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Review of literature on the properties and studies done on MTA as a pulp rehabilitating agent

Nikitha Suzanne Varghese[1], Deepa Gurunathan[2*]

[1]Post graduate, Department of Pediatric and Preventive Dentistry, Saveetha Dental College and Hospitals, Saveetha Institute of Medical and Technical Sciences, Saveetha University, Chennai 77

[2]Head of Department, Department of Pediatric and Preventive Dentistry, Saveetha Dental College and Hospitals, Saveetha Institute of Medical and Technical Sciences, Saveetha University, Chennai 77

*__Corresponding author:__ Deepa Gurunathan, Head of Department, Department of Pediatric and Preventive Dentistry, Saveetha Dental College and Hospitals, Saveetha Institute of Medical and Technical Sciences, Saveetha University, Chennai 77

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ABSTRACT

It has not been long since MTA has been introduced into the market. Perforations, retrograde fillings in root-end resections, open apices, and essential pulp caps can all be sealed with it. Physical, chemical, and physiological aspects of MTA are covered in this review of the literature. According to studies, MTA offers a superior seal than earlier materials like IRM, amalgam, and Super-EBA. Additionally, MTA has great biocompatibility and low cytotoxicity. Studies conducted in vivo showed that MTA had a positive impact on pulpal and periodontal regeneration. MTA looks to be a good material to tightly seal dental hard tissues from the periodontium or to cover the exposed pulp, even though controlled randomised clinical trials are still lacking.

Keywords: *Rehabilitation, MTA, properties, invivo studies, pulp therapy*

INTRODUCTION

According to "Oral health in America: a report of the Surgeon," published in 2000, dental caries is the most common chronic disease in the world and affects primarily children. It is an infectious, chronic, degenerative, and complex condition. Despite the widespread use of preventive measures in developed nations, 486 million children and 2.4 billion adults worldwide suffer from dental decay in their permanent and deciduous dentitions, respectively (Vos et al., 2017). It would appear that tooth decay is one of the major public health issues affecting both primary and permanent teeth.

According to Kassbaum et al. (2017), dental caries is one of the most common health issues affecting children and adolescents globally. According to Smal-Faugeron et al. 2018, the thickness of the enamel and dentin as well as the prominence of the pulpal horn are the main causes of the rapid spread of caries in primary teeth. Maintaining the integrity of the tooth structure and preserving the tooth's vitality are the key goals of conservative therapy for primary teeth. This aids in maintaining the tooth's structure so that phonation, aesthetics, and masticatory function are maintained until exfoliation. Ineffective disease treatment causes pain and abscesses, which lowers quality of life(Itthagarun, King, and Anthonappa 2007).

Early caries therapy should prevent the gradual deterioration of dental hard tissue and ensuing loss of dental vitality, which can lead to critical circumstances that necessitate early tooth extraction (Bossù et al. 2020). This is mostly true for primary teeth, which exhibit a rapid progression of tooth decay due to anatomical considerations, a slower pace of mineralization, and a high incidence of risk factors (Irvine et al. 2011). In order to protect the pulp vitality of deciduous or early permanent teeth with immature roots afflicted by caries and without indications of radicular pathology, vital pulp therapy (VPT) has been recommended (Dhar et al. 2017). According to Dhar et al. (2017), pulpotomy, direct pulp capping, and indirect pulp therapy (indirect pulp capping) are currently available therapeutic options for VPT.Direct capping, however clinically useful in primary molars, is primarily advised in the VPT of permanent young teeth (Brizuela et al. 2017), and indirect capping appears to have a comparative advantage over pulpotomy methods. According to Smal-Faugeron et al. (2018), the latter offers favourable clinical survival rates over time and permits primary teeth to remain healthy until they naturally exfoliate. According to Smal-Faugeron et al. (2016), a pulpotomy involves removing the pulp from the pulp chamber in order to treat the bacterial infection. Following this, the decontaminated tooth is then filled with a medication. Mineral trioxide aggregate (MTA), Biodentine (BD), formocresol (FC), ferric sulphate (FS), and calcium hydroxide (CH) are the most often used agents.

