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Review article

Mineral Trioxide Aggregate in Dentistry: A Review of Literature

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ABSTRACT

The introduction of mineral trioxide aggregate (MTA) in dentistry revolutionized the conservative and endodontic field. MTA sets by hydration process to produce insoluble calcium silicate hydrate gel barrier and alkaline calcium hydroxide. The high flux of calcium hydroxide is responsible for the rapid rise of pH and high calcium ion release into the surrounding environment, which in turn contributes to the bioactivity and antibacterial properties of this cement. MTA is considered the gold standard for various clinical applications including pulp capping, pulpotomy, apexification, root-end filling, and perforation repair owing to their superior biocompatibility as well as its sealing properties and antibacterial properties. However, it presented several limitations including prolonged setting time in addition to poor handling and washout characteristics, which presented several challenges during use in the clinical settings. This article reviews the history and evolution, composition, setting reaction, properties, and limitations of MTA as well as its applications in the clinical field.

Keywords: Mineral trioxide aggregate, Portland cement, endodontics, vital pulp therapy, pulp capping.

1. Introduction

1.1 History and evolution of mineral trioxide aggregate

Tricalcium silicate cements were first used during the prehistoric roman times for civil engineering by mixing raw earth products to form a quick set concrete for civil engineering [1]. In the early 19th century, Portland cement, based on tricalcium silicates, was patented by an English bricklayer called Joseph Aspdin. It was formed by calcination of a mixture of limestones excavated from Portland, England with silicon and clay-based materials [2]. Nowadays, Portland cement is obtained by heating lime, silica, alumina, and ferric oxide until fusion [1].

In 1993, Mineral trioxide aggregate (MTA) was patented by Torabinejad and Dean White as a tricalcium silicate-based formulation with great similarity in composition to ordinary Portland cement and was then approved by the U.S Food and Drug Administration (FDA) [3]. The main compositional difference between ordinary Portland cement and MTA is the addition of bismuth oxide as a radiopacifier to the latter [4, 5]. By 1999, the first commercial grey MTA (ProRoot MTA, Dentsply, Tulsa, USA) was launched into the U.S market [6]. However, grey MTA was usually associated with tooth discoloration potential due to the presence of iron oxides. To address this drawback, a white version of MTA was launched in 2002 with less iron oxides and finer particle size distribution [2, 6, 7]. By 2005, MTA Angelus (Angelus, Londrina, Brazil) was launched for clinical use following ProRoot MTA in both grey and white versions. The main difference was the reduced concentration of gypsum which is mainly added to control the reaction rate. This in turn contributed to a much shorter setting time of MTA Angelus [8, 9].

Despite continuous modifications of MTA, it presented several limitations including prolonged setting time in addition to discoloration potential, poor handling, and washout characteristics. This encouraged world-wide researchers to navigate possible improvements and alternatives [9]. MTA plus was introduced by Avalon Biomed (Bradenton, FL, USA) with higher specific surface area compared to other MTA formulations. This allowed for greater surface area for the cement reaction with a faster hydration rate [8, 9]. Another fast set MTA-based cement introduced later into the market was RetroMTA (BioMTA, Seoul, Korea), with a final setting time of around 12 minutes [7]. Nano-hybrid MTA is an experimental Portland-based dental cement developed in the laboratory of the Parseh Dental Promotion Center (Tehran, Iran) with a setting time of around 15 min. This cement contains several nano oxide particles including

silicon, aluminum, and titanium dioxide in addition to micro silica to enhance its physicochemical properties [10].

In 2011, Biodentine was introduced by Septodont (Saint Maur des Fosses, France) as a rapid-set tricalcium silicate cement to address the long setting time of MTA. It was prompted as a dentin replacement and pulp capping material [11]. Biodentine was introduced with claims of reduced setting time owing to reduced liquid content with added calcium chloride as accelerator. Moreover, the added calcium carbonate by the manufacturer act as a nucleation site for calcium silicate hydrate, thus densifying its microstructure and reducing the induction period [12].

