bakland L.K. Direct pulp capping with mineral trioxide aggregate).

over a period of 12–26 months with an average of 17.5 months. The authors reported that 79% of the teeth tested positive to sensibility testing with no clinical or radiographic failures. Seven of the teeth which had immature apices at the beginning of treatment showed continued root maturation. A similar outcome was also reported by Witherspoon *et al*. in permanent molars with clinical signs of irreversible pulpal disease. El-Meligy and Avery reported a study comparing MTA and calcium hydroxide as pulpotomy agents in young permanent teeth.

This was a split-mouth study, in which 15 pairs of young permanent molar teeth in the same number of children were followed up for a period of 12 months.

The authors reported similar clinical and radiographic success for MTA and calcium hydroxide as pulpotomy agents in immature permanent teeth, and concluded that MTA was a suitable alternative to calcium hydroxide.

Pulp treatment in deciduous(primary) teeth. Pulpotomy: Several studies have evaluated MTA as a wound dressing following pulpotomy in primary teeth. Six of these studies have compared formocresol to the two forms of MTA (grey and white), and reported MTA to be an acceptable alternative to formocresol as a wound dressing in the pulpotomy of primary teeth [12].

Maroto *et al.* have reported longitudinal and observational clinical studies on grey and white MTA. Both studies reported favourably on the clinical outcomes with these materials as a pulpotomy medicament in primary teeth. Percinoto *et al.* have compared MTA to calcium hydroxide as a pulpotomy dressing, and reported both materials to be equally effective in primary teeth.

MTA has also been compared to formocresol and calcium hydroxide as a pulpotomy dressing in primary molars by Moretti *et al.* with satisfactory clinical and radiographic outcomes.

The clinical outcome measures are similar in all the mentioned studies, but there is variation in the definition of radiographic ‘success’, making comparisons difficult. The radiographic outcome has been perceived to be successful in all of the mentioned studies if there have been no pathological signs of peri-apical and furcal radiolucencies, and there has been variable or no sign of reparative dentine bridge formation at the time of the reported recall. Sign of internal resorption has been recorded as a negative radiographic outcome in most of the studies. Root canal calcification of the primary molars has been observed and recorded, but not perceived as a negative radiographic outcome in the study reported by Maroto *et al*.

Pulp-capping: A single study was identified on the outcome of MTA pulp capping in primary teeth. Tuna and Olmez reported that MTA was as successful as calcium hydroxide in direct pulp capping and recommended further histological validation to support their findings.

Root-end filling in immature permanent teeth. Two prospective, observational studies have investigated MTA as an apical barrier in non-vital immature permanent incisors. Simon *et al*. reported a range of follow up periods from 6 to 36 months for 57 teeth, 14 of which were in patients under the age of 16, in which an apical plug of MTA was placed as a barrier. This group of workers reported a decrease in the size of the pre-existing peri-apical lesion in 81% of their cases. A similar study by Saris *et al*. reported similar results in 17 non vital permanent immature incisors. The one step placement of an MTA apical barrier was viewed as a promising alternative to traditional, multiple-visit apexification with calcium hydroxide. The advantages of a one step MTA procedure were cited as reduced treatment time, reduced risk of calcium hydroxide- induced changes to dentine, and consequently reduced fracture risk, and the early placement of a sealing and possibly reinforcing coronal/ intra-radicular restoration. **Figure 3** shows the radiographic appearance of an MTA apical barrier in the non vital immature maxillary incisors of a 13 years old.

Figure 3. Radiographic image of mineral trioxide aggregate placed as an apical barrier in a non-vital immature maxillary incisors in a 13 years old.

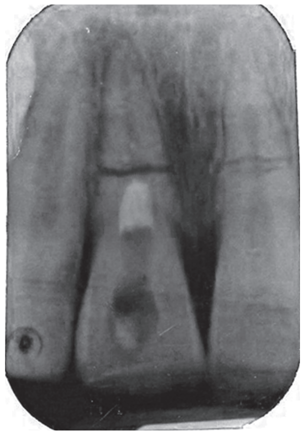

Figure 4. Radiographic image of mineral trioxide aggregate placed as an apical seal in a coronal fragment of a maxillary right central incisor in an 11 years old.

Apical seal in the non-vital coronal portion of permanent teeth following root fracture. Root canal treatment of the coronal fragment with calcium hydroxide followed by filling with gutta-percha is the traditional treatment of choice for non vital root-fractured teeth.

As in the case of open root apices, the use of calcium hydroxide has been promoted to induce hard-tissue barrier formation at the fracture site. The hard tissue barrier is then able to serve as a matrix for the condensation of gutta-percha and sealer. In this situation, MTA has the potential to offer all of the advantages noted for one step root-end filling. Currently, there have been no human or animal studies reported on the use of MTA as an apical barrier for the coronal fragment of the root-fractured tooth. There are, however, case reports explaining the technique with follow up of up to 2 years. **Figure 4** illustrates the radiographic appearance of MTA placed as an apical seal in a coronal fragment of a fractured maxillary right central incisor in an 11 years old.

Conclusion. The paucity of human clinical studies on MTA is likely to change within the next decade. Considering that the material has been in routine clinical use for a little more than a decade, all aspects of its profile as a dental material are currently being investigated.

Studies designed to conform with CONSORT guidelines in terms of power, blinding, control groups, and recall times have the potential to validate the clinical impressions of MTA as a useful and versatile material in the armamentarium of the pediatric dentist.

