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Review Article

New Era of Endodontic Materials: Bioceramics

Mohamed Hany Ahmad Fouad[1]*, Duaa Matooq ALYahya[2], Asim Abdulrahman M Alqarni[2], Raed Abdullah Alshahrani[2], Maher Marwan Aref[2], Abed Mohamed Abduljawad[2], Abdulaziz Abdullah Alshahrani[2], zohair Ali Alghamdi[2], Saleh Mohammed Alegayel[2], Abdulrahman Abdulghani Sarhan[2], Majed Abdullah Alrudayan[2], Moayad Eyad Nasser[2], Mahmoud Adel Slaghour[2], Ahmad Saeed Balubaid[3] and Zyad Emad Almasri[4]

[1]Cairo University, Saudi Arabia

[2]Ministry of Health, Saudi Arabia

[3]King Abdulaziz University, Saudi Arabia

[4]Umm Al-Qura University, Saudi Arabia

***Corresponding Author:** Amandeep Gupta, Assistant Professor, Division of Integrated Biomedical Sciences, University of Detroit Mercy School of Dentistry, Detroit, Michigan, USA. Number: 05JD0323.

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Abstract

Introduction: With the advent of new techniques and technological advances, the field of Endodontics is constantly changing. Advances in endodontic material sciences play a major role in exponential growth in endodontic practice. Bio-ceramic-based materials are one of the recent advancements introduced in the field of endodontics that have changed the face of endodontic practices. Ceramics are non-metallic and inorganic materials made by the firing of raw minerals at high temperatures. Bio-ceramics are metal oxides biocompatible in nature and with enhanced sealing ability, antibacterial and antifungal activity applied for use in medicine and dentistry. Because of their excellent physicochemical and biocompatible property, they are widely used in endodontic applications. One of the key abilities of bioceramic material is to encourage the regeneration of natural tissues or function as human tissues or resorb over a period of time. In the past 20 years, a number of major advances have been made in the field of bioactive ceramics, particularly used for endodontic treatment. They have a wide variety of applications such as root canal sealers, cements, root repair materials, and canal filling materials and possess the advantages of increased biocompatibility, enhanced root strength after obturation, sealing ability, and antibacterial properties. Therefore in this way, new bioceramic materials have shown to overcome some of the major limitations of previous generations of endodontic materials.

Aim of the Study: The aim of the present literature review is to understand the concept of new bioceramic materials introduced in the field of endodontics and their different application.

Methodology: The present study is the comprehensive research of PUBMED since the year 2005 to 2015.

Conclusion: The application of bioceramic material in the field of endodontics technology has changed both surgical and non-surgical treatment. These materials provide a promising direction for the preservation of patients' teeth. Hence, this is the reason that most of the current bioceramic materials have rapidly gained popularity in clinical applications because of their Physicochemical and biological properties. However, certain disadvantages still exist when considering the requirement for an ideal material used in endodontics. Therefore, the currently available bioceramic materials need to be further modified and developed to overcome the few

remaining drawbacks. MTA is the standard, long-standing bioceramic material used in the field of endodontics. Advances in these materials have constantly tried to overcome the drawback of MTA and improve its properties, as a result of which bioceramics materials are now widely used both in endodontics and restorative dentistry. Thorough knowledge of these new bioactive materials is necessary to ensure the selection of the most suitable material in different clinical situations.

Keywords: *Bioceramic Sealers; MTA; Biodentine*

Introduction

Leakage is the most common cause of endodontic failure. Bacterial invasion from filled root canals finds its portal of entry into the periapical tissues [1]. The leakage can occur at any interface, be it between the root filling, sealer, or repair materials and dentin after root canal treatment. Considering this situation, endodontic materials used permanently in the root canal should inhibit the entry of bacterial invasion into periapical tissues via the root canal system to ensure the long-term success of endodontic treatment [2].

Therefore, the criteria for the ideal material for use in endodontics have become comprehensive and should have the following properties [3]:

1. Non-toxic
2. Insoluble in tissue fluids
3. Dimensionally stable
4. Antibacterial
5. Hard tissue conductive
6. Biocompatible
7. Radiopaque and easy to handle.

However, the traditional root filling and restorative or reparative materials presently used in the field of endodontics do not possess all these desired properties.