The most contentious issue in paediatric dentistry to date has been pulp therapy for primary teeth. According to the American Academy of Paediatric Dentistry (AAPD), pulpotomy should be done on primary teeth that have significant decay and pulp exposure but no signs of radicular pathology or symptoms. The procedure is used when carious removal exposes the pulp in a tooth with healthy pulp or pulpitis that is reversible, or when there has been trauma to the pulp and there are no radiographic indications of infection or pathologic resorption. The coronal pulp is removed during a pulpotomy, while the remaining radicular pulp is preserved using medication. There shouldn't be any symptoms or clinical indications of discomfort, sensitivity, or edoema in the radicular region of the pulp. In cases of pathologic root resorption lesions, pulpotomy is not advised. Maintaining the integrity of the arch width and halting the spread of caries are the primary goals of vital pulp therapy.

Pulpotomy (Ranly 1994) can be classified based on the treatment objectives as devitalization of the pulp (mummification, cauterization), preservation of pulpal tissue (non inductive and minimal devitalization) or regeneration of pulpal tissue which includes inductive and reparative.

Devitalization therapy using a multiple visit formocresol technique was introduced by Sweet. The pulpal tissue became devitalized and sterilized. Overtime, Sweet reduced the number of visits over the years. Doyle finally in 1962 compared formocresol and calcium hydroxide. After which Spedding and Redig introduced the 5 minute formocresol protocol. Since the reduction to 5 minutes, the pulp remains half dead, half vital and chronically inflamed which may result in abscess formation, internal resorption of the root.

Formocresol was the gold standard material for pulpotomy in primary teeth until the introduction of a calcium silicate material by Torabinejad called Mineral Trioxide Aggregate (MTA) (Academy of Pediatric Dentistry 2016)

Recently calcium silicate cements have been introduced and found to show better results when compared to other pulpotomy agents. This is due to the ability to preserve the vitality of the pulp and form a calcific barrier. The aim of this review is to assess the properties, application and past research conducted on MTA.

MTA

Bioceramic materials are biocompatible ceramics that are compatible in humans(De-Deus et al. 2009). They were first introduced into endodontics in the year 1990 as primary retrograde filling materials which then branched out into root repair, sealers and coating for gutta percha cones(Wang 2015). Mineral trioxide aggregate (MTA) has been acknowledged as the gold-standard material for a variety of clinical situations and possibly the closest to the ideal reparative material since the introduction of bioceramic materials into clinical endodontics (Khurshid et al. 2021). This is because of their excellent physic-chemical and biological properties.

In the opinion of Viola, Tanomaru Filho, and Cerri (2011), MTA is generated from the same parent compound as Portland cement, despite the fact that these compounds share several characteristics. When compared to Portland cement, MTA undergoes further purification processing, has a smaller mean particle size, and contains fewer hazardous heavy metals (Jefferies 2014). Mahmoud Torabinejad created MTA at Loma Linda University in California, USA, and it was first mentioned in dentistry literature in 1993. In 1998, the FDA gave its approval. According to Tawil, Duggan, and Galicia (2015), the objective was to create a substance that would aid in preventing communication between the inside and exterior of the tooth.

The first MTA product to be commercially accessible was Pro Root MTA (Dentsply Tulsa Dental Specialities, Johnson City, TN) in 1999. MTA Angelus followed in 2001 and was approved by the FDA in 2011. According to Tawil, Duggan, and Galicia (2015), MTA is a calcium silicate-based material with outstanding sealing and biocompatibility properties. According to Tawil, Duggan, and Galicia (2015), it has a variety of clinical uses, including apical plugs in teeth with necrotic pulps and open apices, root-end filling material, pulp therapy, and perforation repair.

Composition And Classification

MTA is a fine hydrophilic powder with an ash-like appearance. According to Mahmoud Torabinejad (2014) and Song et al. (2006), it is commercially available as Grey MTA (GMTA) and White MTA (WMTA), both of which are made of 75% Portland cement, 20% bismuth oxide, and 5% gypsum (Ca) by weight. According to Roberts et al. (2008) and Rao, Rao, and Shenoy (2009), MTA is mostly composed of bismuth oxide (17% to 18%), refined Portland cement, and trace amounts of SiO2, CaO, MgO, K2SO4, and Na2SO. In order to make the substance radiopaque, bismuth oxide is added. This addition affects the calcium hydroxide precipitation that occurs after MTA has been hydrated, and it can also be released into the environment under acidic conditions (inflammation), which reduces MTA's biocompatibility because it prevents cell proliferation (Camilleri et al. 2004; Camilleri 2007).