Other modifications aiming to reduce setting time included replacement of the water-based liquid with resin, which gave rise to resin modified calcium silicate cements with shorter setting and enhanced bonding to both tooth structure and the overlying restoration [13]. TheraCal (Bisco Inc., Schaumburg, IL, USA) is a resin-modified calcium silicate pulp capping material in which the setting reaction of the resin component is light-activated. This facilitates immediate placement of the final restoration where no delay is required to ensure complete setting as with water-based materials such as MTA and Biodentine [14].

Despite the development of a white version of MTA, several studies [15-17] showed that even white MTA was associated with tooth discoloration and attributed this to the presence of bismuth oxide. When bismuth oxide comes in contact with the tooth structure, it causes a change in the color of the cement due to its conversion to bismite, which consequently causes discoloration of the adjacent tooth structure [7]. Thus, new MTA formulations with eliminated bismuth oxide have also been developed, such as NeoMTA Plus (Avalon Biomed Inc, Bradenton, USA) and MTA Repair HP (Angelus, Londrina, Brazil) [7]. NeoMTA plus has a similar composition to MTA plus except for replacing the conventional bismuth oxide radiopacifier with tantalum oxide, which in turn reduced the discoloration potential caused by the presence of bismuth oxide, while still maintaining sufficient radiopacity [18]. By 2016, MTA Repair HP was introduced with added calcium tungstate as a radiopacifier. Additionally, its liquid contains an organic plasticizer, which facilitates manipulation of the cement and contributes to its plasticity [19].

MTA is traditionally supplied as fine powder to be mixed manually with distilled water until it reaches a sandy-like consistency [3, 20]. Alternative mixing techniques were later launched to facilitate manipulation, which included capsules mechanically mixed in an

amalgamator as with Biodentine. This includes MM MTA (Micromega, Besançon, France) and MTA-Caps (Acteon, Merignac, France) [21].

1.2 Composition of MTA

Portland cements are cements that consists of more than 65% dicalcium and tricalcium silicates according to the European standard EN 197-1:2000 [22]. The addition of a radiopacifier to Portland cement creates a class of materials referred to as mineral trioxide aggregate [23].

MTA consists mainly of tricalcium silicate, dicalcium silicate, tricalcium aluminate, tricalcium oxide, silicate oxide in addition to bismuth oxide as a radiopacifier. The white and grey versions of MTA differ mainly in the content of iron, magnesium, and aluminum oxides. [24, 25]. MTA is manufactured by firing crushed limestone, clay, and bauxite in a rotatory kiln. The final product is ground into fine powder for clinical use with dicalcium and tricalcium silicates as the main reaction products after addition of calcium sulfate in the form of gypsum to control the setting reaction rate [3].

Concerns about the presence of trace elements in MTA have led to the exploration of other possible formulations based on laboratory raw pure materials with elimination of tricalcium aluminate. These formulations include Biodentine, BioRoot (Septodont, Saint Maur des Fosses, France), EndoSequence (Brasseler, Savannah, GA, USA) and TotalFill (FKG Dentaire, La Chaux-de-Fonds, Switzerland) [2, 8].

1.3 Setting reaction of MTA

MTA sets by hydration reaction that starts once mixed with water or water-based liquids. It is a dissolution-precipitation exothermic reaction [26]. During setting, the hydration reaction takes place between dicalcium and tricalcium silicates to precipitate calcium hydroxide and nucleate calcium silicate hydrate (CSH) [9]. This creates a CSH-based colloidal gel matrix that solidifies to form a highly alkaline tight solid barrier within the first six hours, that is stable under aqueous conditions [3, 25]. Meanwhile, calcium hydroxide particles are distributed within the water filled spaces present within the matrix [1].

Eventually, the CSH matrix contains excess calcium hydroxide formed by hydroxyl ions from the water content and calcium ions from the cement particles. This provides a high flux of calcium hydroxide which is responsible for the rapid rise of pH and high calcium ion release into

the surrounding environment (Figure 1). The setting reaction requires several days to achieve complete setting where moisture of the biological fluids is considered an essential factor to activate bioactivity of MTA [1].