The introduction of bioceramic materials has led to these changes because of their wide variety of applications ranging from filling materials to root repair cements as root canal sealers. It was introduced in the field of endodontics in the 1990s. The major advantages of bioceramic materials in endodontics are related to their physicochemical and biological properties. Since the introduction of bioceramic materials in the field of endodontics, mineral trioxide aggregate (MTA) is recognized as the gold-standard material which is used in a variety of clinical situations and is considered closest to the ideal reparative material due to its excellent biological and physicochemical properties [4,5].

Advantages [6]:

1. Good biocompatibility properties and similarity with biological hydroxyapatite.
2. Non-toxic, non-shrinking, and chemically stable within the biological environment.
3. Able to form hydroxyapatite and ultimately create a bond between dentin and the material.
4. Have the ability to absorb osteoinductive substances in the vicinity of bone healing hence they are intrinsic osteoconductive.
5. Acts as a regenerative scaffold of resorbable lattices and provides a framework to rebuild tissue.
6. Dissolves over a period of time.
7. Fluoride ions are part of apatite crystals in these materials, and the resulted nanomaterial has antibacterial properties.
8. Porous powders in bioceramic material containing nanocrystals with diameters of 1 - 3 nm help prevent bacterial adhesion.

Classification of bioceramic materials

There are various classifications of bio-ceramic materials used in endodontics on the basis of composition, setting mechanism and consistency. One of the simpler classifications of bioceramics is as follows [7].

Primer	Primer Sequence (5'- 3')	Amplification condition	Amplicon product size (bp)/Ref
bla_{TEM} (forward) bla_{TEM} (reverse)	TCAACATTTCCGTGTCGCAC AGTTACCAATGCTTA	Initial denaturation: 94°C, 5 minutes Denaturation: 94°C, 30 seconds Annealing: 55°C, 1 minute Extension: 72°C, 2 minutes Final extension: 72°C, 5 minutes	861 Zong., *et al*. [11]
bla_{CTX-M} (forward) bla_{CTX-M} (reverse)	CGCTTTGCGATGTGCAG ACCGCGATATCGTTGGT	Initial denaturation: 94°C, 5 minutes Denaturation: 94°C, 30 seconds Annealing: 55°C, 1 minute Extension: 72°C, 2 minutes Final extension: 72°C, 5 minutes	544 Zong., *et al*. [11]
bla_{SHV} (forward) bla_{SHV} (reverse)	CGCCTGTGTATTATCTCCCT CGAGTAGTCCACCAGATCCT	Initial denaturation: 94°C, 5 minutes Denaturation: 94°C, 30 seconds Annealing: 54°C, 30 seconds Extension: 72°C, 1 minutes Final extension: 72°C, 10 minutes	445 bp Pitout., *et al*. [12]

Table 1: *Primer sequences and their amplification condition.*

Basic composition

The basic composition of all bioceramic materials includes zirconia and alumina, glass ceramics, bioactive glass calcium silicates, resorbable calcium phosphates, hydroxyapatite, and radiotherapy glasses [8].

Bioceramics used in endodontics [8]

Organism	Chicken faeces (n = 52) N (%)	Poultry environment (n = 134) N (%)	Meat (n = 86) N (%)	Total (n = 272) N (%)
E. coli	17 (32.7)	44 (32.8)	47 (54.7)	108 (39.7)
K. pneumoniae	24 (46.2)	20 (14.9)	20 (23.3)	64 (25.3)
Total	41 (78.8)	64 (47.8)	67 (77.9)	172 (63.2)

Table 2*: Isolation rate of the E. coli and K. pneumoniae from different samples.*

Some commercially available bioceramic material according to usage [8]

Antibiotics class	Antibiotics	Poultry and Environment		Meat		Total
		E. coli **N = 61 (%)**	***K. pneumoniae*** **N = 44 (%)**	***E. coli*** **N = 47 (%)**	***K. pneumoniae*** **N = 20 (%)**	**N = 172 (%)**
Carbapenems	IPM	8 (13.1)	8 (18.2)	6 (12.8)	2 (10.0)	24 (13.9)
Cephalosporins	CEF	26 (42.6)	32 (72.7	25 (53.2)	20 (100)	103 (59.8)
	CAZ	16 (26.2)	31 (70.5)	47 (100)	18 (90.0)	112 (65.1)
	CTX	24 (39.3)	32 (72.7)	46 (97.8)	20 (100)	122 (70.9)
	FOX	20 (32.7)	30 (68.2)	24 (51.1)	8 (40.0)	82 (47.7)
Penicillin	AUG	25 (40.9)	25 (56.8)	45 (95.7)	19 (95.0)	114 (66.3)
Macrolide	E	15 (24.6)	22 (50)	21 (44.7)	9 (45.0)	67 (38.9)
Fluoroquinolones	MFX	9 (14.8)	6 (13.6)	29 (61.7)	7 (35.0)	51 (29.7)
Phenicols	C	27 (44.3)	28 (63.6)	35 (74.5	18 (90.0)	108 (62.8)
Aminoglycosides	CN	26 (42.6)	24 (54.5)	36 (76)	16 (80.0)	102 (59.3)