According to Segura-Egea et al. (2011), the main components of grey MTA (GMTA) include calcium sulphate, silicate oxide, tricalcium silicate, dicalcium silicate, tricalcium oxide, tricalcium aluminate, tetracalcium aluminoferrite, and bismuth oxide. White MTA (WMTA) is essentially devoid of the tetracalcium aluminoferrite component and has lower levels of iron, aluminium, and magnesium oxides, according to Roberts et al. (2008) and Asgary et al. (2005).

MTA-Angelus(Song et al. 2006),(Ravindran et al. 2022; Panchal, Jeevanandan, and Subramanian 2019; Bramhecha and Sandhya 2021) which is made of 80% Portland cement and 20% bismuth oxide and is more radiopaque than Grey MTA, is another MTA material that is readily available commercially.

Chemical And Physical Properties Of MTA

The main benefits of MTA over other dental materials like amalgam, calcium oxide, zinc oxide eugenol, glass ionomer cement, etc. include a superior ability to seal, antimicrobial action, adequate radiopacity, dimensional stability, biocompatibility, and tolerance to moisture (S. Kim and Kratchman 2006; Roberts et al. 2008(Akshayaa, Ravindran, and Madhulaxmi 2021; Teja and Ramesh 2021; Shenoy, Salam, and Varghese 2019)). In addition to the qualities described above, MTA's sealing capacity and biocompatibility have both been the subject of several studies.

Strength

The compressive strength of MTA is around 70 MPa, which is similar to that of IRM but lesser than that of Amalgam(Basturk et al. 2013). Due to its low compressive strength, placement of MTA should be avoided in functional areas with high compressive strength(Islam, Chng, and Yap 2006).

When exposed to moisture content, MTA undergoes a protracted maturation process that results in increased compressive strength, push-out strength, and retention strength over time. After 24 hours of placement, MTA's initial compressive strength is 40 MPa, and it rises to 67.3 MPa over the course of 21 days (M. Torabinejad et al. 1995; Dds and Dds 2001). Due to the fact that dicalcium silicate hydrates more slowly than tricalcium silicate, if there is enough

moisture present after placement at the operating site, ideal physical qualities will develop over time (Rao, Rao, and Shenoy 2009; Parirokh and Torabinejad 2010a).

According to the intracanal irrigants and oxidising agents utilised, the push-out strength and retention strength of Grey MTA can change (Islam, Chng, and Yap 2006). The retention strength of the material is unaffected by the use of saline, sterile water, or lidocaine, but is more vulnerable to oxidising agents such sodium perborate combined with saline, 30% hydrogen peroxide, and sodium perborate mixed with 30% hydrogen peroxide. Contrarily, 5.25% sodium hypochlorite and 2% chlorhexidine had no appreciable effect on the material's strength (Loxley et al. 2003; Yan et al. The retention strength of the material is impacted by dentin with blood-stained root surfaces. Investigations showed that following phosphoric acid (37%) etching, the compressive strength drastically decreased. Therefore, restoration with resin-based composite should be postponed for at least 96 hours following placement of MTA(Kayahan et al. 2009).

Retentive Strength And Bond Strength

The retentive strength of MTA is much less than that of glass ionomer or zinc phosphate cement, consequently it is not considered as a viable luting agent in clinical applications (Vargas et al. 2004). Because the bond strength between Grey MTA and dentin rises with surface area, studies have demonstrated that a 4-mm thickness of MTA (apical barrier) provides more resistance to displacement than a 1-mm thickness (Hachmeister et al. 2002; Lawley et al. 2004). Over White MTA, a single-step self-etch method was superior to a total-etch single-bottle adhesive using a resin-based composite or compomer in terms of binding strength.

Microhardness

MTA experiences deleterious effects on the material's microhardness (either white or grey MTA) when exposed to an acidic pH (pH5), as shown in an inflammatory environment (Y.-L. Lee et al. 2004). This is caused by the absence and growth of needle-like crystals, which take place during the hydration phase, between the cubic crystals. Surface roughness and a considerable decrease in the microhardness of MTA are produced by the use of EDTA, BioPure MTAD, and acid etching (DENTSPLY Tulsa Dental Specialties). The microhardness of the material decreases as condensation pressure rises because the mass becomes more compact and has fewer microchannels accessible to absorb water (Parirokh and Torabinejad 2010a).

pH

MTA when hydrated has an initial pH of 10.2 which increases to 12.5 after 3 hours which is identical to the level in calcium hydroxide(Roberts et al. 2008). The high pH of MTA results in its high antimicrobial property due to the constant release of calcium to form calcium hydroxideCa(OH)2(Torabinejad et al. 1995).

