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Apexification with Mineral Trioxide Aggregate: an overview of the material and technique

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Abstract - *Mineral Trioxide Aggregate (MTA) was introduced as an alternative to traditional materials for the repair of root perforations, pulp-capping and as a retrograde root filling due to its superior biocompatibilty and ability to seal the root canal system. Traditionally, calcium hydroxide has been the material of choice for the apexification of immature permanent teeth but MTA holds significant promise as an alternative to multiple treatments with calcium hydroxide. The paper discusses the use of calcium hydroxide as a traditional apexification material and provides an overview of the composition, properties and applications of Mineral Trioxide Aggregate with emphasis on its use in apexification of immature permanent teeth. A case report is presented to highlight its use.*

KEY WORDS: Mineral Trioxide Aggregrate, Apexification, Immature Apex, Calcium Hydroxide

INTRODUCTION

Root development is through the continuous deposition of dentine and cementum by stimulation and differentiation of Hertwig's Epithelial Root Sheath (HERS) and surrounding undifferentiated progenitor cells [1]. HERS is a continuous sleeve of epithelial cells, which separates the pulp from the dental follicle. It consists of an inner layer of cuboidal cells and an outer layer of more flattened cells. It completely encloses the dental papilla except for an opening in its base, the primary apical foramen. Odontoblastic differentiation takes place adjacent to the basal aspect of HERS, after which mantle dentine is deposited. At this time, the innermost layer of cells in the root sheath secrete an intermediate material which combines with the mantle dentine to from intermediate cementum layer. After odontoblastic differentiation and formation of intermediate cementum, HERS disintegrates and the epithelial cells migrate away from the root surface to form the epithelial cell rests of Malassez. Simultaneously, cells from the dental follicle migrate towards the root surface and become cementoblasts. Interruption of this process by trauma or infection can lead to incomplete root development and the presence of an open apex and a wide funnel shaped canal.

A common cause for the interruption of root development is trauma. The nature of the injury depends on the location of the tooth, the energy of impact, resiliency and the angle of the impact [2]. However, the majority of injuries occur in young individuals when the root development is incomplete [3]. Luxation injuries appear to be associated with the greatest risk of incomplete root development with between 15 and 59% of teeth losing their vitality [3]. The maxillary central incisor is the most frequently affected tooth in both dentitions [3].

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Incomplete root development can provide a challenging clinical situation since cleaning, shaping and obturation during root canal therapy may become difficult and unpredictable.

Morse *et al.*[4] reported in their literature review three techniques to obturate an immature tooth, which involved the use of a root-filling material without the induction of the apical closure:

- placement of a large gutta-percha filling or customized gutta-percha cone with sealer at the apex;
- placement of gutta-percha with sealer or zinc-oxide/eugenol short of the apex;
- peri-apical surgery.

These techniques did not gain popularity since there was no physical apical barrier to facilitate obturation. However Morse *et al.* also reported two techniques, which aimed to provide the formation of an apical barrier:

- placement of calcium hydroxide to induce a mineralised apical barrier;
- placement of a biocompatible material such as dentinal chips against which a root-filling could be placed.

Until recently, the traditional approach to the treatment of non-vital teeth with incompletely developed roots has been apexification by inducing the formation of mineralised tissue in the apical portion of incompletely formed apex [4]. The barrier facilitates the placement of an appropriate root-filling whilst reducing the possibility of the sealant or root-filling extruding into apical tissues [7]. Calcium hydroxide has been the material of choice for apexification and has been widely studied and reported. Granath [5] was the first to report the use of the material for apical closure. Its potential to induce mineralisation was shown by Mitchell in 1958 [6]. It has also been combined with other materials such as sterile water, camphorated monochlorophenol, methylcellulose, cresatin, iodoform, and Ringer's solution [4].

Foreman and Barnes [8] in a review of calcium hydroxide reported the findings of several authors with regard to the mechanism of action of calcium hydroxide in the induction of mineralization, however it still remains unclear. It is suggested that the calcium ions which are incorporated in the mineralised repair tissue are derived from the vascular supply of the pulp and not the material itself [8]. A rise in pH due to free hydroxyl ions acts as an initiator of the process, the alkalinity acting as a buffer against the acidic reactions produced by the inflammation. It is postulated that calcium hydroxide activates alkaline phosphatase and stimulates undifferentiated mesenchymal cells into cementoblasts and osteoblasts. It is also possible that Hertwig's epithelial root sheath remains intact and resumes function once the canal is debrided of the necrotic tissue [9]. This would then result in true apex formation. In the absence of the root sheath, a calcific barrier is formed and not a true apex.