Table 3: *Antibiotic resistance pattern of the E. coli and K. pneumoniae isolates.*

Key: IMP: Imipenem; CEF: Cefpirome; CAZ: Ceftazidime; FOX: Cefoxitin; CTX: Cefotaxime; AMG: Amoxicillin-Clavulanic Acid; E: Erythromycin; MFX: Moxifloxacin; C: Chloramphenicol; CN: Gentamycin.

Portland cement

In1824, Joseph Aspdin patented a product called Portland cement (PC). Portland cement is obtained from the calcination of the mixture of silicon-argillaceous materials and limestones from Portland in England. It is known to be an inexpensive material. PC and MTA have similar main compositions. PC differs from MTA by the absence of bismuth oxide and the presence of higher levels of calcium sulfate and calcium aluminate. Like MTA, PC is available in grey and white material [9].

Properties of portland cement

Discoloration: When compared to grey MTA, PC (grey) shows lesser discoloration, but discoloration seen by white MTA and white PC is similar [9].

Solubility: Greater solubility is seen with MTA when compared to white PC. When placed in a different solution, PC has better washout resistance compared to MTA [10].

Bioactivity: After hydration, maturation is more structured in MTA, but the formation of hydroxyapatite crystals and calcium ion release is seen with both grey and white PC [9,11].

Particle size: White ProRoot MTA has a significantly smaller particle size when compared to white PC both before and after the hydration of cement [9].

Antibacterial properties: Antibacterial and antifungal properties of PC are similar to that of MTA against microbes like *Enterococcus faecalis, Staphylococcus epidermidis, Micrococcus luteus, Candida albicans, Staphylococcus aureus* and *Pseudomonas aeruginosa* [9].

Sealing ability: When compared to white and grey MTA sealing ability of material as root-end filling material is similar to PC, but as a perforation repair material, white PC showed better sealing ability in comparison to white and grey MTA [9].

Biocompatibility: There is the variable result shown in a variety of cell culture studies done to assess the biocompatibility of these materials. Essentially there was no cytotoxicity or genotoxicity was seen associated with PC. But in terms of human bone marrow-derived mesenchymal stem cells. There was greater proliferation and migration seen with MTA in comparison to PC. Pulpotomy procedure done with PC and MTA was successful, but greater obliteration in root canal was seen with PC [9].

Limitations: Lead and arsenic were released in a higher amount from PC. PC also exhibits its high solubility compared to MTA. This higher solubility of portland cement may jeopardize the long-term seal required for successful endodontic treatment. There was crack formation due to excessive setting expansion with PC [9,12].

Mineral trioxide aggregate (MTA)

MTA cement was the first bioceramic material successfully used in endodontics. It was introduced by Dr. Torabinejad in the year 1993. It is biocompatible, osteoconductive, and inductive in nature. Initially, it was developed as a root-end filling material and further has been used in a variety of procedures such as pulpotomy, pulp capping, apexogenesis, repair of root perforations, apical barrier formation in teeth with open apexes, and lastly the, as a root canal filling material. In the year 2002, white MTA (WMTA) was introduced as ProRoot-MTA by Dentsply Endodontics, Tulsa, OK, USA, to overcome the drawback of discoloration of teeth associated with Grey MTA [13].

In grey MTA, grey color is imparted to cement by iron ions, which were removed from white MTA. The difference between grey and white MTA is that White MTA has 54.9% less Al_2O_3, 56.5% less MgO and 90.8% less FeO than Grey MTA. Hence, it can be concluded that the conclusion reduction in FeO is most likely the cause of the color change [14].

