BIOCERAMICS IN ENDODONTICS – A REVIEW

Endodontide Biyoseramikler: Derleme

Srinidhi Surya RAGHAVENDRA 1, Ganesh Ranganath JADHAV 1, Kinjal Mahesh GATHANI 2, Pratik KOTADIA 2

Received: 05/09/2017
Accepted: 05/10/2017

ABSTRACT

Bioceramics are materials which include Alumina, Zirconia, Bioactive glass, Glass ceramics, Hydroxyapatite, resorbable Calcium phosphates, among others. They have been used in dentistry for filling up bony defects, root repair materials, apical fill materials, perforation sealing, as endodontic sealers and as aids in regeneration. They have certain advantages like biocompatibility, non toxicity, dimensional stability and most importantly in endodontic applications, being bio-inert. They have a similarity to Hydroxyapatite, an intrinsic osteo conductive activity and have an ability to induce regenerative responses in the human body. In Endodontics, they can be broadly classified into Calcium Phosphate/ Tricalcium/ Hydroxyapatite based, Calcium Silicate based or mixtures of Calcium Silicate and Phosphates. This review focuses on an overview of Bioceramics, classification and their advantages. It also gives a detailed insight into individual bioceramic materials currently used in the fields of Endodontics along with their properties and applications.

Keywords: Bioceramics; Bioactive glass; calcium phosphate; calcium silicate; hydroxyapatite

ÖZ

Biyoseramikların içeriğinin bir kısmını alümina, zirkonya, biyoaktif camlar, cam seramikler ve rezorbe olabilen kalsiyum fosfatlar oluşturu. Biyoseramikler, diş hekimliğinde kemik defektiinin doldurulmasında, kıkırmızı ve kök uçu dolgu materyalleri olarak, perforasyonların kapatılmasında, endodontik patlar olarak ve rejenerasyon işlemleriinde kullanım alanı bulunmaktadırlar. Biyoaktif materyaller, toksik olmamaları, boyutsal stabilitete sahip olmalardı, biyoaktif osteokondüktif aktiviteye sahip olmaları, insan vücudunda rejeneratif yanıtları indükleyenler. Endodontide genel olarak kalsiyum fosfat/trikalsiyum/hidroksiapatit esaslı, kalsiyum silikat esaslı, veya kalsiyum silikat ve fosfatların karışımı olarak sınıflandırılabilirler. Bu derlemenin kapsamlı bir biçimde biyoseramikler, sınıflamaları ve avantajları anlatılmaktadır. Endodonti alanında kullanılan bazı güncel biyoseramik materyallerin detaylı açıklamaları yanında özellikleri ve uygulamaları hakkında da bilgi verilmiştir.

Anahtar kelimeler: Biyoseramikler; biyoaktif camlar; kalsiyum fosfat; kalsiyum silikat; hidroksiapatit

1 Dept of Conservative Dentistry & Endodontics, Sinhgad Dental College and Hospital, Pune, Maharashtra, India.
2 Private practice, Pune, Maharashtra, India.

How to cite: Raghavendra SS, Jadhav GR, Gathani KM, Kotadia PR. Bioceramics in endodontics – a review. J Istanb Univ Fac Dent 2017;51(3 Suppl 1):S128-S137.

This work is licensed under a Creative Commons Attribution-NonCommercial-NoDerivatives 4.0 International License.
Introduction

The field of Endodontics is constantly changing due to introduction of new techniques and technological advances. Advances in endodontic material sciences contributes significantly to the exponential growth in endodontics. Bio-ceramics are amongst the recently introduced materials in endodontics which have changed the face of endodontics. Ceramics are inorganic, non-metallic materials made by the heating of raw minerals at high temperatures (1). Bio-ceramics are biocompatible ceramic materials or metal oxides with enhanced sealing ability, antibacterial and antifungal activity applied for use in medicine and dentistry. They have the ability to either function as human tissues or to resorb and encourage the regeneration of natural tissues. They include alumina and zirconia, bioactive glass, glass ceramics, calcium silicates, hydroxyapatite and resorbable calcium phosphates, and radiotherapy glasses (2, 3). Various classifications of bio-ceramic materials used in endodontics were given based on composition, setting mechanism and consistency. One of the simpler ways of classifying bioceramics is as follows (4, 5):

- **Bioinert**: non-interactive with biological systems (Alumina, zirconia)
- **Bioactive**: durable tissues that can undergo interfacial interactions with surrounding tissue (bioactive glasses, bioactive glass ceramics, hydroxyapatite, calcium silicates)
- **Biodegradable**: soluble or resorbable, eventually replaced or incorporated into tissue (Tricalcium phosphate, Bioactive glasses).