Sealing Ability (Microleakage)

In comparison to the standard dental filling materials including amalgam, zinc oxide eugenol-based materials, ordinary glass-ionomer, and gutta-percha, MTA generally demonstrated less microleakage and improved sealing performance, according to several studies (Sönmez et al. 2012). In the treatment of immature apices, root-end restoration, root canal obturation, and furcation repair, they can be utilised as an alternative (Schwartz et al. 1999).According to Sluyk, Moon, and Hartwell (1998), MTA's outstanding sealing ability may be a result of expansion during setting. Typically, a thickness between 3 and 5 mm is adequate to create a strong seal. In comparison to amalgam, IRM, and super EBA, MTA has also been demonstrated to leak much less when contaminated with blood (Mahmoud Torabinejad 2020; Pitt Ford and Harty 1997).When employed either orthogradely (root-canal filling) or retrogradely (root-end filling), there has been no documented difference in microleakage. However, residual calcium hydroxide from its previous use as an intracanal dressing may obstruct adaptation and lessen MTA's capacity for sealing. It can interact chemically with MTA or function as a mechanical barrier (Andelin et al. 2002).

Solubility

MTA has a little to no solubility due to the addition of bismuth oxide(Parirokh and Torabinejad 2010). It has a solubility of 18.8% in

water, however an increase in the liquid/ water ratio will increase the porosity of the matrix thereby increasing its solubility(Rao, Rao, and Shenoy 2009).

Radiopcaity

According to Parirokh and Torabinejad (2010)b, MTA has a mean radiopacity of 7.17 mm of equivalent aluminium thickness, which is smaller than IRM, super EBA, amalgam, or gutta-percha. It is significantly more radiopace than dentin and has a radiodensity that is comparable to zinc oxide eugenol. In addition to these features, MTA does not react with or interact with restorative substances such as resin-based composites or glass-ionomer cements, which are frequently used permanent filling substances with MTA(zcan, Garcia, and Volpato 2021).

Setting Time

Currently, MTA is marketed as either premeasured water packs for simple handling and application or as a box of five 1-gram single-use packets. This needs to be kept dry and airtight in sealed containers.

A paper pad, glass slab, or metal spatula are used to combine the powder with sterile water in a 3:1 powder to liquid ratio until a putty-like consistency is achieved. According to S. J. Lee, Monsef, and Torabinejad (1993), mixing shouldn't last longer than 4 minutes because it can cause the mixture to become dehydrated.Using a plastic or metal spatula, the mixture can be inserted into the oral cavity (Bogen and Kuttler 2009).Empty film canisters that have been sterilised can be used to store any leftover MTA powder.

The setting of MTA is not affected by the presence of blood or water, as moisture is necessary for optimal material hardening. To facilitate hydration and setting, a moist cotton pellet is temporarily placed in direct contact with the material or the surrounding tissues until the next appointment (Arens and Torabinejad, 1996). The hydration process involves a reaction between tricalcium silicate ($3CaO \cdot SiO2$) and dicalcium silicate ($2CaO \cdot SiO2$), resulting in the formation of calcium hydroxide and calcium silicate hydrate gel, which leads to an alkaline pH (Camilleri, 2008). Calcium ions released during this reaction diffuse through dentinal tubules, gradually increasing in concentration as the material cures (Ozdemir et al., 2008). Upon hydration, the initially poorly crystallized and porous gel formed by the components solidifies into a hard structure within approximately 3 to 4 hours (initial set), with an average setting time of 165 ± 5 minutes (Witherspoon, 2008). While moisture is essential for the material's setting, excessive moisture can result in a watery mixture that is difficult to work with.

Cubic and needle-like crystals are interlaced in the hydrated set material. According to Y.-L. Lee et al. (2004), the needle-like crystals are present as thick bundles that are sharply defined and fill the inter-grain area between the cubic crystals.According to Dds and Dds (2001), MTA retention and push-out strength increase over time, going from 72 hours to 21 days. This indicates a protracted maturation phase for the material. This slower setting time might lessen setting shrinkage, which would explain the material's low microleakage.