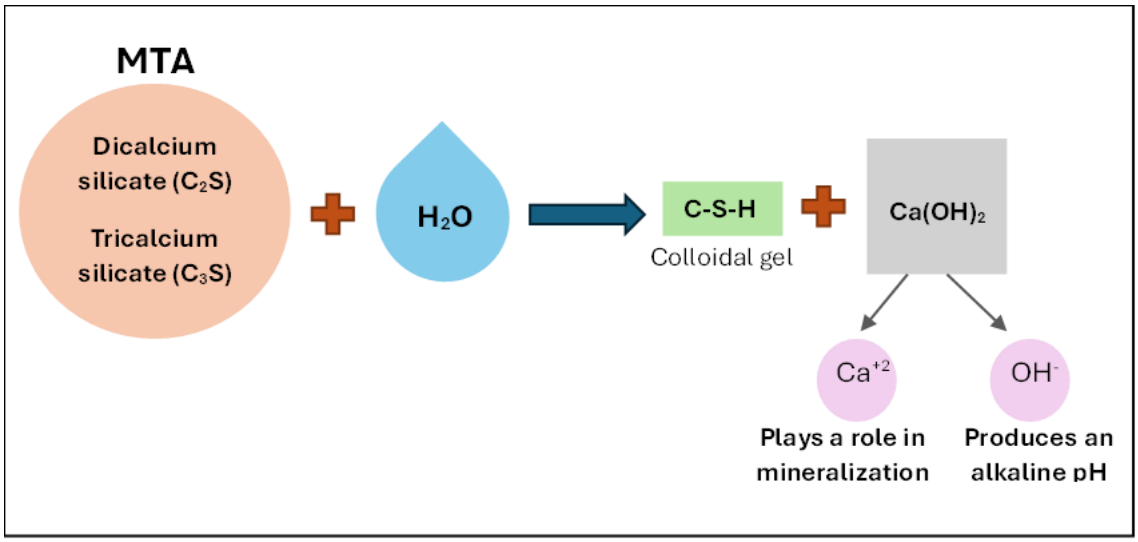

Figure (1): Setting mechanism of MTA

The setting reaction of MTA is highly dependent on particles' size where smaller particles result in much faster hydration. The presence of bismuth oxide as a radiopacifier also has a pronounced effect on setting time of MTA. Bismuth oxide particles do not contribute to the hydration reaction, which in turn increases its setting time. Also, the higher the powder to liquid ratio, the shorter will be the setting reaction. Setting time of MTA is also affected by water temperature and by air bubbles incorporated within the cement during mixing [27].

MTA offers sufficient working time of 4-5 minutes, whereas the setting time is extremely long that may reach up to 4 hours, which jeopardizes the integrity of the formed seal and increases the risk of material's washout and reinfection [28]. Quintana et al. [18] evaluated the setting time of NeoMTA plus, Biodentine, and MTA Angelus. Biodentine presented the shortest setting time of about 30 min, followed by MTA Angelus and NeoMTA plus with setting time of 41 and 67 min, respectively. Gandolfi et al. [29] evaluated setting time of Biodentine and ProRoot MTA. The setting time of Biodentine was 12 min while that of ProRoot MTA was 170 min.

In literature, there have been several reports on adding various chemicals to address the main drawback of MTA and reduce its setting time. The most commonly used accelerators are calcium chloride ($CaCl_2$), calcium formate [$Ca(HCO_2)_2$], and disodium hydrogen phosphate

(Na_2HPO_4) [28]. In a study conducted by Zavare et al. [30], the authors evaluated the effect of incorporation of different alkaline salts including calcium chloride, calcium oxide, sodium fluoride, and calcium nitrate added separately to MTA Angelus on setting time. The addition of either calcium chloride or calcium oxide reduced the setting time of MTA significantly while the addition of sodium fluoride and calcium nitrate adversely affected the setting time. In addition to reducing the setting time, calcium chloride may also improve sealing ability and increase its pH and calcium ion release [31]. Furthermore, it has been reported that adding tannic acid to MTA cement reduced the setting time and grain size of the resulting cement while increasing its hydrophilicity [32].

