Arsenic content in Portland cement: A literature review

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ABSTRACT

Portland cement (PC) is a hydraulic binding material widely used in the building industry. The main interest in its use in dentistry is focused on a possible alternative to mineral trioxide aggregate (MTA) because PC is less expensive and is widely available. In dentistry, PC has been used in dental procedures such as pulpotomy, pulp capping, repair of root perforation and root-end filling. The purpose of this article is review the dental literature about the PC, its composition with special attention to arsenic content, properties, and application in dentistry. A bibliographic research was performed in Bireme, PubMed, LILACS and Scopus data bases looking for national and international studies about the PC composition, properties and clinical use. It was observed that PC has favorable biological properties very similar to those of MTA. The PC has shown good cell proliferation induction with formation of a monolayer cell, satisfactory inflammatory response, inhibitory effect of prostaglandin and antimicrobial effect. Studies have shown that PC is not cytotoxic, stimulates the apposition of reparative dentin and permits cellular attachment and growth. Regarding arsenic presence, its levels and release are low. PC has physical, chemical and biological properties similar to MTA. Arsenic levels and release are low, therefore, unable to cause toxic effects.

Key words: Arsenic, dentistry, Portland cement

Portland cement (PC) is a hydraulic binding material, which once mixed with water tends to harden. This material is widely used in the building industry and, recently, its use in dentistry has been largely studied. The main interest in its use in dentistry is focused on a possible alternative to mineral trioxide aggregate (MTA) because PC is less expensive and widely available.[14]

Several studies have shown that the composition of PC is similar to MTA, excepting by the absence of bismuth ions, which confers radiopacity to MTA.[3,4] Furthermore, PC exhibits others properties similar to MTA,[5] such as antimicrobial effect,[6] induction of cell proliferation and inhibitory effect of prostaglandin.[7]

In dentistry, PC has been used in dental procedures such as pulpotomy, pulp capping, repair of root perforation and root-end filling. Studies have shown that PC is not cytotoxic, stimulates the apposition of reparative dentin and permits cellular attachment and growth.[8-11]

Despite its good properties reported in the literature, PC has undesirable contaminant substances to human organism. The arsenic quantity in the PC is one of the major concerns regarding to its use.[12] The purpose of this article is to review the dental literature about the PC, its composition, with special attention to arsenic content, properties, and application in dentistry.

A literature review was performed on Bireme, Pubmed, LILACS and Scopus databases in order to identify studies reporting the composition and properties of PC, its application in dentistry and the arsenic presence and release. For this search, terms used were “Portland cement+arsenic release” and “Portland cement+dentistry”. Descriptive studies, case reports, literature review, in vitro and in vivo studies were included. Exclusion criterion was papers published before 1997.

Literature review

Composition and properties

The basic constituents of PC are lime (CaO), silica (SiO₂),
alumina (Al₂O₃) and iron oxide (Fe₂O₃). In the manufacturing process, they are crushed, ground, proportioned for the desired composition and then heated up to 1400–1600°C. The inclusion of gypsum (CaSO₄·2H₂O) controls the setting time of the cement.\[14\]

The resulting product consists of tricalcium silicate (3CaO·SiO₂), dicalcium silicate (2CaO·SiO₂), tricalcium aluminate (3CaO·Al₂O₃), tetracalcium aluminoferrite (4CaO·Al₂O₃·Fe₂O₃) and dehydrated calcium sulfate (CaO·SO₃·2H₂O).\[14,15\] Small differences can be noticed depending on the manufacturer and the location of the source of mineral extraction. In chemical assays of PC, the components were present according to the following average percentages: CaO (58.5%), SiO₂ (17.7%), Al₂O₃ (4.5%), MgO (3.3%), SO₃ (3.0%), Fe₂O₃ (2.9%), K₂O (0.9%), Na₂O (0.2%).\[6\]

Wucherpfennig and Green\[5\] report that mineral trioxide aggregate (MTA) and PC have similar macro, micro features as well as biological behavior. Comparative analysis shows no significant difference between PC and MTA with regards to their composition. However, MTA has bismuth oxide added to improve its radiopacity.\[3,4\]

Studies have shown that PC has an efficient antimicrobial effect. Estrela et al.\[6\] observed that the antimicrobial effect of MTA and PC was similar. The results obtained with MTA on S. aureus, E. faecalis and B. subtilis were identical to those obtained using PC. Sipert\[16\] studied in vitro the antimicrobial effect of PC on several species of microorganisms: Enterococcus faecalis, Micrococcus luteus, Escherichia coli, Staphilococcus aureus, Staphilococcus epidermidis, Pseudomonas aeruginosa and Candida albicans. PC presented antimicrobial potential in all cases except on E. coli that did not show inhibition of activity Mendonça et al.\[17\] report that the addition of metronidazol to PC did not improve the antimicrobial effect of PC.

