Will Portland cement be a cheaper alternative to mineral trioxide aggregate in clinical use?: A comprehensive review of literature

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Abstract

Mineral trioxide aggregate (MTA) was introduced in 1993 as root perforation repair material. Since then it is widely used as a successful dental hard tissue repair material especially in vital pulp therapy, apical plug, and perforation repair. In last 14 years, more than 100 publications have shown that Portland cement (PC) (which forms the bulk of MTA) has similar properties like MTA through different in vivo, in vitro, animal studies and recently through human trials. The experiments are still under process to see whether the PC can be used as a cheaper alternative of MTA. This article reviews the experiments done comparing the properties of these two materials and the potential of PC for clinical use in future along with the possible drawbacks.

Keywords: Gray MTA, Portland cement, White MTA

Introduction

Mineral trioxide aggregate (MTA) has been first introduced as a root perforation sealing material by Lee et al.\(^\text{[1]}\) from Loma Linda university, CA in 1993. Since then hundreds of publications came in support of MTA to be used in dentine and cementum injuries and the MTA gradually become an essential material in dentistry for all kinds of dental hard tissue repair like pulp capping, pulpotomy, perforations, and apical seal in wide open apex, etc. Couple of years later an article presented by Dr. Torabinejad, the introducer of MTA; where it has been observed that MTA has similarity with Portland cement (PC) in its composition and physical and chemical properties.\(^\text{[2]}\) Next in 1999 Wucherpfennig showed through X-ray diffraction analysis that both MTA and PC have “identical characteristics”\(^\text{[3]}\) and in 2000 Estrela used ordinary PC as a reference material to MTA.\(^\text{[4]}\) Till then both the materials has experimentally compared through several in vivo and in vitro experiments, animal studies and recently through human trials to see whether PC can be used as a cheaper alternative of MTA in clinical use. In the next part, we will review the comparative studies published involving these two materials in different parameter.

Chemical Composition and Properties

Material safety data sheet (MSDS) of Commercial MTA materials shows that all MTA’s are a mixture pure PC, bismuth oxide (BO), and in some products CaSO\(_4\) is also added. Chemical composition of MTA and PC has been analyzed through various methods like X-ray diffraction analyses, X-ray fluorescence spectrometry, etc., and found that both the material are similar in their composition.\(^\text{[5-8]}\) The basic major content of MTA and PC are tri-calcium silicate, dicalcium silicate, tricalcium aluminate, and tri-calcium oxide. Beside this silica, alumina, ferric oxide, magnesium oxide are also present. The basic difference between these two materials is that the PC does not contain BO\(^\text{[6,9]}\) but contains potassium.\(^\text{[7]}\) Calcium hydroxide is produced as a byproduct of hydration reaction of MTA and PC, which is mainly responsible for its biological action and biocompatibility. This calcium hydroxide is also responsible of high pH (12.5-12.9) of the end product of hydration reaction.\(^\text{[10,11]}\) The pH of MTA immediately after manipulation with distilled and deionized water is 10.2, increasing to 12.5 after 3 h and then remain constant.\(^\text{[12]}\) Almost similarly, the pH of PC rises from that of 7-12.3 after mixing with water and continues...
rising to a maximum pH of 12.9 after 3 h.\[^4\] The other oxides such as ferric and magnesium oxide present in both MTA and PC provides an additional source of hydroxyl ions responsible of their higher pH.\[^4\] Though there are mild variations of pH between gray and white MTA and PC, but it seems that doesn’t have much clinical significance.

**Physical Properties**

The compressive strength, setting time, dimensional changes, and radio-opacity of MTA and PC have been compared in many studies. Compressive strength of MTA and PC that developed in a period of 28 days are more than 50 MPa. The strength of set MTA is slightly higher than PC.\[^9\] Close similarity of setting characteristic of MTA and PC has been observed in many publications. Though MTA shows slightly higher setting time than PC, but the different is statistically insignificant.\[^9\] PC is having calcium chloride, calcium nitrate, calcium formate as an accelerator, but unmodified (without addition of Calcium chloride) PC and MTA shows almost equal compressive strength and PC has faster setting time.\[^9\] It is interesting to observe that the addition of metallic phase like gold or silver amalgam in PC leads to reduced setting time and increased compressive strength.\[^14\] In a recent study PC, PC with 2 and 5% calcium sulfate and MTA were compared for their setting time using Gilmore needles weighing 113.5 G and 456.5 G. The available data were analyzed through Tukey’s test. The shortest initial and final setting time was observed in PC followed by PC with 2% calcium sulfate, then PC with 5% calcium sulfate, and then MTA in the increasing order.\[^15\]