The composition of MTA often makes it difficult to handle owing to its granular consistency, making it especially difficult for use in some clinical applications. Once the water content decreases, the material becomes non cohesive with poor handling properties [33]. Ber et al. [33] used a combination of methylcellulose and calcium chloride in different concentrations to improve the poor handling characteristics and long setting time of MTA. The results showed that this combination improved the handling characteristics and reduced the setting time in a concentration of up to 1 wt.% methyl cellulose.

2. Properties of MTA

2.1 Mechanical properties

One of the main requirements of endodontic materials with coronal applications is high compressive strength to resist dislodgement and fracture under masticatory forces [34]. Compressive strength of MTA is affected by multiple factors including particles' size, powder to liquid ratio, and porosity. Small sized particles have greater surface area and in turn greater reactivity. This allows the formation of a more homogenous microstructure which is directly related to the strength of the cement [35]. The powder to liquid ratio used also has a pronounced effect on the mechanical properties, where the higher the ratio, the higher the strength. There is an inverse relation between porosity and mechanical properties of these cements, as the presence of pores causes the material to be weaker. The mixing time, technique, and the compaction pressure are also among the iatrogenic factors that may adversely affect the cement's consistency and strength [35].

Compressive strength has become a crucial factor especially when used for pulp capping where it should resist occlusal load and the placement pressure of the final restoration as well [35, 36]. The compressive strength of MTA after 24 h is around 40 MPa and it may reach up to 67 MPa after 3 weeks. According to ISO standard (9917-1:2007) for water-based cements in dentistry [37], minimum compressive strength required for pulp capping agents is 50 MPa. However, ideally, these cements should have compressive strength similar to that of natural dentin or the permanent restoration placed over them [38]. It was also reported in literature that grey MTA exhibits higher compressive strength values when compared to the white version, which may be attributed to the less iron oxide content used in white MTA [25, 39].

In a study conducted by Ravindran et al. [40], the authors evaluated the compressive strength of Biodentine and MTA Angelus at 1 and 7 days. Biodentine showed compressive strength values of 230 MPa at 1 day that increased to 350 MPa at 7 days. Results also showed that compressive strength of MTA Angelus was 41 MPa at 1 day that increased to 93 MPa at 7 days which agreed with those reported by Torabinejad et al. [34].

2.2 Biological properties

The biocompatibility of any dental material is of vital importance especially when used in close proximity to pulpal and periradicular tissues. MTA has several distinctive properties that make it attractive as a pulp therapy agent, such as its biocompatibility, bioactivity, sealing potential, in addition to its antibacterial properties [6, 41, 42]. Several studies [43-45] evaluated the biocompatibility of different types of MTA. Results showed that MTA is non-mutagenic, non-toxic, and biocompatible.

The bioactivity of any dental cement depends on its ability to hydrolyze and produce calcium hydroxide, which in turn is responsible for formation of an apatite layer [46]. Upon contact with water, the hydration product, calcium hydroxide, dissociates into calcium and hydroxyl ions [47]. Calcium ions can promote differentiation of osteoblasts and pulp cells, which in turn allow for hard tissue mineralization. The release of calcium ions can modulate bone sialoproteins and morphogenetic proteins (BMP), as well as enhance the activity of pyrophosphatase, which helps to promote mineralization and dentin bridge formation [29]. The alkaline pH, resulting from the release of hydroxyl ions, can also stimulate alkaline phosphatase and BMP-2 release, which also plays a role in the mineralization process [29, 47].

In a study conducted by Benoist et. al [48], the authors compared dentin bridge formation with calcium hydroxide product Dycal and MTA, when used as pulp capping material in permanent posterior teeth. Results showed a higher success rate with MTA compared to Dycal after three months follow-up period. In another study conducted by Eskandarizadeh et. al [49], the authors compared the pulpal response of permanent premolars restored with grey MTA, white MTA, and Dycal as pulp capping agents. Results showed that both types of MTA showed less pulpal inflammation and thicker dentin bridge formation compared to Dycal.