PC has shown good cell proliferation induction with formation of a monolayer cell, satisfactory inflammatory response and inhibitory effect of prostaglandin.\[7\] In vitro studies with cell cultures have been widely used to evaluate the biocompatibility of those materials.\[18\] Saidon et al.\[19\] compared the cytotoxic effect in vitro and the tissue reaction of MTA and PC in bone implantation into the mandible of guinea pigs. Results show that there was no difference in cell reactions in vitro. Bone healing and minimal inflammatory response adjacent to MTA and PC implants were observed, suggesting that both materials are well tolerated.\[19\] Ribeiro et al.\[20\] evaluated in vitro on mouse lymphoma cells the genotoxic and cytotoxic effects of MTA and PCs and observed that none of them were cytotoxic. Those results seem to indicate that MTA and PCs are not genotoxic and do not induce cellular death. Ribeiro et al.\[21\] investigated MTA and Portland potential to induce DNA breakage in Chinese hamster ovary (CHO) cells and reported that those compounds tested did not show genotoxic effects in all concentrations evaluated. Min et al.\[11\] also reported that PC is not cytotoxic and it allows cell adhesion and growth. Braz et al.\[22\] evaluated human peripheral lymphocytes treated with PC at concentrations up to 1000 mg/mL\[1\] and did not observed damage to lymphocyte DNA. They concluded that the exposition to PC could not be able to increase the risk of genetic damage in lymphocytes.

Clinical applications of PC

In dentistry, material is mainly used to replace lost dental tissue due to dental caries and tooth preparation procedures. Studies have been looking for materials with the ability to promote regeneration of original tissue and capacity of integration with the biological environment.\[23,24\] PC has shown similar features of dental materials used for this purpose. Wucherpfennig and Green\[5\] reported apposition of reparative dentin when PC was used to direct pulp capping in rat teeth. Studies that analyzed the behavior of dog dental pulp after pulpotomy and direct pulp protection with PC, observed that there was a complete tubular hard tissue bridge in almost all specimens, showing that PC could be used as direct pulp protector.\[8-10\] De Deus et al.\[25\] evaluated furcal perforations in molar teeth sealed with PC and conclude that this material has ability to seal furcal perforations.

PC has calcium oxide that forms calcium hydroxide when mixed with water. The reaction of the calcium from calcium hydroxide with the carbon dioxide from the pulp tissue produces calcite crystals.\[8\] Tay et al.\[26\] report that PC releases calcium hydroxide that interacts with a phosphate fluid to produce calcium.

Sakai et al. (2009) compare the clinical and radiographic effectiveness of MTA and PC as pulp dressing agents in carious primary teeth. No statistically significant difference regarding dentine bridge formation was found between both groups throughout the follow-up period. The mineralized material deposition could be radiographically detected in 100% and 57.14% of the teeth treated with PC and MTA, respectively. It was observed that all pulpotomized teeth were clinically and radiographically successful.\[27\]

Arsenic presence in Portland cement

PC has undesirable contaminant substances to human
organism. The arsenic quantity in the PC is one of the major concerns regarding its use.\cite{12} Arsenic is a metalloid encountered in water, air, and soil in both inorganic and organic forms and in different stages of oxidation. The genotoxicity of arsenic depends on its chemical formula and oxidation state. Trivalent and pentavalent stages of oxidation are the most toxic.\cite{28,29}

The soluble salts of arsenic are absorbed by all mucosa and sites of parenteral administration, and almost all arsenic absorbed is firstly found in the erythrocyte fraction of blood. The element leaves the bloodstream and is deposited in tissues and the main storage sites are liver, kidneys and lungs.\cite{30} The exposure to the trivalent inorganic form and its mono- and dimethylated derivatives respectively, are associated with cancers of skin, lung, urinary bladder, kidney and liver.\cite{31} Because of its high toxicity, arsenic might cause widespread tissue necrosis in the oral cavity when used for endodontic purposes.\cite{32}

The carcinogenic effect of arsenic could be explained by a theory that proposes alterations in DNA repair. It seems to be attractive because trivalent arsenic compounds, such as arsenite, can bind strongly to both dithiol and sulphhydryl groups. Those protein bonds may cause inhibition of DNA repair, genetic mutations, or an increase in cell proliferation,\cite{33} which might induce subsequent mutations by inhibition of DNA repair.\cite{34}