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ЗНАЧЕННЯ І ХАРАКТЕРИСТИКИ МІНЕРАЛЬНОГО ТРИОКСИДНОГО АГРЕГАТУ В ЛІКУВАННІ МОЛОЧНИХ І ПОСТІЙНИХ ЗУБІВ

Масуд Кіані

Резюме. Часто лікарі-стоматологи мають сумніви при виборі порівняно нових матеріалів у своїй лікарській практиці через відсутність очевидних ефективних результатів їх застосування і невивчених властивостей, або високій вартості матеріалу. У статті представлено наочне підтвердження успішного лікування ряду стоматологічних проблем із застосуванням мінерального триоксидного агрегату (MTA): пульпотомія молочних зубів, захисне покриття пульпи молодих постійних зубів, травмування незрілих постійних зубів, травмування постійних зубів з переломами кореня зуба, відновлення постійних зубів при наскрізному ушкодженні.

Важливо, щоб дитячі стоматологи знали основні властивості матеріалів, які вони використовують при лікуванні пацієнтів. У статті також представлена корисна інформація відносно порівняно нових реставраційних матеріалів, які вступають в прямий контакт з м'якими сполучними тканинами (пульпа зуба і періапікальні тканини). Метою даної роботи був огляд публікацій, в яких описані хімічні і фізичні властивості мінерального триоксидного агрегату і його клінічне застосування в лікуванні молочних і постійних зубів.

Ключові слова: мінеральний триоксидний агрегат, WMTA, GMTA, пульпотомія, захисне покриття пульпи.

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ЗНАЧЕНИЕ И ХАРАКТЕРИСТИКИ МИНЕРАЛЬНОГО ТРИОКСИДНОГО АГРЕГАТА В ЛЕЧЕНИИ МОЛОЧНЫХ И ПОСТОЯННЫХ ЗУБОВ

Масуд Киани

Резюме. Зачастую врачи-стоматологи испытывают сомнения при выборе сравнительно новых материалов в своей врачебной практике из-за отсутствия очевидных эффективных результатов их применения и неизученных свойств, или высокой стоимости материала. В статье представлено наглядное подтверждение успешного лечения ряда стоматологических проблем с применением минерального триоксидного агрегата (МТА): пульпотомия молочных зубов, защитное покрытие пульпы молодых постоянных зубов, травмирование незрелых постоянных зубов, травмирование постоянных зубов с переломами корня зуба, восстановление постоянных зубов при сквозном повреждении.

Важно, чтобы детские стоматологи знали основные свойства материалов, которые они используют при лечении пациентов. В статье также представлена полезная информация относительно сравнительно новых реставрационных материалов, которые вступают в прямой контакт с мягкими соединительными тканями (пульпа зуба и периапикальные ткани). Целью данной работы был обзор публикаций, в которых описаны химические и физические свойства минерального триоксидного агрегата и его клиническое применение в лечении молочных и постоянных зубов.

Ключевые слова: минеральный триоксидный агрегат, WMTA, GMTA, пульпотомия, защитное покрытие пульпы.

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Role and Properties of MTA in Deciduous and Constant Teeth

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Abstract. Dentists may be hesitant to adopt a relatively new material into their clinical regimes, lacking confidence in the available evidence or having concerns about its cost and handling characteristics. This paper provides illustrated evidence on the success which can accompany the use of MTA in a range of settings including: deciduous teeth, as a pulpotomy medicament; young permanent teeth, as a pulp-capping agent; immature traumatized permanent teeth, as an apical barrier; traumatized permanent teeth with root fractures, as an apical barrier of the coronal root fragment; and permanent teeth, as a repair material for perforation and analysis defects.

Also, pediatric dentists should be familiar with the fundamental properties of the materials they use on patients. This paper provides readers with helpful information on a relatively new restorative material which comes into direct contact with soft connective tissues (pulp and peri-apical tissues). The aim of this paper was to present a review of the reported literature on: the chemical and physical properties of mineral trioxide aggregate; and Clinical applications of mineral trioxide aggregate in deciduous and permanent teeth.*Clinical applications of MTA in constant and deciduous teeth.* There is a paucity of *in vivo* human studies on the performance of MTA in its various clinical applications. This section will review these studies.

Pulp treatment in permanent (constatnt) teeth. Pulp-capping: There have been few studies to date on MTA as a pulp capping agent in human permanent molars. Four prospective human clinical studies have compared MTA and calcium hydroxide as pulp-capping medicaments in third permanent molars following the *mechanical exposure* of healthy pulps.

Pulp treatment in deciduous(primary) teeth. Pulpotomy: Several studies have evaluated MTA as a wound dressing following pulpotomy in primary teeth. Six of these studies have compared formocresol to the two forms of MTA (grey and white), and reported MTA to be an acceptable alternative to formocresol as a wound dressing in the pulpotomy of primary teeth.

Root-end filling in immature permanent teeth. Two prospective, observational studies have investigated MTA as an apical barrier in non-vital immature permanent incisors. Simon *et al*. reported a range of follow up periods from 6 to 36 months for 57 teeth, 14 of which were in patients under the age of 16, in which an apical plug of MTA was placed as a barrier. This group of workers reported a decrease in the size of the pre-existing peri-apical lesion in 81% of their cases.

Apical seal in the non-vital coronal portion of permanent teeth following root fracture. Root canal treatment of the coronal fragment with calcium hydroxide followed by filling with gutta-percha is the traditional treatment of choice for non vital root-fractured teeth.

Conclusion. The paucity of human clinical studies on MTA is likely to change within the next decade. Considering that the material has been in routine clinical use for a little more than a decade, all aspects of its profile as a dental material are currently being investigated.

Studies designed to conform with CONSORT guidelines in terms of power, blinding, control groups, and recall times have the potential to validate the clinical impressions of MTA as a useful and versatile material in the armamentarium of the pediatric dentist.

Keywords: Mineral Trioxide Aggregate, WMTA, GMTA, pulpotomy, pulp-capping.

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