2.3 Antibacterial properties

MTA has superior antibacterial and antifungal properties which is attributed to its alkaline pH upon setting. This alkalinity aids in disinfection of dentin and inhibition of growth of various microorganisms, which in turn can arrest caries progression as well as prevent reinfection and relapse [50, 51]. Additionally, the coefficient of thermal expansion and contraction of MTA is very similar to that of dentin, thus contributing to a superior seal which offers resistance to leakage as well as form a tight bacterial barrier [6].

Kato et al. [50] compared the antimicrobial activity of calcium hydroxide product Dycal, ProRoot MTA, and three tricalcium silicate-based cements; Biodentine, TotalFill, and TheraCal LC against Streptococcus mutans using antibiofilm formation method. All tested cements showed strong antibacterial effect with the highest effect recorded by ProRoot MTA followed by Dycal and TheraCal. Biodentine and TotalFill showed the least antibacterial activity. Koruyucu et al. [52] compared durability of the antibacterial effect of three pulp capping materials; Biodentine, MTA Angelus, and Dycal against Enterococcus faecalis using direct contact test. The highest immediate antibacterial activity was observed in MTA followed by Biodentine. The one-week antibacterial activity of MTA and Biodentine was almost equivalent. Dycal showed the least immediate and delayed antibacterial activity.

3. Drawbacks of MTA

Despite its superior biological properties, MTA presented several limitations which include prolonged setting time, poor washout resistance, poor handling properties, teeth discoloration potential, difficulty of removal in case of retreatment, and relatively high cost [26, 42, 53, 54]. The long setting time of MTA is not considered of prime concern when used for endosurgeries or perforation repair. However, it presents a challenge for dental practitioners

when used for vital pulp therapy procedures including pulp capping or pulpotomy, as these procedures require faster setting once inserted to allow safe placement of a final restoration in a single visit [9]. Long setting time also contributes to the cement's solubility and wash-out from root canals, which may in turn cause bacterial recolonization and failure of the endodontic treatment [55].

The solubility of MTA is highly influenced by the pH of the surrounding tissues, where high acidity increases disintegration potential of the cement. This in turn causes leaching of various components of the cement into the surrounding dental tissue, which may adversely affect the biological properties of these tissues [51]. The cement's solubility is also highly affected by moisture where increased amount of water contributes to increased solubility [55]. The solubility of MTA may also be influenced by the powder to liquid ratio as using more water contributes to higher calcium ion release and eventually increased solubility. Time of immersion and the commercial type of the cement are other factors that also play a role in the cement's solubility and disintegration [55].

Discoloration potential of MTA may be related to its composition, conditions of the surrounding environment, blood contamination, or exposure to irrigants. To address the discoloration potential of grey MTA, a tooth-colored version of MTA was introduced in the market. However according to Carvalho et al. [56], white ProRoot MTA also showed induced tooth discoloration, especially over time. Parirokh and Torabinjad [55] suggested that iron and manganese may be the elements responsible for this discoloration. However, several studies [57-59] showed that bismuth oxide was the main cause of discoloration potential caused by white MTA.

Another drawback of MTA is difficulty in removal of the material in case of retreatment as it has no known solvent. Chhabra et al. [60] suggested using various acids combined with ultrasonic instrumentation to facilitate removal of the material from the canal, however this may deteriorate the mechanical properties of the tooth structure if used for more than few minutes.

4. Applications of MTA

MTA is considered the gold standard for various conservative and endodontic procedures including pulp capping, pulpotomy, apexification, revascularization, root canal end filling material in endodontic surgeries, and sealing of perforations [1, 26, 61]. These numerous

applications are related to their superior properties including their biocompatibility, antibacterial properties, and sealing capabilities [2, 26, 61].

4.1 Pulp capping

Direct and indirect pulp capping are vital pulp therapy (VPT) strategies that aim to resolve pulpal inflammation and stimulate hard dentin bridge formation, thus eliminating the need for more extensive endodontic treatment. Dressing used for VPT include calcium hydroxide, MTA, and other calcium silicate-based cements. Several studies [62-64] showed that MTA promoted thicker dentin bridge formation, lesser hyperemia, and showed better histopathological and clinical outcomes compared to calcium hydroxide. Moreover, calcium hydroxide has higher tendency for resorption and necrosis in addition to its weak adherence to the tooth structure [65].

