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An update on the use of MTA in endodontics

Zastosowanie MTA w endodoncji – aktualny stan wiedzy

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DOI: http://dx.doi.org/10.20883/df.2016.8

Abstract

Mineral trioxide aggregate, MTA, is a cement material based on Portland cement with added bismuth oxide to confer radiopacity. It is now widely is used for a variety of applications in endodontic, including root-filling and sealing. It is biocompatible in contact with human hard tissues and promotes both osteogenesis and cementogenesis at the root tip. MTA has good physical properties, and provides a durable seal for endodontically treated teeth. The setting reaction, based on hydration chemistry, is described and the biological properties of MTA are also covered. The review concludes that MTA is a useful and versatile endodontic material which gives good clinical outcomes.

Keywords: endodontics, mineral trioxide aggregate, biocompatibility, root canal sealing.

Streszczenie

MTA (*mineral trioxide aggregate*), agregat trójtlenków mineralnych, jest cementem na bazie cementu portlandzkiego z dodatkiem tlenku bizmutu jako środka poprawiającego kontrast na zdjęciach RTG. Znajduje obecnie szerokie zastosowanie w endodoncji, w tym jako wypełnienie i uszczelniacz kanałowy. Jest biokompatybilny w kontakcie z ludzkimi tkankami twardymi i promuje zarówno osteo- jaki i cementogenezę w okolicy wierzchołka korzenia. MTA charakteryzuje się dobrymi właściwościami fizycznymi i zapewnia trwałe uszczelnienie zębów leczonych endodontycznie. W niniejszej pracy przedstawiono reakcję wiązania, polegającą na reakcjach uwodnienia, a także właściwości biologiczne tego materiału. We wnioskach podkreślono, że MTA jest użytecznym i wszechstronnym materiałem endodontycznym, dającym dobre wyniki kliniczne.

Słowa kluczowe: endodoncja, mineral trioxide aggregate, biokompatybilność, uszczelniacze kanałowe.

Introduction

Endodontic treatment is carried out to preserve a tooth where there has been damage to the pulp [1]. Such damage may extend to the peri-radicular tissues, and repair is necessary so that the natural tooth may be preserved. Surgical endodontic treatment includes a variety of procedures, including direct and indirect pulp capping, where the aim is to restore the pulp to a functioning and fully viable condition. It also includes the treatment of a tooth where the pulp is damaged beyond repair, either by trauma or infection. When this happens, the pulp needs to be extirpated, after which the tooth must be sealed at the root. This procedure enables the tooth to be retained and, though no longer viable, allows it to function structurally.

Mineral Trioxide Aggregate, MTA, is one of several different materials that have been used in endodontic therapy. In particular, it has been used to seal the apex of the tooth root, and therefore prevent infection via ingress of fluids from the surrounding tissue [2]. The appropriate clinical procedure uses MTA in association with pre-formed gutta percha points. The overall combination is dimensionally stable, and able to conform to the contours of the root canals, providing both an apical and lateral seal. The MTA-gutta percha combination is insoluble in tissue fluids and not affected by them, and can be readily placed under clinical conditions.

As well as root sealing, MTA has been used for a variety of applications within endodontics. These include pulp capping, perforation repair and root-end filling. A full list of uses is given in **Table 1**, and these uses are illustrated in the **Figure 1**.

Mineral Trioxide Aggregate

Mineral Trioxide Aggregate was introduced to the dental profession in the mid 1990s, following the pioneering work of Torabinjad [3]. It is based on the building material Portland cement, a material that consists of various calcium silicates, of which the main one is tricalcium silicate. Other components are dicalcium silicate and tricalcium aluminate [4, 5], and also a small fraction (up to 5% by mass) of gypsum ($CaSO_4.2H_2O$). This latter substance is able to react with water and to regulate

Table 1. Clinical uses of MTA in endodontics [8]
Tabela 1. *Zastosowanie kliniczne MTA w endodoncji [8]*

In permanent teeth
Root canal sealing
Pulp capping
Partial pulpotomy
Perforation repair
Resorption repair
Repair of fracture
Root-end filling
Apical barrier for teeth with necrotic pulps and open apex
Coronal barrier for regenerative endondontics

