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Understanding Mineral trioxide aggregate and Portland cement- A review.

Dental Science

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ABSTRACT

-Introduction: Both Mineral Trioxide Aggregate (MTA) and Portland cement (PC) have been highlighted because of their favorable biological properties, with extensive applications in Endodontics, including the possibility of using them into root canal filling. Objective: This article reviews literature related to MTA and PC comparing their physical, chemical and biological properties, as well as their indications. Literature review: Literature reports studies revealing the similarities between these materials properties, including both biocompatibility and bone repair induction. Moreover, there is the need for the development of a root canal sealer based on these materials (MTA and PC). Conclusion: MTA and PC show promissory perspective both in Dentistry and Endodontics

INTRODUCTION

The search for biocompatible dental materials presenting good physical, chemical and mechanical properties still continues today. In Endodontics, this search has been intense [1]. Several studies have demonstrated that mineral trioxide aggregate (MTA) shows good physical, chemical, mechanical and biological properties [2, 3, 4, 5] and its behavior has been largely investigated in several clinical applications [6,7]. However, its high cost does not allow its use in all levels of attention to health. A comparative analysis of mineral trioxide aggregate and Portland cement using plasma emission spectrometry showed that except for no detectable quantity of bismuth in Portland cement, significant difference did not exist between the other 14 elements in both Portland cement and MTA. Both are composed of calcium phosphate, calcium and silicon oxide. MTA, however, contains bismuth oxide, which provides radiopacity [8]. MTA's main composition is 80% of PC added by 20% of bismuth oxide [9].

The aim of this article was to analyze literature relating to researches conducted with MTA and PC, comparatively reporting their physical, chemical, and biological properties as well as to discuss about researches on the new indications for these materials.

Literature Review-

Mineral Trioxide Aggregate

Development of MTA-In 1993 so called Mineral trioxide aggregate (MTA) was described for the first time in dental literature [Lee et al., 1993] developed by Mahmoud Torabinejad at Loma Linda University, in USA, aiming to seal the communications between the tooth and its outer surface [10]

Consequently, MTA was introduced to be used in pathological or iatrogenic root perforations [11] as well as in rootend fillings [12, 13]. The hydrophilic nature of MTA particles allows its use in the presence of moisture [13], providing sealing [14] and marginal adaptation [15].

MTA has also been employed in pulp covering or pulpotomy, both in humans and animal-model experiments, demonstrating noticeable success, similar to the results obtained with calcium hydroxide. Commercial MTA materials such as ProRoot MTA (Tulsa Dental Products, Tulsa, OK, USA) or MTA Angulus (Industria de Produtos Odontologicos Ltda, Londrina, Brazil) are a mixture of Portland cement (PC), gypsum and bismuth oxide (BO). These materials contain fine hydrophilic particles of tricalcium silicate, tricalcium aluminate, tricalcium oxide, silicate oxide and bismuth oxide. Hydration of MTA material forms a colloidal silicate hydrate gel that sets in about 3-4 hours. The resulting MTA gel contains CH that is mainly responsible for its biocompatibility. MTA is employed as root-end filling material[18] , in cases of external apical root resorptions[16] , perforation repair[17], pulp-capping and pulpotomy medicaments, as an apical and furcation restorative material[19] as well as preparation for apexogenesis and apexification treatments pulpotomies and in the treatment of teeth with incomplete rhizogenesis. These indications are possible because MTA is a biocompatible material presenting an alkaline pH about 12.5, antimicrobial activity, marginal adaptation, low solubility, low bacterial leakage, resistance to displacement and low cytotoxicity.

On the other hand, MTA lacks in some properties: the cement resulting from the mixture of the powder with water is difficult to be handled [20]; its granular consistency makes its insertion into cavities difficult [21]; its working time is short [22] and its setting time is large, favoring the material's solubility, disintegration or displacement [21]. Moreover, additional moisture is required [23] to activate the cement setting, and finally, it has a relatively high cost [24].

Portland cement (PC)

In 1824, Joseph Aspdin patented a product so-called Portland cement (PC) obtained from the calcination of the mixture of limestones coming from Portland in England and silicon-argillaceous materials[25].

Portland cement (PC) is a fine powder produced by grinding cement clinker. It is classified as a hydraulic cement, which normaly is, composed of 65% lime, 20% silica, 10% alumina and ferric oxide and 5% other compounds. Lime is composed of calcium and magnesium oxides. PC is produced by grinding clay and lime-bearing minerals in the correct proportions and then heating the mixture to 1,400°C. This

process called calcination produces physical and chemical changes in the raw materials. The resulting "clinker" is ground to a fine powder and a small amount of gypsum is added to retard the setting process. Two principle constituents are tricalcium silicate (3CaOSiO2) and dicalcium silicate (2CaO-SiO2). Adding water to set PC results in a complicated hydration reaction as PC sets in a series of stages. First there is dispersion of clinker grain in water. Secondly hydration products eat into and grow out from surface of each grain. Thirdly setting occurs when the different clinker grains join together. Finally, hardening occurs with further development of the gel and crystalline particles are disseminated throughout [Harrington, 2005].