The micro-leakage and sealing ability of both the materials have been evaluated by many using different parameters. The better the sealing ability of a material the better it will prevent micro-leakage and the setting expansion of a material aids to its better sealing ability. In an experiment, Storm et al. showed that in water immersion for 24 h, setting expansion of PC is 0.29%, gray MTA is 1.02%, and white MTA is 0.08%.\[^16\] The pulp chambers of 36 human mandibular molar teeth (15 sealed with MTA and 15 sealed with PC and 5 kept in control group) were accessed using a polymicrobial leakage model. The result showed no statistical significant difference between the two groups, concluding that PC and MTA have a similar ability to seal furcal perforations.\[^17\] In another experiment, flow porometry analysis was used in an in vitro apexification model, using MTA, MTA with 10% CaCl₂ accelerator, PC, PC with 10% CaCl₂ accelerator. The maximum and mean flow pore diameters of the samples were tested by capillary flow porometry at 90 min and 48 h. There was no statistically significant difference found in the maximum pore diameter of MTA and PC at 90 min and 48 h.\[^14\] De-Deus et al. experimented possible microleakage through sealing of furcal perforations using PC, white Angelus MTA, MTA Bio in extracted human molar teeth. Leakage was measured by the movement of an air bubble traveling within a pipette connected to the teeth. The results showed that there was no significant difference in mean fluid flow between the experimental groups. They concluded that the sealing ability promoted by the 3 cements was similar and no cement was able to produce a fluid-tight seal.\[^19\] White PC does not meet the ISO standard of radiopacity because of its poor radio-opaque character. In most of the current studies, PC is modified with the addition of 20% BO to get the radiopacity. A study evaluated the radiopacity of PC associated with BO, zinc oxide, lead oxide, bismuth subnitrate, bismuth carbonate, barium sulfate, iodoform, calcium tungstate, and zirconium oxide. A ratio of 20% radiopacifier and 80% white PC by weight was used for analysis. Pure PC and dentin are kept as controls. PC/BO and PC/lead oxide presented the highest radiopacity values.\[^20\] Interestingly this addition of BO does not alter the biocompatibility of MTA or PC.\[^21\] Subcutaneous connective tissue reactions toward of MTA, PC, and PC plus BO and the radiopacity of those three materials were evaluated in a study. The result showed MTA is little more radio-opaque than PC plus BO and all the material including BO are biocompatible.\[^22\] In another experiment, PC was added with other radio-opaque agents in place of BO like zirconium oxide, calcium tungstate, and strontium carbonate to observe the setting time and compression strength changes. It has been observed that all these radio-opaque agents gives PC a similar radio-opacity as well as better short-term (24 h) and long-term (21 days) compressing strength than addition of BO, and these compressive strengths are almost equivalent to set MTA and PC without addition of radio-opaque agents. It has also been observed that initial setting time is enhanced with addition of those materials in comparison to setting time of unmodified PC and MTA, though the final setting time is negligibly higher when comparing with unmodified PC and MTA. In the same study, it has also been observed that the compressive strength of MTA at 21 days is 43.4 MPa and the compressive strength of PC was 41.2 MPa.\[^21\]

**Antimicrobial Property and Biocompatibility**

While testing for antimicrobial potentiality MTA and PC both have shown almost no antimicrobial activity against Candida albicans, Staphylococcus aureus, Enterococcus faecalis, Escherichia coli in Agar diffusion test.\[^24\] Whereas in another agar diffusion test Tanomaru-Filho et al. found both MTA and PC has antimicrobial activity against Micrococcus luteus, S. aureus, E. coli, Pseudomonas aeruginosa and C. albicans.\[^25\] In another experiment Muller-Hinton agar diffusion test was used and it has been seen that both MTA and PC can only able to inhibit E. coli.\[^26\]