The prolonged setting period and maturation phase are thus one of the key downsides of MTA. The compressive strength and setting time of MTA powder can be altered by the addition of various liquids and additives. To enable the hydration reaction to take place, the manipulation liquid must, however, contain enough water and have the requisite diffusion properties.Gels of sodium hypochlorite and calcium chloride solutions (3% to 5%) speed up the setting process, whereas saline and 2% lidocaine slow it down. During the first 24 hours, chlorhexidine gluconate has an impact on the MTA (WMTA) surface hardness. However, use of calcium chloride and sodium hypochlorite reduce the final compressive strength (as compared to sterile water) with saline and 2% lidocaine, having no significant affect on it(Kogan et al. 2006).

Biocompatibility

(Perinpanayagam, 2009) Grey and White MTA are both regarded as biocompatible. No chromosomal breaks, genetic mutations, altered DNA repair capabilities, or cellular transformation have been linked to MTA. In comparison to amalgam, super EBA, and IRM, it was discovered to be less cytotoxic, with set MTA being less toxic than fresh MTA (Perinpanayagam 2009).On the set-surfaces of MTA, periodontal ligament and gingival fibroblasts were seen to connect and proliferate

more readily (Pistorius, Willershausen, and Briseo Marroquin 2003). Similar to this, studies on cell cultures using human alveolar bone cells, mouse preosteoblasts, osteoblasts, dentinoblasts, and cementoblasts, as well as human alveolar bone cells, have shown good survival, proliferation, and attachment, with a faster and better growth of cells on the MTA surface(S. Kim and Kratchman 2006). According to Min, Yang, and Kim (2009), MTA has also demonstrated to have a more effective stimulating impact on human dental pulp cells than a commercial calcium hydroxide preparation. MTA has been shown to express alkaline phosphatase, bone sialoprotein, periostin, and osteocalcin in human and animal cells, including rat bone marrow cells, mouse preosteoblasts, and gingival fibroblasts, periodontal ligament fibroblasts, and alveolar bone cells. It has been demonstrated that adding enamel matrix derivative to MTA enhances mineralization, alkaline phosphatase activity, and human dental pulp cell differentiation. Chlorhexidine was added to MTA, which enhanced its antibacterial characteristics, but had a negative impact on the material's biocompatibility (Mahmoud Torabinejad and Parirokh 2010).

According to Perinpanayagam (2009), both Grey and White MTA are considered biocompatible, with no reported cases of chromosomal breaks, genetic mutations, altered DNA repair capabilities, or cellular transformation associated with MTA. In comparison to amalgam, super EBA, and IRM, MTA has been found to be less cytotoxic, and set MTA was observed to be less toxic than fresh MTA (Perinpanayagam, 2009).

Pistorius, Willershausen, and Briseo Marroquin (2003) observed that periodontal ligament and gingival fibroblasts exhibited better connection and proliferation on the set-surfaces of MTA. Similarly, studies on various cell cultures, including human alveolar bone cells, mouse preosteoblasts, osteoblasts, dentinoblasts, and cementoblasts, showed favorable survival, proliferation, and attachment on the surface of MTA (S. Kim and Kratchman, 2006). These findings were consistent with the research on human alveolar bone cells, which also demonstrated faster and improved cell growth on MTA surfaces.

Furthermore, Min, Yang, and Kim (2009) found that MTA had a more stimulating effect on human dental pulp cells compared to a commercial calcium hydroxide preparation. Studies conducted on human and animal cells, including rat bone marrow cells, mouse preosteoblasts, gingival fibroblasts, periodontal ligament fibroblasts, and alveolar bone cells, revealed the expression of alkaline phosphatase, bone sialoprotein, periostin, and osteocalcin when exposed to MTA. Additionally, the addition of enamel matrix derivative to MTA was shown to enhance mineralization, alkaline phosphatase activity, and differentiation of human dental pulp cells. However, the introduction of chlorhexidine to MTA improved its antibacterial properties but had a negative impact on its biocompatibility (Mahmoud Torabinejad and Parirokh, 2010).

Invitro Studies Done Using Mta

Various invitro studies have been conducted till date.

Two studies (Kettering and Torabinejad 1995) (Osorio et al. 1998) checked the mutagenicity/ cytotoxicity of MTA along with Intermediate Restorative Material (IRM), Super-EBA.MTA had no mutagenic effect when a standard Ames mutagenic assay was conducted. De Menezes et al. (2009) conducted a study in which the invitro cytotoxicity of MTA was compared to that of calcium hydroxide, ferric sulphate solution, diluted formocresol, and Buckley's formocresol, which are all main tooth pulpotomy agents. The lowest cytotoxcity among the primary teeth pulpotomy agents was found to be MTA.