Chemical expression is called alite and belite phase reaction.
The simplified reaction of alite with water may be expressed as:
2Ca3OSiO4+6H2O 3CaO.2SiO2.3H2O+3Ca(OH)2
It is a fast reaction and causes setting and strength development in the first few weeks.

The simplified reaction of belite is:
2 Ca2SiO4+4H2O 3CaO.2SiO2.3H2O+Ca(OH)2This is a relatively slowly reaction responsible for gaining strength after one week

[Taylor, 1997]. About one third of the volume of these end products is $Ca(OH)_2$ (CH phases) and it is enclosed in the form of complex gels or crystalline substances. There exist also a C-S-H (calcium-silicate-hydrate) phase and an AFt (sulphatic hydrates) phases. The forces that bind the colloidal particles together in the gel are thought to be hydrogen bonds, Vander Waals forces, ionic attractions and covalent bonds such as Si-O-Si bonds. Part of the water will be consumed by the reaction but other parts of the water will be trapped in the pores. Evaporation may occur during or even after setting. This water that is lost will refill in an "osmotic-effect". During setting the continuity of the capillary system is broken. The hydration of the powder produces tricalcium silicate, tricalcium phosphate, tricalcium oxide and others [Harrington, 2005].

MTA versus PC-

Biocompatibility and toxicity studies.- Biocompatibility evaluation of MTA and PC has been reported in 12 articles. Taking into consideration the similar chemical composition between MTA and PC, in a study on the evaluation of PC biocompatibility through odontoblast cell line (MG-63), extracellular matrix neoformation was observed in cell line cultures of both materials (MTA and PC). When these same materials were used for direct pulp covering in molars of rats, a response similar to the in vitro study was found; in some cases, the authors observed the formation of reparative dentin [26]. Teeth of dogs undergoing pulpotomy and remnant pulp tissue covering with both MTA and PC exhibited tubular dentin formation in almost all samples. The authors concluded that when both cements were applied directly onto pulp, they allowed dentin formation [27]. Concerning to the biological properties, studies have demonstrated that MTA promotes a favorable tissue response, characterized by the presence of moderate inflammatory response at the initial periods, which tends to decrease after 30 or 60 days. Generally, it is reported that MTA is surrounded by a fibrous capsule and induced the formation of a mineralized tissue . Other studies proved that because MTA is a biocompatible material, it enables the repair in several situations, inducing the deposition of dentin, cementum and bone.

One study on cavities executed in guinea pigs' mandibles evaluated PC and MTA biocompatibility. Despite of the presence of inflammatory process, bone tissue neoformation was observed in cavities containing both MTA and PC . The similarity between MTA and PC suggests that some resources used for improving MTA's physical and chemical characteristics could be used in PC. The addition of accelerating agents reduces PC setting time. One of the most common agents used for this purpose is calcium chloride. Therefore, the addition of 5% of calcium chloride to MTA reduces the setting time from 50 min (MTA mixed with sterile water) to 25 min, allowing an improvement in the sealing capacity.

MTA and PC also are similar regarding to antimicrobial properties [28]. The antimicrobial action of these materials and of calcium hydroxide, Sealapex, and Dycal was evaluated against four bacterial species – Staphylococcus aureus, Enterococcus faecalis, Pseudomonas aeruginosa, Bacillus subtilis – and the fungus Candida albicans; and against a mixture of all of them. The chemical elements of MTA and of two PC (Itau Portland Cement and Liz Portland Cement) were also analyzed. The results showed that all materials exhibited some antimicrobial activity, and calcium hydroxide paste was better than all the other materials against the tested microorganisms . To improve the antimicrobial properties, studies were conducted in which chlorhexidine was added to MTA, allowing an increase of the antimicrobial activity without apparently interfering in its biological properties [29].

Chemical, physical and mechanical studies. -The microleakage and sealing ability has been evaluated using bacterial penetration [30,31], and all sorts of capillary flow porometry [32] and ai rbubble leakage models have been used [33]. In all of these studies there was no statistically significant difference between MTA and PC. The analysis of bacterial microleakage by Enterococcus faecalis in human central incisors, by using two different cements – white MTA (Angelus) and an experimental material with calcium aluminate – revealed that these materials employed as filling materials did not allow microbial growth. Additionally, when they were used as root-end filling materials, these materials were effective in root canal sealing, avoiding Enterococcus faecalis contamination during a 30-day period [20].

The ability of MTA and PC in preventing coronal leakage was analyzed by the repair of furcal perforation in human molars through a model of polymicrobial leakage. The teeth were extracted and stored at 37°C in culture medium containing saliva. After 50 day storage, the authors observed that eight (53%) out of fifteen MTA samples and nine (60%) out of fifteen PC samples were completely contaminated. The results were not statistically significant, and the authors concluded that both materials exhibited a similar sealing ability in furcal perforations . By Compressive strength, dimensional change, setting time, pH and radiopacity have been compared [34]. MTA and PC have similar properties. The only significant difference is a lower radiopacity of PC. The difference between white and grey MTA is more significant than that between white MTA and white PC. X-ray defraction analysis of crystalline phases of grey and white MTA and PC showed absence of bismuth ions and presence of potassium ions in grey PC. Grey MTA contained a significant higher amount of iron when compared with white MTA [35]. MTA and PC showed both no [36] antimicrobial activity. White MTA and white PC showed significant lower arsenic levels than grey MTA and grey PC [37].