Several publications are available which showed that PC and MTA are equally biocompatible. Tissue reaction of MTA and PC are tested through bone implantations of freshly mixed MTA and PC in bony cavities of the mandibles of guinea pigs and this mix is also added to culture plates with attached L929 cells. When evaluated in both vitro and in vivo tests, MTA, and PC showed comparative biocompatibility.\[^27\] MTA and PC were interacted with Endothelial ECV 304 cells to evaluate their cytotoxic level. Both the material showed an initial mild cytotoxic activity which reduced with time.\[^28\] In a study
which dealt with the cellular effects of PC on cultured human pulp cells, no cytotoxicity was observed in the PC. Whereas, in the same study other materials like glass ionomer cement, intermediate restorative material, and Dycal showed cellular survival rate was less than 40% on direct contact with pulp cell. In addition to the better biocompatibility of PC, this study showed that it allows the expression of mineralization related genes on cultured human pulp cells, and has the potential to be used as a proper hard tissue developing material in dental treatment.[39] In an another experiment, Chinese hamster ovary cells were exposed to MTA and white PC at a concentration ranging from 1 to 1000 μg/mL for 1 h at 37°C. MTA and PC did not show genotoxic effects in all concentrations evaluated and no significant differences in cytotoxicity were observed in MTA and PC.[30] Bio-mineralization ability of 3 types of MTA, PC with 20% BO, and PC with 10% CaCl2, was evaluated by filling cavities in dentin disks and keeping them immersed in phosphate buffered solution (PBS) for 2 months. An scanning electron microscope observation was done for apatite formation by the cement-PBS system and concluded that all the cements were almost equally bioactive.[31] More recently bioactivity of two types of MTA, PC with BO, and PC with 10% CaCl2, were tested by filling these materials in seventy-two human dentin tubes and implanted subcutaneously on dorsal area of 18 rats. 30, 60, and 90 days follow-up observation showed mineral deposition in the material-dentin interface and the subsequent formation of intertubular mineralization. The researchers concluded that all cements tested are bioactive and both MTA cements were more effective than two types of PC in 30 and 60 days observation.[32]

Arsenic Release

Concerning about the presence of arsenic, few researches have shown that set MTA and PC both release arsenic in an aqueous medium. However, the amount of release is much lower than set limit by Environmental Protection Agency (EPA)/FDA, which is 0.01 ppm for arsenic in drinking water. In one study, three types of PC, MTA angelus, and pro root MTA had been analyzed for arsenic release. The result shows that mean release of arsenic from all the materials are 0.002 ppm at 168 h. Only one kind of PC showed release of 0.007 ppm. All of which are much below the permissible level of EPA.[33] In another study, the arsenic release is observed in white PC (0.52 mg/Kg), white MTA-obtura (0.39 mg/Kg), and white MTA angelus (1.03 mg/Kg). All of them are much lower than ISO standard limit for arsenic release in water based cements(2mg/Kg), whereas, pro-root MTA(5.25 mg/Kg), gray MTA-angelus(5.91 mg/Kg), and gray PC (34.27 mg/Kg) showed their release of arsenic little higher than permitted level.[34] De-Deus et al. tested four most common commercially available MTA and two brands of white PC from Brazil for presence of arsenic and concluded that Gray MTA-Angelus, Gray Pro Root MTA, and one brand of PC does not contain arsenic and all other material tested have very negligible presence of arsenic.[35]

Animal Studies

The first classical animal study was carried out by Holland et al. implanted human dentine tubes (done by reducing extracted tooth roots), filled with MTA, PC, and CH in the jaws of rat. Exactly same kind of calcific deposition is seen at the apex of those tubes when observed under SEM at intervals on weeks and months.[36] In another study, 18 teeth of a dog pulpotomized, and MTA and PC pulpotomy done dividing them into two groups. The teeth were restored. After 60 days, formation of hard tissue bridges and retaining of the vitality of pulp is seen in all cases where fillings were not dislodged.[37] In a similar study, 76 dog teeth was pulpotomized using pro-root MTA, MTA-Angelus, gray PC, and white PC. Pulp vitality was maintained in all specimens and the pulp had healed with a hard tissue bridge.[38] Shayegan et al. get the similar result of pulpal tissue repair with hard tissue formation when they used white MTA, white PC and Beta tricalcium phosphate on pulpotomized primary teeth of pigs.[39] They also made pulp capping using the same materials in forty primary teeth of pigs and observed same result of pulpal preservation with hard tissue formation in all materials.[40] New bone formation was observed which was characterized by osteoid formation, osteoblastic rimming, and formation of new bone trabeculae around a surgically created bony cavity in mandible of a dog filled with accelerated PC (APC), indicating possible use of APC as bone substitute.[41] Successful and similar type of perforation repair found in deliberately perforated dog’s teeth using WPC, PC Type II, Type V, and MTA (as control). Histological analysis showed no significant differences in the amount and histology of newly formed bone in all materials.[42] Lately Bidar et al. carried out pulpotomies in 64 dog’s premolars using gray and white MTA and gray and white PC. They concluded that all of those materials used in the study were equally effective as pulp protection materials following direct pulp capping in dog teeth.[43] An experimentally manufactured PC was developed as an alternative to MTA by the Turkish Cement Manufacturers Association with pure components such as clay or chalk are taken directly from nature, including the arsenic; which appeared in PC. This PC and MTA were implanted beneath the dorsal skin of rats containing in sterile polythene tubes. The tubes were removed after 7, 14, and 28 days to observe the reaction of those materials to the surrounding tissue. Tissue reactions associated with both the materials were comparable. Initial inflammatory processes decreased significantly after 28 days, suggesting that both materials are equally biocompatible.[44]