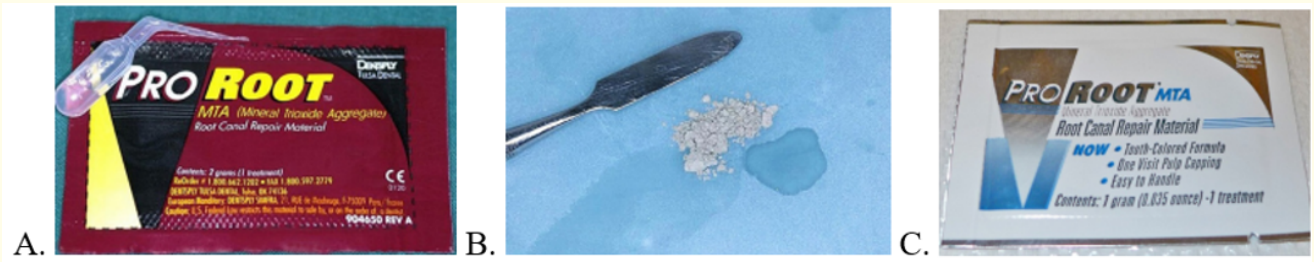

Figure 1: *Figure MTA is often regarded as the golden standard of bioceramic cements against which other products are compared. Both grey and white MTA are powders that are manually mixed with water [15].*

Physical properties

The compressive strength-of both grey and white MTA is around ~40 MPa at the end of 24 hours and ~67 MPa at the end of 21 days [14].

Setting reaction: Setting reaction of MTA is a hydration reaction. It is an exothermic reaction, requiring hydration of its powder to produce the end product matures over time. Tricalcium silicate and dicalcium silicate reacts with water to form calcium hydroxide [$Ca(OH)_2$] and calcium silicate hydrates (C-S-H). The bioactivity of MTA is attributed to calcium ion dissolution, diffusion, and reaction product formation (CS-H and $Ca[OH]_2$) and the subsequent reactions result in apatite formation [14]:

$2[3CaO.SiO_2] + 6H_2O$ ---->$3CaO.2SiO_2.3H_2O + 3Ca(OH)_2$

$2[2CaO.SiO_2] + 4H_2O$ ---->$3CaO.2SiO_2.3H_2O + Ca(OH)_2$

$7Ca(OH)_2 + 3Ca(H_2PO_4)_2$ ----> $Ca_{10}(PO_4)_6(OH)_2 + 12H_2O$.

Setting time: The recommended powder liquid ratio is 3:1 for MTA. The setting time of grey ProRoot MTA is 2 hr and 45 minutes. The final setting times of White MTA are 140 minutes (2h and 20 minutes) and 175 minutes (2h and 55 minutes) for Grey MTA. Gypsum extends the setting time. To reduce setting time, sodium phosphate dibasic (Na_2HPO_4) and calcium chloride ($CaCl_2$) have been added to products like MTA Bio to obtain a rapid-setting material [14].

pH: Initial pH of hydrated MTA is 10.2, which rises to 12.5 3 hours after mixing [14].

Flexural strength: The placement of a moist cotton pellet over MTA for 24 hours showed an increase in flexural strength [14].

Porosity: The amount of porosity is directly related to the amount of water used to make a paste and entrapment of air bubbles during the mixing procedure.

Microhardness: Microhardness is adversely affected by the presence of a chelating agent, less humidity, low pH values, and more condensation pressure.

Sealing ability: There is overall less microleakage with MTA materials than traditional materials for apical restoration as well as for preparation used to repair furcal perforations [14].

Particle size: The physical properties are influenced by crystal size. The smaller the particle size is, the more surface contact with the liquid, leading to greater early strength. The size of some particles is as small as 1.5 mm, smaller than the diameter of some dentinal tubules. White MTA has finer particles in comparison to Grey MTA. The handling characteristics of these materials are dictated by particle size [14].

Biocompatibility: It is non-neurotoxic and non-mutagenic. It does not produce a side effect on microcirculation. MTA is found to have anti-inflammatory effects on pulp tissue, and its cementoinductive, cementoconductive and osteoconductive effects have been confirmed in many studies [16].

Advantages: MTA forms calcium hydroxide that releases calcium ions for cell attachment and proliferation. Its alkaline pH creates an antibacterial environment by cytokine production. MTA encourages differentiation and migration of hard tissue-producing cells to form hydroxyapatite on the surface and may provide a biologic seal [16].

Limitations: Long setting time, difficult handling properties, and high cost are some drawbacks associated with MTA. Tooth discoloration with Grey MTA is another drawback [14].