Characterization of MTA / PC.- The different MTA materials (white ProRoot, grey ProRoot, white MTA-Angulus, grey MTA-Angulus and PC) showed different numbers of small particles and different range of size distribution [38]. PC has a cumulative percentage of particles diameter between 0.5 and 3 μm, which may be able to penetrate dentine tubuli [39]. Comparative analysis of MTA materials and PC using plasma emissions spectrometry [40], Energy Dispersive Analysis by X-ray [41] and X-ray diffractometry [34] showed similar constitution and no significant difference between MTA and PC.

Aiming to accelerate the setting, calcium chloride was added to ProRoot MTA, white MTA and PC to evaluate pH influence on calcium ion releasing. The results showed that calcium chloride added to MTA improved its physico-chemical properties. Additionally, calcium chloride addition to the materials facilitates the handling process because it demands a smaller water amount . It was demonstrated than the addition of 3% NaOCl (sodium chloride) gel to MTA improved its setting time. The addition of sodium chloride to MTA, ProRoot MTA, MTA-Angelus and white radiopaque PC also promotes a better sealing capacity of the three cement types . Calcium chloride did not alter MTA biological properties because it enabled the formation of a hard tissue barrier when it was used after

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pulpotomy . White MTA mixed to sodium hypophosphate (Na2HPO4), placed into subcutaneous of rats, showed more favorable results than white MTA, indicating that this addition makes the material more biocompatible than white MTA alone.

The role of bismuth oxide (BO).- Testing PC and a linear increasing amount of BO, mechanical strength, porosity and flaw size have been compared [42]. Strong linear correlations were found between relative porosity, dry and strut densities and BO content. The amount of gypsum in PC is relatively smaller when BO is added to MTA materials. This has probably had an influence on hardness and solubility of MTA [43]. Because low radiopacity is one of the most advantages of PC, one recent study evaluated the hypothesis that the experimental cement containing PC and bismuth oxide would show the same biocompatibility of MTA and PC in addition to MTA radiopacity. To determine the experimental cement's characteristics, it was compared to the other cements' chemical composition, radiopacity, cytotoxicity and tissue reaction, which did not present statistically significant differences, suggesting that the experimental cement would replace MTA . To improve PC radiopacity, some substances have been associated to this cement, such as bismuth oxide, zinc oxide, plumber oxide, bismuth subnitrate, bismuth carbonate, barium sulphate, iodoform, calcium tungsten and zircon oxide. All tested substances showed greater radiopacity than dentin and potential to be used as PC radiopacifying agents . However, further studies are necessary to investigate whether these agents would interfere on PC biocompatibility.

Previous reviews.- Two reviews have been made contrasting both, MTA and PC. One, a review of the constituents and biological properties of MTA materials [44] found 53 articles on biocompatibility and 13 articles on constituents of MTA. No specific distinction was made between MTA and PC articles. Reviewing every MTA article from 1990 to August 2006 gave 156 articles. The second review, gave an overview concerning most scientific work published but in English (only) [Roberts et al., 2008]. Their conclusion was, that MTA materials could not be substituted by PC. Basing this statement as they did on only two articles [34], can be questioned, as these authors emphasize exactly the opposite.

Accelerated MTA and PC.- MTA materials and PC have been mixed with calcium chloride (CaCl2) [45,

46], with Jodoform and with methylcellulose . All of these modifications brought advantages in setting time, but also disadvantages, for example in calcium ion release and in hardness.

CONCLUSION-MTA materials have an excellent potential for endodontic use. Their good radio opacity keeps them indispensable for certain clinical applications. PCs seem to have a biocompatible nature and similar technical characteristics like commercial MTA materials. A disadvantage of Portland cement is that it has lower radioopacity and its main advantage is its very low cost.

Claiming that white MTA is the result of a new investigation is not tenable. Changing usage from grey to white MTA was simply changing from grey to white PC as base material to mix with bismuth oxide. Precise information about production processes are not available. PC contains the same principle chemical elements as MTA, with similar mechanisms of action and physical properties and biocompatibility. Accordingly several articles recommended starting substituting.

MTA materials by PC for clinical use.- Only very few articles enable an exact identification of the actual type of PC used in those studies. The hydration characterizations as described of MTA materials are very close to the hydration characterizations of portland cement that have been well investigated.

Further investigations concerning the role of Bismuth oxide in chemical reaction and biocompatibility have started and are very necessary. As yet unsolved is the occurrence of clinical discolouration after the use of MTA materials. Clinical studies testing PC on discolouration are desirable. It should be mentioned that to date PC has undergone more tests to show its suitability for clinical use, then MTA materials in 1995.

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