The type of arsenic exposure, ingestion and inhalation seems to influence the shape of dose–response curve between arsenic concentration and the risk of cancer development. There are several factors such as gender, ionizing radiation, smoking, diet or genetic susceptibility which may act synergistically or as confounders influencing the dose–response curve.\cite{35}

According to ISO 9917-1\cite{36} standard, entitled water-based cements, a material to be used to dental procedures should contain no more arsenic than 2 mg/kg of cement. Arsenic was detected in this material in levels above those recommended by ISO 9917-1 standard.\cite{36} Achternbosch et al.\cite{37} analyzed 417 samples of PC and found an arsenic average of 6.8 ppm. Bramante et al.\cite{38} found 34.27 mg/kg of arsenic in the gray PC and 0.5 mg/kg in the white PC. However, Duarte et al.\cite{39} observed low concentration of arsenic in PC and MTA demonstrating that there is no contraindication for using those materials in clinical practice.\cite{40} The authors reported that the release of arsenic ranged from 0.002 to 0.007 ppm, being this concentration dependant on time and brand of PC.

**DISCUSSION**

In the last few years, studies have compared MTA to PC and the findings suggest that PC has the majority of the ingredients in common with MTA.\cite{6,19} PC could be used as an effective, widely available and less expensive MTA substitute.\cite{19,2} However, some substances in PC are undesirable to human organism, such as arsenic. The arsenic quantity in PC is one of the major concerns regarding its use.\cite{12}

Arsenic is an impurity of limestone that is used to manufacture PC.\cite{40} This metalloid adversely affects the enzymes that generate cell energy in the citric acid. The inhibitory action is based on the inactivation of pyruvate dehydrogenase by complex formation with trivalent arsenic and the subsequent inhibition of adenosine-5′-triphosphate production. Trivalent arsenic replaces the two hydrogen atoms in the thiol group and binds to a sulfur molecule, inhibiting the major step of enzyme activity. As a result, energy production is reduced and cell damage finally occurs. Arsenic also shows a carcinogenic effect because of its alterations in DNA repair. However, those toxic effects depend on the levels of arsenic found in the organism.\cite{33}

Several studies have evaluated the release of arsenic by PC. Those studies aim to analyze the levels of arsenic release and its toxicity, guiding the use of PC in clinical practices. Duarte et al.\cite{39} only analyzed the release of arsenic but not the presence of this metallic element, leaving unanswered the question of whether the arsenic levels in those materials are within ISO 9917-1\cite{36} standard limits.\cite{38} Primus\cite{41} questioned the results of Duarte et al.\cite{39} stating that, while PC contains arsenic in their composition, ProRoot-MTA does not have this metallic element because this material is specially manufactured under controlled conditions to ensure freedom from contamination, criticizing the use of PC.\cite{38}

Bramante et al.\cite{38} evaluated the amount of arsenic in different commercial and experimental MTA formulations and gray and white PC. The majority of materials tested in this study present arsenic levels above those recommended by ISO 9917-1\cite{36} standard (maximum of 2 mg/kg material). Only two types of MTA (MTA-Obtura and white MTA-Angelus) and white PC respected the standard of arsenic content for using.

The higher arsenic content does not necessarily indicate a greater release of arsenic. Materials such as MTA and PC have higher content of ferric salts,\cite{42} which stabilize the arsenic.\cite{43} This may explain why the release of arsenic was
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minimal in previous studies. Duarte et al. compared different forms of MTA containing bismuth oxide and PC without this oxide and they did not find any difference in arsenic release.

The amount of MTA used for endodontic purposes is very small, less than 1g. Thus, the 34.27 mg of arsenic per kilogram of material recorded for Gray PC correspond to 34.27 µg of arsenic per gram of cement. Considering that the median lethal dose (LD50) for arsenic trioxide administered orally is 2 to 3 mg per kg body weight, the toxic dose for an individual weighing 70 kg would be 140 to 210 mg. This is considerably above the arsenic content in PC used to a root end filling (approximately 35 µg). This provides a significant safety margin.

Studies that evaluated the biocompatibility of PC in cell cultures and animals showed satisfactory results. It would not happen if arsenic levels were higher in those materials. Therefore, the results indicate that PC does not cause toxic effects.

CONCLUSION

PC has physical, chemical and biological properties similar to MTA. Concerning arsenic presence and release, it was concluded that the levels are low, therefore, unable to cause toxic effects. However, further researches are needed to assure its safety and suitability in clinical practice.

REFERENCES


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