Biodentine

'Biodentine' became commercially available in the year 2009 by Septodont, Saint Maur des Fosses, France. It is a calcium silicate-based product. The material is formulated based on MTA cement by improving some of its physical and handling properties [17].

Setting reaction: The setting reaction is similar to that of MTA with the formation of calcium hydroxide and calcium silicate hydrate gel (C-S-H), but in biodentine, calcium carbonate acts as a nucleation site for calcium-silicate-hydrate gel, reduces the induction period, and leads to faster setting time as well as enhancing the microstructure. The presence of hydrosoluble polymer reduces the viscosity of the cement and improves the handling characteristics of cement [17].

Setting time: The initial setting period is 9 - 12 minutes, and the final setting time is 45 minutes, with a working time of up to 6 minutes. This shorter setting time is due to the addition of calcium chloride in the liquid, which is an improvement compared to MTA [17].

Compressive strength: More than 100 MPa in the first hour, which continues to improve and reach more than 200 MPa at the end of 24h, which is more than the value of most Glass Ionomers cement. The compressive strength reaches up to 300 MPa after one month.

Microhardness: The hardness of Biodentine was 51 VHN after 2 hours and reached 69 VHN at the end of 1 month [17,18].

Sealing ability: The alkaline effect of biodentine causes micromechanical adhesion during the setting reaction, causing organic tissues to dissolve out of the dentin tubule [17,18].

Flexural strength: After 2 hours, the flexural strength was 34 MPa as compared with other materials such as Conventional Glass Ionomer Cement; 17 - 54 MPa for Resin modified GIC and 61 - 182 MPa for Composite resin [19]. Therefore, it was concluded that the bending resistance of Biodentine is greater than conventional GIC but much lower than the composite [17].

Antibacterial activity and pH: The pH increases up to 12.5 due to the release of calcium hydroxide ions released from cement during setting, which inhibits the growth of microbes and disinfects the dentin [19].

Biocompatibility: Biodentine is non-toxic and has shown no adverse effects on cell differentiation and cell function. It is an excellent material in pulpotomy because it increases TGF-B1 (growth factor) secretion from pulp cells which in turn causes angiogenesis, recruitment of progenitor cells, cell differentiation, and aids in mineralization [19].

Advantages: The advantage of Biodentine over MTA is its improved handling property which is better suited to the clinical use when compared to MTA. It also has better mechanical properties than MTA and does not require a two-step restoration procedure like MTA. The setting is faster than MTA; thus, there is a lower risk of bacterial contamination [19].

Conclusion

The application of bioceramic material in the field of endodontics technology has changed both surgical and non-surgical treatment. These materials provide a promising direction for the preservation of patients' teeth. MTA is the standard, long-standing bioceramic material used in the field of endodontics. Advances in these materials have constantly tried to overcome the drawback of MTA and improve its properties, as a result of which bioceramics materials are now widely used both in endodontics and restorative dentistry. Thorough knowledge of these new bioactive materials is necessary to ensure the selection of the most suitable material in different clinical situations.

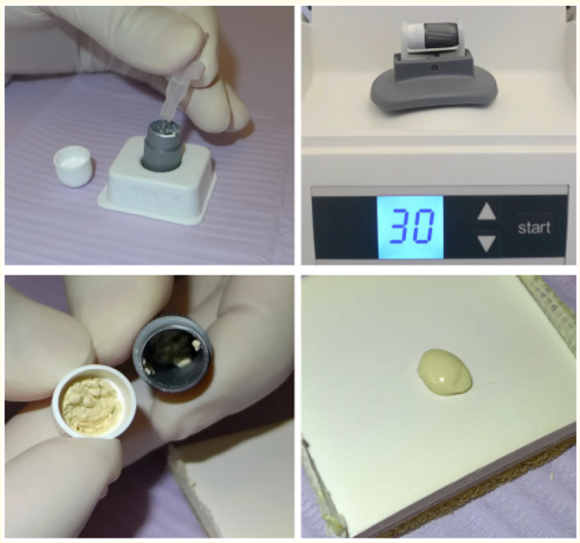

Figure 2: *Figure showing biodentine is the only bioceramic cement where the powder and liquid are mixed using a mixing device. Final mixing and adjustment of suitable water content are made manually to obtain the desired consistency for each case (bottom right) [15].*

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