MTA was found to have good antibacterial activity when Fill Canal, Sealapex, Mineral Trioxide Aggregate (MTA), Portland Cement, and EndoRez were tested for their antimicrobial effects on diverse kinds of microorganisms (Sipert et al. 2005). Despite this conclusion, a another investigation found that MTA Angelus and ProRoot MTA had no antibacterial effect on E. faecalis (R. J.-Y. Kim et al. 2015). Numerous studies have added other substances into the structure of MTA, including tetracycline, calcium hydroxide, and 0.2% CHX, to overcome this obstacle and boost its antibacterial activity against E. faecalis (Gupta, Singh, and Thapar 2016). FHA has not yet been examined in relation to MTA's antibacterial characteristics, nevertheless.

Kaup evaluated MTA and Biodentine's solubility, microhardness, radiopacity, and

setting time in 2015. It was discovered that the characteristics of MTA and Biodentine were dissimilar. MTA had a better radiopacity and a noticeably longer setting time (Kaup, Schäfer, and Dammaschke 2015).FHA has not yet been examined in relation to MTA's antibacterial characteristics, nevertheless. Further research is required because there are no comparable studies to compare the findings to.

Animal Studies Done Using MTA

The biocompatibility of the material was initially assessed in a number of animal tests before moving on to clinical trials. After pulpotomy with white MTA versus 15.5% ferric sulphate (FS), one study compared the inflammatory cells, vascular density, and IL-6 immunolabeled cells present in the pulp both qualitatively and quantitatively. They then histologically compared the groups and discovered that the MTA group displayed better histological features and greater IL-6 expression when compared to the formocresol group (Lopes et al. 2019).

In a different study, the histologic effects of curcumin and MTA were compared in rat molars. It was found that MTA caused more dentin bridge development than curcumin did (Prabhakar, Mandroli, and Bhat 2019). The cytotoxicity of MTA and bone morphogenic protein 2 (BMP-2) as well as the pulpal response of the rat pulp tissue were evaluated in a comparable investigation. Although there was no statistically significant difference, it was discovered that BMP-2 had a positive effect in vitro, reducing the early cytotoxicity of MTA(Ko et al. 2010).

A similar study was conducted in dogs where the pulpal response to pulpotomy using ProRoot MTA, RetroMTA, and TheraCal in dog teeth. The calcific barrier was observed in ProRoot MTA and RetroMTA when compared to TheraCal specimens(Lee et al. 2015).

Invivo Studies Done Using Mta As Pulpotomy Agents In Primary Teeth

An in-depth study comparing MTA and formocresol as pulpotomy agents in primary molars revealed that MTA was superior to formocresol in terms of long-term clinical and radiographic success rates and should be chosen over it because it does not produce unfavourable outcomes (Holan, Eidelman, and Fuks 2005).

A comparative study investigated the outcomes of pulpotomy using mineral trioxide aggregate (MTA) and 15.5% ferric sulphate (FS) on the dentin-pulp complex of primary molars. Thirty-one first molars were randomly assigned to either the MTA or FS group. Clinical and radiographic evaluations were conducted at 3, 6, 12, and 18 months of follow-up. Histological analysis was performed on extracted teeth during the normal exfoliation period. At 3, 6, and 12 months, both groups exhibited complete radiographic success. However, histological examination demonstrated that only the MTA group presented a hard tissue barrier surrounded by odontoblasts over the pulp stumps, indicating the success of both MTA and 15.5% FS in pulpotomies of primary teeth (Junqueira et al., 2018).

In a 2005 study comparing MTA to Formocresol as pulpotomy agents in primary molars, favorable results were obtained with MTA. However, the study had a short follow-up period of 6 months and lacked statistical tests, diminishing its significance (Hegde and Naik, 2005).Another study evaluated the clinical and radiographic effectiveness of mineral trioxide aggregate (MTA) and Portland cement (PC) as pulp dressing agents in carious primary teeth. The study conducted a 24-month follow-up period and employed resin-modified cement for tooth restoration (Sakai et al., 2009).

CONCLUSION

Evidence shows that various invitro and invivo studies have been conducted using MTA and shows that MTA can be used in endodontic procedures an vital pulp therapy. More randomized control trials are needed for stronger evidence with a longer follow up period.

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