In a study conducted by Nowicka et al. [66], the authors evaluated the use of MTA and Biodentine for direct pulp capping in non-carious molars. Results showed that both MTA and Biodentine had similar clinical results after 6 weeks follow-up. Histological findings revealed the absence of inflammatory response and complete dentin bridge formation. Linu et al. [67] investigated direct pulp capping in mature permanent teeth with carious exposures using ProRoot MTA and Biodentine. Success rates, at 18 months follow-up, were 84.6% and 92.3% respectively.

4.2 Pulpotomy

Pulpotomy is a treatment option that involves amputation of the infected coronal pulpal tissue while maintaining the integrity of the healthy radicular pulp, to conserve the natural primary teeth till eruption of the permanent successors. An ideal pulpotomy replacement material should be harmless to the remaining tissues, bactericidal, promotes healing, and does not interfere with physiological resorption [68]. The management of vital pulp with calcium hydroxide was prevalent prior to the use of MTA. However, due to the high solubility of calcium hydroxide, researchers aimed to find new and improved pulpotomy agents. The introduction of MTA caused a paradigm shift towards cements that promotes healing, support the regeneration of the pulpal and periradicular tissues, as well as efficiently reduce the possibility of future dental pulp infections [65, 69].

Meligy et al. [70] compared calcium hydroxide and MTA as pulpotomy agents in immature permanent molars. Results showed 2 failures in the calcium hydroxide group and none in the MTA group. Qudeimat et al. [71] conducted a similar study where results showed one failure in the calcium hydroxide group and none in the MTA group as well. Çelik et al. [72] evaluated success rates of MTA and Biodentine in pulpotomy of mandibular primary molars. The clinical and radiographic success rates of MTA at the two-year follow-up appointment were 100% while that of Biodentine were 89.4%.

4.3 Apexification

Apexification is the treatment modality used to address pulp necrosis or trauma in permanent teeth with open apices. It aims to produce a hard tissue barrier or an apical plug against which the obturating material can be condensed. Among the materials commonly used for apexification are calcium hydroxide and MTA [73, 74]. Calcium hydroxide has long been considered the material of choice for apexification. However, the use of calcium hydroxide weakens the root structure and may lead to root fracture due to reduced fracture resistance. In addition, its application requires several visits where the treatment outcome highly depends on patients' compliance [74, 75].

MTA on the other hand, requires shorter treatment protocol and can effectively seal the periapical area and reduce inflammation [74]. Both calcium hydroxide and MTA offered positive success rates in terms of apexification, however MTA showed an overall better success rate. This was attributed to the fact that most of the failures of calcium hydroxide apexification were associated with poor patient follow-up due to the longer treatment protocol [74, 75].

Several studies [76-78] validated the use of other bioactive endodontic cements such as Biodentine for apexification. However, the level of evidence on replacing MTA apical plugs with other bioactive cements is extremely low with only few studies [79-81]. In a study conducted by Bani et al. [78] , the authors evaluated and compared the apical microleakage of MTA and Biodentine apical plugs in maxillary anterior teeth in different thicknesses. There was no significant difference between both materials in terms of microleakage. Results also showed that increased thickness of apical plug showed significantly lower microleakage for both MTA and Biodentine.

4.4 Revascularization

Revascularization is a regenerative endodontic procedure that aims to provoke blood clot formation within the root canals to promote tissue healing in immature permanent teeth. This procedure includes the use of intracanal irrigants and antibacterial agents with no mechanical instrumentation. Following induced intracanal bleeding, a tight seal material is placed in the pulp space to prevent ingress of bacteria. MTA is commonly used as a coronal plug to obtain this bacterial tight seal [79].

In a study conducted by Aly et al. [82], the authors compared Biodentine and white MTA as coronal plug materials in revascularization of immature necrotic anterior permanent teeth. Both materials showed success rates ranging from 90-100% with resolution of clinical symptoms and 5% increase in the mean root length of these teeth.