Clinical Trials

Soon after the report of in vitro apical plug using MTA and PC by PZA Coneglian et al.,[45] where MTA and PC showed the similar result, De-Deus et al. tried first clinical trial of apical plugging in an immature upper right second premolar tooth apex using PC. 1-year follow-up of that case revealed adequate clinical function, absence of clinical symptoms, and no signs of periapical rarefaction.[46] Four anterior teeth with open apex
were treated with single step apexification plug using WPC. 3 to 24 months follow-up demonstrated successful apical repair. In another clinical trial, the author and his associates used White PC with 20% BO as an apical plug in three non-vital upper central incisors with radiographic apical pathosis. Three to 6 months follow-up showed total healing of radiographic apical pathosis and the teeth become symptom-free. Successful pulpotomy was done in several mandibular molars using PC, that has shown to retain their vitality, clinically, and radiographically, after a 3, 6, and 12 months follow-up. Pulpotomy was carried out in 29 mandibular primary molars using MTA (14 teeth) and PC (15 teeth). No statistical difference was found regarding dentin bridge formation in pulpotomized teeth in 6 to 24 months follow-up. The author suggested that PC can be substituted in place of MTA as an effective and cheaper material in primary molar pulpotomies. Thirty cases of perforations in permanent molars in Mashhad Dental School Clinic had been treated with PC and MTA in equally divided group. Six months follow-up showed only one failure in each group showed that PC is equally effective as MTA in repairing dental perforations. Recently pulpotomy has been carried out in 45 primary molars using MTA, PC, and Ca(OH)₂. 6, 12 and 24 months clinical and radiographic follow-up showed 100% success rate in pulpotomies done using MTA and PC. Histologic analysis revealed the presence of dentine-like mineralized material deposition obliterating the root canal in the PC and MTA groups, whereas Ca(OH)₂ pulpotomies resulted in failures in most of the cases. 86 patients with deep carious lesions were treated with indirect pulp capping procedure using medical PC, MTA, and Ca(OH)₂. After 6 months, color, humidity, consistency of dentin, and microbiological (Lactobacilli/Mutans Strept. counts) were recorded and evaluated. The study concluded that the treatment for deep carious lesions preferably should be done with non-resorbing materials such as MTA or medical PC.

**Discussion**

In 1993, MTA was described for the first time in dental literature. MSDS of Commercial MTA materials such as ProRoot MTA, MTA Angelus, etc., shows that all MTA’s are a mixture of 75-80% of pure PC (CAS # 65997-15-1), 20% BO, and in some products 5% CaSO₄. Though no information about production processes of included PC are available.

MTA sets through a hydration reaction in two stages, initially by hydration of anhydrous mineral oxide compounds and later by crystallization of hydrates. The initial reaction could be expressed as: \(2(3\text{CaO.}\text{SiO}_2) + 6\text{H}_2\text{O} \rightarrow 3\text{CaO.}2\text{SiO}_3\cdot3\text{H}_2\text{O} + 3\text{Ca(OH)}_2\). And the delayed reaction as: \(2(2\text{CaO.}\text{SiO}_2) + 4\text{H}_2\text{O} \rightarrow 3\text{CaO.}2\text{SiO}_3\cdot3\text{H}_2\text{O} + \text{Ca(OH)}_2\).

MTA is already established to be a very good biocompatible material with excellent potential to use in pulp capping, pulpotomy procedure, as a perforation restorative material, in apexitification procedure, and apical sealing in management of open apex non-vital tooth. Studies have also shown that MTA showed an excellent clinical and radiographic success in primary teeth pulpotomies. The limitation of MTA is its extended setting time, higher cost, difficulty in storage, and only be used in low-stress bearing areas. Gingival and tooth discoloration were reported from use of both, gray and White MTA.