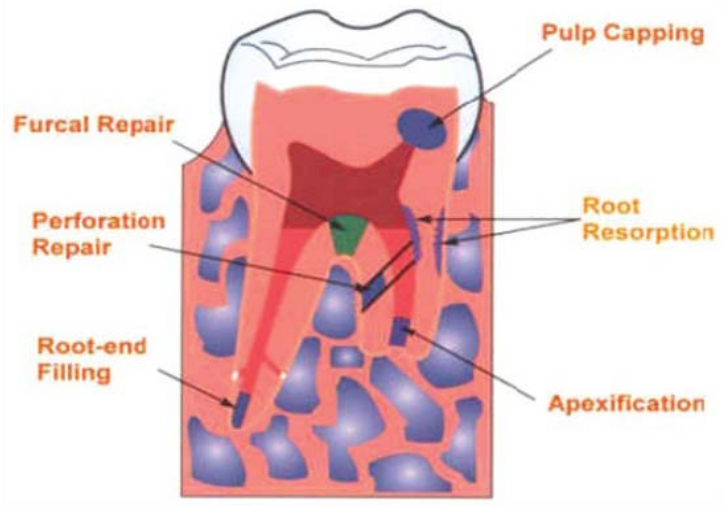

Figure 1. Illustration of uses of MTA in endodontics
Rycina 1. *Ilustracja zastosowania MTA w endodoncji*

the hydration-based setting of the aluminate component [4].

MTA is supplied as a powder containing small particles generally below 50 μm in size consisting of the various components (tricalcium silicate, tricalcium auliminte, etc) [5]. For clinical use, this powder is mixed with sterile water at a powder:liquid ratio of 3:1 to form a paste which gradually sets for form a brittle solid [6]. After seven days, the material has a compressive strength of approximately 28 MPa [7], though this may be increased slightly by the presence of additives [5]. MTA is widely approved for use in the human body as an endodontic repair material, including by the US Food and Drugs Administration, FDA.

MTA is available in two forms, grey and white. The grey one was the first to be made available to the dental profession, and the colour was provided by the presence of a small amount of tetracalcium alumino ferrate. This is a dark coloured substance that occurs naturally in Portland cement. It has the undesirable property of darkening a tooth in which it is placed [8]. To overcome this drawback, MTA can be purified at the manufacturing stage by removal of the tetracalcium alumino ferrate, and the resulting product is light-coloured, so-called white MTA [9]. The main components of these materials are shown in **Table 2** [10].

In clinical service, MTA has been found to have good sealing ability [2, 11, 12]. It is also very biocompatible with the tissues at the apex of the tooth root [12, 13]. The biocompatibility of MTA is considered in detail later in this article.

Setting of MTA

The setting reactions of MTA resemble those of Portland cement. Two phases, alite (Ca_2SiO_5) and belite (ß-Ca_2SiO_4), are involved in the initial setting reaction, and these two substances become hydrated to form a non-crystalline gel phase of calcium hydroxide dispersed in calcium silicate hydrate. The latter substance has the approximate formula $Ca_3Si_2O_7$ [14]. After the initial step, which brings about hardening of the cement mixture, there are further condensation reactions. These cause the strength to increase through the formation of short silicate chains within the material [15].

As well as setting by means of forming calcium silicate hydrate gel hardening of MTA involves formation of a small proportion of calcium hydroxide. The presence of this substance in the set cement is important because it makes the material

Table 2. Composition of Grey and White MTA [48]
Tabela 2. *Skład Grey i White MTA [48]*

Component	Grey MTA	White MTA
CaO	40.45%	44.23%
SiO_2	17.00%	21.20%
Bi_2O_3	15.90%	16.13%
Al_2O_3	4.26%	1.92%
MgO	3.10%	1.35%
FeO	4.39%	0.40%
Remainder	14.90%	14.77%

alkaline, and this feature is vital in making MTA bioactive.

Setting involves other components apart from alite and belite. Both the aluminate and ferrite constituents undergo reactions with the gypsum component in the presence of water. The aluminate forms a substance called ettringite, which has the overall formula $6CaO.Al_2O_3.3SiO_3.32H_2O$. Ferrite undergoes a similar reaction to form the iron substituted equivalent substance $6CaO.Fe_2O_3.3SiO_3.32H_2O$. The latter product is stable within the set MTA, by contrast with ettringite, which slowly converts to free water and so-called monosulphate $4CaO.Al_2O_3.SiO_3.12H_2O$. This combination of products is thermodynamically stable, so undergoes no further changes with time [14].

In addition to the usual constituents of Portland cement, MTA contains bismuth oxide, a substance which is added as a radiopacifying agent [16]. It has been claimed that bismuth oxide participates in the setting reaction and becomes incorporated within the calcium silicate hydrate [17]. However, this is unlikely as bismuth oxide is very insoluble in water and aqueous media, and also does not undergo any known reactions in alkaline conditions [18]. Experimental studies using a variety of techniques, such as XRD, solid-state NMR spectroscopy, FTIR and isothermal conduction calorimetry have confirmed that it does not react but instead, remains as inert filler within the cement matrix [19].

Calcium hydroxide within the set MTA causes the cement to be alkaline [20, 21]. In one study, MTA was shown to have a pH of 10.2 in water immediately following setting, and this rose to be 12.5 after 3 hours, when extra calcium hydroxide had been formed within the cement [22]. Such high alkalinity is an important feature of MTA, as it is responsible for the bioactivity of the cement in the vicinity of the tooth root.