The Royal College of Surgeons of England [7] have published guidelines on the management of immature non-vital teeth using calcium hydroxide and details on the technique. Sheehy and Roberts [10] reported a success rate of 74-100% in their review of apexification using calcium hydroxide. There does not appear to be a consensus on how frequent the material needs to be changed. However calcium hydroxide's inherent solubility means that replacement at 3 monthly intervals until closure of the apex occurs would appear advisable. The duration of treatment is variable with between 5.1- 20.2 months being reported as the time before an apical barrier was formed [10].

Whilst the advantage of calcium hydroxide lies in the fact that it has been widely studied and has shown success, the disadvantages are its prolonged treatment time, the need for multiple visits and radiographs. In some cases, root resorption [10] possibly caused by trauma and increased risk of root fracture [11] due to dressing the root canal for an extended time with calcium hydroxide has been reported in teeth undergoing apexification. In cases where apexification does not occur, there are no clear guidelines on the next best approach.

Over the last decade, Mineral Trioxide Aggregate (MTA) has been researched extensively and reported as a possible answer to many clinical endodontic challenges. The material was developed in Loma Linda University, California, and first appeared in the endodontic literature as a material to repair lateral root perforations [12]. It has evoked much interest since the first report was published in 1993 [13].

What is MTA?

Until recently, MTA has been commercially available in the UK as ProRoot® MTA (Dentsply, Tulsa Dental, USA), in two colours: an original grey and a newer white. White Pro-Root was introduced as an aesthetic improvement over the original grey MTA. Both materials are available in the form of a biocompatible, hydrophilic powder that sets in the presence of moisture [14]. The material consists of tricalcium silicate, tricalcium aluminate, tetracalcium aluminoferrite, calcium sulfate dihydrate and silicate oxide but other mineral oxides may also be added to improve physical and chemical properties [14, 15]. The addition of bismuth oxide powder makes it radio-opaque [15]. The tetracalcium aluminoferrite is reportedly absent in the white MTA [15]. The material is mixed with sterile water, which results in hydration (pH 12.5) leading to a set in approximately four hours [12]. It is currently dispensed as a powder, in five 1g sachets and should be stored in a dry environment. Comparisons between the two commercially available types of MTA [16] have shown no significant differences in terms of biocompatibility and micro-leakage. However, in another study, Matt *et al.* [15] found that a 5 mm apical barrier of grey MTA using the recommended 2-step apexification procedure leaked significantly less than the white MTA.

PHYSICAL PROPERTIES

pH

MTA has a pH similar to that of calcium hydroxide of 12.5 at 3 hours [14]. This similarity with calcium hydroxide is thought to contribute to its inductive potential and the resultant hard tissue formation [14]. However conclusive evidence is yet to be proved to demonstrate this. MTA, like amalgam and super EBA do not show any signs of solubility in water at 7 days as per ISO and ADA specifications [14].

Sealing ability and marginal adaptation

Lack of an ideal apical seal is largely responsible for failure of surgical endodontics[17]. The quality of apical seal for different retrograde materials has been assessed by different research groups, based on the degree of penetration by (i) dye (ii) radio-isotope (iii) bacterial (iv) electro-chemical means and (v) fluid filtration techniques [18]. These studies have shown superior results for MTA when compared with other materials [18]. MTA is also associated with less overfills [12] and the superior outcome associated with the material is observed with or without blood contamination of the root cavities [19]. In a study carried out by Fischer *et al.*[19], using bacterial leakage model, the time period in which materials began leaking was 10-63 days for amalgam, 24-91 days for IRM, and 42-101 days for super EBA. MTA did not begin to leak till day 49. The superior sealing ability of MTA is thought to be due to the setting expansion it undergoes in moist environment [19].

Compressive strength

MTA has a relatively low compressive strength; however, this does not compromise its success as it is used in situations that experience low compressive forces[14]. Sluyk *et al.*. studied the setting properties of MTA and found that MTA reached its maximum resistance level if left undisturbed for 72 hours before placement of a permanent restoration [20].