4.5 Root canal sealer

During endodontic treatment and after mechanical instrumentation, a root canal sealer is placed to form an adhesive junction between gutta-percha and the root canal walls, thereby preventing the possibility of reinfection in the periapical tissues. Among the cements commonly used as endodontic sealers are zinc oxide eugenol-based sealers, calcium hydroxide, resin-based sealers, and MTA [83].

In 2001, Holland et al. [84] studied the effect of using MTA obturation on apical and periapical tissues and established its use as a root canal sealer. After its compaction against the tooth structure, a dentin-MTA interstitial layer is formed along the presence of phosphate, which resembles hydroxy apatite in structure and composition when examined under scanning electron microscope and X-ray diffraction analysis [84]. MTA, as a root canal sealer, has regeneration potential of the periodontal ligament and cementum formation in main and accessory canals, which contributes to treatment success [85].

4.6 Root-end filling

Endosurgery may be indicated in case of unsuccessful root canal treatment to enhance the treatment outcome [42]. This treatment option removes any diseased apical tissues, followed by

placement of a root-end filling material to form an apical seal that prevents reinfection and allows for the formation of new normal periodontal tissues at its surface [75, 86].

Several endodontic materials have been used for this purpose, however none of which was able to prevent microleakage. Compared to calcium hydroxide, MTA showed better regeneration of periradicular tissues and enhanced cementum formation when used as a root-end filling material. MTA can also be used as an obturating material for primary teeth with no permanent successors. However, they are not recommended as obturating materials for primary teeth that are expected to shed as they may not resorb at the same rate as the tooth structure [64].

Kumbhar et al. [87] evaluated marginal adaptation of glass ionomer, MTA, and Biodentine when used as root-end filling material in extracted human maxillary anterior teeth. The highest adaptation was found in Biodentine group followed by MTA, while the least adaptation was recorded by the glass ionomer group. Singh et al. [88] compared solubility of Biodentine, glass ionomer, IRM which is a reinforced zinc-oxide eugenol based cement, and MTA as root-end filling materials at 1, 3, 10, 30, and 60 days according to ISO standard (6876) for root canal sealing materials. Biodentine demonstrated significantly higher solubility than MTA for 30- and 60-days immersion periods. Glass ionomer showed significantly higher solubility than MTA for the 10-days immersion period.

4.7 Perforation and resorption repair

Root canal perforation is an abnormal communication between the root canal and the periodontium formed either iatrogenically during endodontic treatment or pathologically due to extensive caries or resorption. The presence of a perforation in the root canal can worsen the tooth prognosis and treatment outcome, therefore requires special attention [42]. This necessitates the use of a proper sealing cement to repair and seal the defective part. Perforation repair materials currently available on the market include amalgam, calcium hydroxide, reinforced zinc oxide eugenol, gutta-percha, glass ionomer cement, and adhesive resin. Amalgam was used for a long time as a perforation repair material. However, concerns regarding the mercury content caused its use to rapidly decline. The use of amalgam was then commonly replaced by ethoxy benzoic acid (EBA) cement which is a reinforced zinc oxide eugenol cement [89].

The use of MTA as perforation repair material has also been emerging for the past years. It is biocompatible and non-irritant to the periodontium, with good sealing abilities [89]. It is currently widely used for their reliable efficacy in sealing off the root canal [42]. Alzahrani et al. [90] evaluated the use of MTA as root perforation repair material in maxillary first molars. Results showed periapical tissue healing and absence of clinical and radiographic symptoms at the one-year follow up appointment.

5. Conclusion

Mineral trioxide aggregate is widely used in endodontics and conservative dentistry owing to its superior bioactivity and sealing properties. Nevertheless, several limitations, including prolonged setting time and poor physical properties, cannot be overlooked. However, MTA still remains the material of choice for various clinical applications and will definitely develop tremendously in the upcoming years.

Conflict of Interest

The authors declare that they have no known conflict of interest that could have appeared to influence the work reported in this paper.

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