Radiopacity of MTA

In clinical service, it is desirable that MTA should be radioapque. as we have seen, radiopacity is conferred by the bismuth oxide that is present in all MTA formualtions. Despite its widespread use, bismuth oxide has some drawbacks as a radiopacifying agent [23]. When it is present, the porosity of the cement is increased, which makes dissolution and disintegration easier [24, 25]. Other radiopacifying agents have been studied in attempts to overcome these problems [26], including zirconium oxide, calcium tungstate [24], gold powder and silver/tin alloy [27, 28]. However, none of them represent a substantial improvement, so are not used in commercial brands of MTA.

Biological properties of MTA

As has already been mentioned, set MTA is a highly alkaline material, a feature which is critical to its biological properties. MTA is considered biocompatible in all its endodontic applications and to be bioactive towards tissues at the tooth root and beyond [29]. This bioactivity shows itself in a variety of ways. For example, MTA promotes only low periradicular inflammation [30], and also causes cementum to form on its surface [31]. The low pH induces the formation of apical hard tissue [32] and supports almost complete regeneration of the periradicular periodontum in non-infected teeth [33].

The biocompatibility of MTA towards a variety of cell types has been studied, including mouse fibroblasts [34], mouse L929 [35, 36], Chinese hamster ovary cells [37] and rat bone marrow cells [38]. In all cases, these cells show positive reactions to the presence of set MTA, exhibiting no signs of either cytotoxicity or genotoxicity. Studies have also been carried out in whole animals, including Guinea pig [39], rat [40] and dog [41, 20]. Results in these studies have also been uniformly positive, with cells attaching readily to the hardened MTA, and production of new hard and soft tissues being stimulated with little or no inflammatory response.

Studies have also been carried out on human cells and have demonstrated, for example, that human osteoblast cells will attach to set MTA *in vitro* and undergo proliferation [43]. Other human cells have been gingival fibroblasts [46–49] and periodontal ligament fibroblasts [44, 45, 47]. Both types of cell are present in the region of use of MTA and their response to the presence of MTA is highly relevant to the end use of the cement. In both cases, cells were found to respond favourably, and to maintain their form and function in contact with the set MTA. The general conclusion is that MTA is highly biocompatible towards all types of cell fo-

Table 3. Examples of commercial MTA materials for clinical use [10]

Tabela 3. *Przykłady nazw handlowych materiałów zawierających MTA o zastosowaniu klinicznym [10]*

Brand	Supplier
ProRoot MTA	Dentsply, Germany
White ProRoot MTA	Dentsply, Germany
MTA Plus	Aralon Biomed, Bradenton, USA
MM MTA	MicroMegha, Besancon, France
MTA-Angelus (Grey)	Angelus, Londrina, Brazil
MTA-Angelus (White)	Angelus, Londrina, Brazil

und in the vicinity of the tooth root, and that the high alkalinity stimulates cell activity and promotes healing.

Clinical outcomes with MTA

MTA is now widely used in clinical endodontics and several brands are available to the dental profession [48]. **Table 3** lists some of the more important examples.

The properties of MTA are generally acceptable for its clinical application. It has reasonable mechanical strength [49, 50], and acceptable sealing ability [50–53] though it does show some slight leakage [54]. MTA can be readily sterilised and is able to set in the presence of body fluids [5].

Many clinical reports of the use of MTA in various aspects of endodontic therapy have been published [55], and these generally confirm its good performance in patients, notably in promoting healing in the tissues. Reports typically show that MTA promotes deposition of cementum and causes no inflammation. Uses with positive clinical outcomes include MTA's use as a root-end filling material [29–32], for pulp capping, in pulpotomy and in repair lateral of root perforations [46–49, 56] and also to promote apical barrier formation in teeth with open apexes [57].

In clinical use, it is recommended that MTA be placed with minimal pressure [58] to avoid extrusion into the periodontal space [59]. However, should MTA be accidentally extruded it appears to cause no damage and shows no cytotoxicity towards the cells of human periodontal ligament.

MTA is a good but not perfect material for endodontics, and it does have some disadvantages. It has a long setting time, and some authors complain about the grainy texture of the unset cement. They also claim that it is difficult to handle and hard to remove once fully set [60, 61]. However, these are considered relatively minor drawbacks and opinion on the material is generally favourable.

Conclusions

Since its first reported use as a material for endodontics in 1993, MTA has established itself as a versatile and acceptable material for a variety of endodontic functions. It is both biocompatible and bioactive in the region of the tooth root, and provides good clinical outcomes. Overall, its introduction into clinical endodontics has been extremely beneficial for patients, and its future in this field seems assured.

Acknowledgements

Conflict of interest statement

The authors declare that there is no conflict of interest in the authorship or publication of contribution.

Funding sources

There are no sources of funding to declare.

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Accepted for editing: 2016-04-28
Accepted for publication: 2016-05-06

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