BIOCOMPATIBILTY

In 1997, Koh *et al.* reported on the biological response triggered by MTA on human osteoblasts in vivo [13]. The study examined an osteoblast-like standardized cell line to determine changes in cytokine release, and levels of osteocalcin (non-collagenous protein characteristic of osteoblast function) and alkaline phosphatases. This was set as an indication of matrix production. Cultured MG-63 cells were trypsinised and seeded into dishes containing standard amounts of MTA and polymethylmethacrylate (PMA). In this study, all markers of osteoblast function that were assessed were increased in the presence of MTA.

Material analysis of MTA shows the material to be divided into calcium oxide and calcium phosphate. The scanning electron microscopic studies revealed that amorphous calcium phosphate showed maximum ingress and growth of cells. They concluded that MTA offers a biological substrate for osteoblasts and the calcium phosphate phase favoured the change in cell behaviour that stimulated growth over MTA [13].

INDUCTIVE POTENTIAL

Torabinejad *et al.* and colleagues used infected premolars in two-year old beagle dogs, which were prepared to receive gutta-percha root-fillings [21]. The root fillings were left to contaminate by means of open access cavities and subsequently underwent root resection and retrograde fillings with either MTA or amalgam. Although periosteum and new bone formation were found in the presence of both materials, histologic findings at 10-18 weeks post-surgery confirmed the formation of cementum exclusively over the root ends with MTA, which included the MTA itself. This led to the conclusion that MTA could be used as a root end filling.

Shabahang *et al.* [22] carried out apexification in immature dog-teeth using Calcium hydroxide osteogenic protein and MTA. MTA induced hard tissue formation more than any other test material at 12 weeks, resulting in root-end closure**.**

Cytotoxicity

An *in vitro* study conducted by Osorio *et al.* in 1998 compared different root canal sealers and root end filling materials using two assay systems and two different mammalian fibroblast cell line [23]. Their conclusions were based on the fact that if a material exhibits a strong cytotoxicity in cell culture tests, it is very likely to do so in living tissue. Of the materials tested, MTA was the least cytotoxic.

Manipulation

ProRoot [R] MTA is mixed immediately before its use in a ratio of 3:1 powder to sterile water ratio [14]. The manufacturers recommend mixing the powder with water for one minute to ensure hydration of all particles. A thick creamy consistency is recommended. If the area of application is too wet, a piece of foam can be applied to remove extra moisture. The mix can be carried to the site with plastic or metal instruments [14].

CLINICAL APPLICATIONS[24]

Root-end filling material or repair of a root perforation

Several materials have been advocated as root-end filling materials or to repair root perforations. These include silver amalgam, glass ionomer, Intermediate restorative material (IRM), and Ethoxybenzoic Acid (super EBA). The ideal material should be biocompatible, have an optimum seal, regenerative potential and not be limited in its application in dry fields [25]. Unfortunately, no single material has all the ideal properties [19, 23], but MTA with its regenerative potential, biocompatibility, superior sealing properties and moisture tolerance appears to offer the best option at present [21].

Pulp capping

MTA has been indicated for pulp exposures in vital immature teeth, under isolation using a rubber dam [24]. After rinsing the pulp with dilute sodium hypochlorite, the procedure of pulpotomy or pulp-capping is carried out conventionally. After haemostasis is achieved, the mixed MTA is places over the exposed pulp with a moist cotton pledget, which is left in-situ under a temporary material. This is then removed a week later to leave a layer of MTA over which a definitive filling is placed.

There are a number of case reports by various authors on apexification and furcation repairs using MTA. Main *et al.* [26] recently reported the largest number of repairs of root perforations using MTA, with all 16 cases showing radiographic healing within a range of 12-45 months. However, there are no long-term studies yet published with regard to other applications of MTA.

CLINICAL CASE

A ten-year-old boy was referred by his general dental practitioner to the Department of Restorative Dentistry, Morriston Hospital, Swansea due to problems with an upper left central incisor - 21. This tooth had been traumatised two years previously and had subsequently lost its vitality. The GDP had attempted apexification with calcium hydroxide for 24 months without the desired root end closure. On presentation the tooth was tender to percussion.