PC is mainly composed of 65% lime, 20% silica, 10% aluminum and ferric oxide, and 5% other compounds. Two major constituents are tricalcium silicate (3CaO.\text{SiO}_2) and dicalcium silicate (2CaO.\text{SiO}_2). PC sets through a hydration reaction in two stages, exactly similar that of MTA. Gray PC is of 5 types from Type I to Type V. Though Type I PC is pure PC, but all the types contain some amount of heavy metals. White PC is manufactured from purest raw materials (kaolinite with very low iron content) and contains no C₄AF (ferric-calcium aluminate phase) and very Low MgO. The heavy metal content of WPC is almost similar to MTA.

The first study which used ordinary PC as a reference material to MTA has been published in 2000. Since then there has been an increasing number of published articles comparing MTA and PC. Searching PubMed and MedLine electronic database we found that there was 1 in the year 2000. Then it is increasing every year to 10 or more articles per year since 2007. We found more than 100 articles comparing several parameters between different types of MTA and PC. We have included 67 articles in this review. Many publications that have similar outcome with several included articles have not been mentioned to reduce the volume of this review. The included studies analyze the comparative analysis of chemical, physical, and mechanical properties along with microleakage and sealing ability has been evaluated using several parameters. Heavy metal including the arsenic content of these materials has also been analyzed. Animal studies and recently clinical application has also been evaluating. We have detailed those comparative studies above in this manuscript.

Most of the articles found the similarity of properties and tissue reactions between these two materials though a few analysis of MTA when compared with PC showed some differences. Interestingly, the number of articles that found dissimilarity between these two materials was very few. The main components of MTA and PC were analyzed through X-ray photoelectron spectroscopy and energy-dispersive X-ray analysis and concluded that PC cannot replace MTA as it contains more toxic heavy metals and are composed of particles with a wide range of size, whereas MTA showed a uniform and smaller particle size. Describing the characterization of hydration product Camilleri commented that The hydration mechanism of MTA is different to that of PC and MTA produces a high proportion of Ca ions than PC, as a by-product of hydration and MTA releases, over several weeks, more calcium ions than white PC while white PC releases nearly no bismuth ions. Analysis of the presence of 10 heavy metals showed that GPC have much higher heavy metal than WPC,GMTA, and WMTA. The WPC is also contains little more heavy meals than WMTA. The white MTA Angelus and MTA bio has the shortest setting times, higher pH, and more calcium ion release in comparison to light cured MTA and PC with 20% BO. MTA was found to...
be much less soluble than two types of PC in water immersion for a different period of time. The same study shows that the microhardness of MTA is significantly higher than PC type I and Type II.\[64\] A review that included 156 citations from January 1990 to August 2006 led to a conclusion that substitution of MTA by PC is discouraged,\[65\] though they have undertaken only two articles which support the possibility of replacement MTA by PC.\[6,66\] In another detailed review, it was concluded that PC can be a possible replacement for MTA, but the type of PC, which is more comparable to MTA has to be determined first through further researches.\[67\]

MTA is an excellent material for several endodontic uses, especially dental hard tissue repair. PC is also shown similar characteristics to MTA with respect to its composition, biocompatibility, and through animal and clinical studies. The disadvantage of PC is its lower radio-opacity, and the main advantage is the cost. Practically the cost of single treatment of MTA is 60-75 USD, which is almost impossible to spent by world’s most population for single dental visit. A cheaper substitute of MTA will certainly benefit millions of people, especially most of the patients in developing countries, who cannot bear the cost of MTA. At present several researches establish that PC is similar to commercially available MTA in its basic composition, physical, chemical characteristics, and in biocompatibility. Though several articles recommended for substituting MTA materials by PC for clinical use, but no reason has been found to substitute MTA at present. Rather PC can be used as a cheaper alternative whenever required, but few parameters regarding the use of PC as a MTA alternative has to be further investigated and established. They are (a) the type of PC can be used, though WPC is used in most investigations. (b) How to achieve uniform particle size when using commercially available PC. (c) Effect of added BO in Modified PC in its hydration reaction and tooth discoloration. (d) A lot more controlled clinical trials are required to establish its clinical success comparable to MTA.

**Conclusion**

The existing researches show that PC, rather WPC has a great potential to be used as an alternative material to MTA. Those literatures give a firm base for further well-designed clinical trials. However, proper selection of material and lot more clinical trials are required to establish PC as an alternative to MTA to appropriate medical/dental regulatory authorities as a permitted material for clinical use.

**References**