An immature apex was observed on the radiograph (Figure 1). The case was considered suitable for apexification with MTA. Treatment was carried out under local anaesthetic and rubber dam isolation utilising an operating microscope. Straight-line access was established and the apex was viewed under magnification. Due to lack of a closed apex, the peri-apical soft tissue was clearly visible. The canal was debrided using hand and ultrasonic files and irrigated with copious amounts of 5% sodium hypochlorite. The canal was dried and dressed with calcium hydroxide for a week. At the following visit, the calcium hydroxide was removed and the canal again cleaned, irrigated and dried.

MTA was mixed according to manufacturer's guidelines to a thick creamy consistency. It was then deposited 1-1.5 mm short of the working length using a carrier and condensed with minimal pressure using the broad end of appropriate sized paper points. This allowed control of the moisture in the MTA mix, as the paper point can be used to absorb or impart moisture as necessary. Due to its hydrophilic nature, MTA adapts well to the peri-apical tissues. This was repeated until approximately 5 mm of the material was deposited in the apical region. A moist cotton wool pledget was then placed in the canal overnight and the system temporarily sealed using thermoplasticized gutta-percha using Obtura II, and a zinc oxide/eugenol dressing. A check radiograph was obtained to evaluate the apical seal. The gutta-percha and cotton wool pledget was removed the following day and a definitive root-filling placed coronal to

Figure 1. *Pre-operative radiograph of 21 showing immature apex*

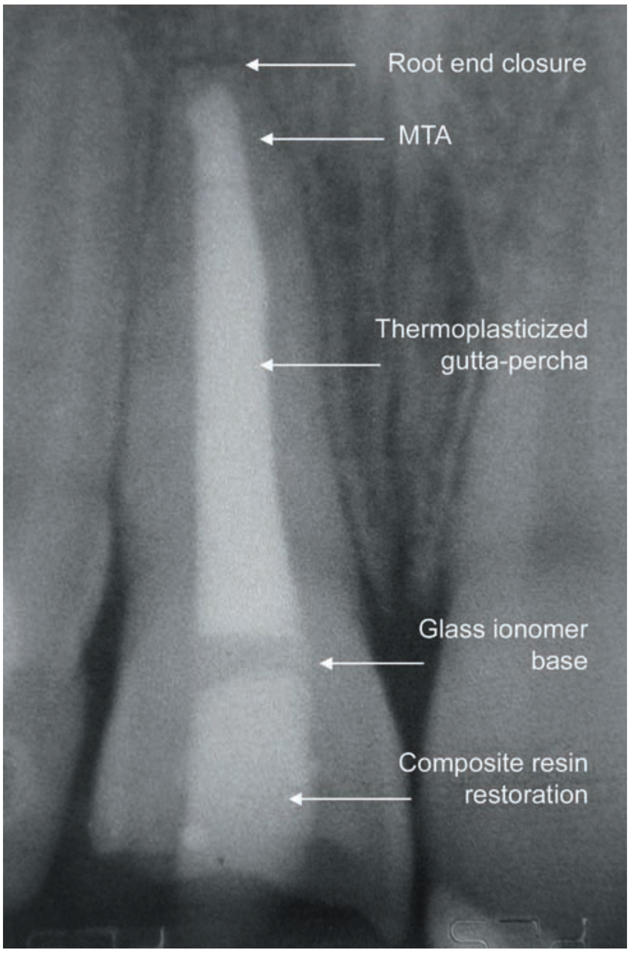

Figure 2. *One-year post-MTA apexification radiograph showing complete closure of root*

the MTA using thermoplasticized gutta-percha. Composite was used to seal the pulp chamber and this was extended into the cervical region of the tooth to fill the access cavity. The tooth was reviewed at intervals of one month, six months and twelve months post treatment. A radiograph was obtained at the one- year interval (Figure 2).

DISCUSSION

Regeneration is the ideal desirable outcome for any restorative procedure. The last decade has seen a quest for a material that can regenerate odontogenic tissue successfully, both from a periodontal and endodontic aspect. MTA offers the option of a two-visit apexification procedure, which must have the benefit of better compliance and reduced number of radiographs over the multiple visit calcium hydroxide apexification, particularly in younger patients. With the limitations of materials which have been routinely used as retrograde filling materials, MTA has been used over the last 10 years as a suitable alternative to achieve a peri-radicular seal. There have been no randomised controlled trial comparing MTA and the other commonly used materials, however there are short-term studies indicating favourable success rates with MTA [26].

MANUFACTURERS' DETAILS

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