Advantages of Bioceramics

Excellent biocompatibility properties due to their similarity with biological hydroxyapatite.

Intrinsic osteoinductive capacity because of their ability to absorb osteoinductive substances if there is a bone healing process nearby.

Function as a regenerative scaffold of resorbable lattices which provide a framework that is eventually dissolved as the body rebuilds tissue.

Ability to achieve excellent hermetic seal, form a chemical bond with the tooth structure and have good radiopacity (6, 7).

Antibacterial properties as a result of precipitation in situ after setting, a phenomenon that leads to bacterial sequestration. Bioceramics form porous powders containing nanocrystals with diameters of 1-3 nm, which prevent bacterial adhesion. Sometimes, fluoride ions are constituents of apatite crystals, and the resulted nanomaterial has antibacterial properties (8).

**Bioceramics used in endodontics**

- Calcium silicate based – Cements- Portland Cement, Mineral trioxide aggregate (MTA), Biodentine (Septodont, France)
- Sealers - Endo CPM Sealer (EGO SRL, Buenos Aires, Argentina), MTA Fillapex (Angelus, Brazil), BioRoot RCS (Septodont, France), TechBiosealer (Profident, Kielce, Poland).
- Calcium phosphates/ tricalcium phosphate/ hydroxyapatite based

Mixed of calcium silicates and calcium phosphates - iRoot BP, iRoot BP Plus,iRoot FS (Innovative Bioceramix Inc., Vancouver, Canada), EndoSequence BC Sealer (Brasseler, Savannah, GA, USA)/ Total Fill (9), Bioaggregate (Innovative Bioceramix Inc., Vancouver, Canada), Tech Biosealer (6), Ceramicrete (developed at Argonne National Lab, Illinois, USA) (10).

**Calcium Silicate based bioceramics**

**Portland Cement**

In 1824, Joseph Aspdin patented a product called Portland cement (PC) obtained from the calcination of the mixture of limestones coming from Portland in England and silicon-argillaceous materials (11). PC is an inexpensive material and except for the absence of bismuth oxide and higher levels of calcium aluminate and calcium sulfate, PC and MTA have a similar main composition. PC like MTA is available as grey and white (12).

- **Discolouration**: Ordinary PC (grey) shows lesser discolouration compared to grey MTA. However there is an equal lack of discoloration seen by white MTA as well as white PC (13).
- **Solubility**: According to Vivaan et al., greater solubility is seen with MTA when compared to white PC (14). It also showed better washout resistance compared to MTA in different solutions (15).
- **Bioactivity**: Maturation of MTA after hydration is more structured than PC hence the former displays better bioactivity (16). Calcium ion release and formation of hydroxyapatite crystals is seen with both grey and white PC (6, 17).
Bioceramics in endodontics

Particle size- The particle size of white ProRoot MTA is significantly smaller than white PC both before and after hydration (18).

Antibacterial properties- PC shows antibacterial and antifungal properties similar to MTA against Enterococcus faecalis, Micrococcus luteus, Staphylococcus aureus, Staphylococcus epidermidis, Psuedomonasaeruginosa and Candida albicans (19).

Sealing ability - White and grey MTA had similar sealing ability as a root end filling material when checked by means of dye penetration when compared to white and grey PC (20). However, when checked as a perforation repair material by means of protein leakage, white PC showed better sealing ability compared to white and grey MTA.

Biocompatibility- Cell culture studies have showed variable result as per the cell type. Essentially there was no genotoxicity or cytotoxicity seen associated with PC similar to MTA with respect to fibroblasts (21). However, with respect to human bone marrow-derived mesenchymal stem cells, MTA displayed greater proliferation and migration compared to PC (22). Biomineralization is greater with MTA compared to PC when observed at 30 and 60 days (23). Pulpotomy performed with PC and MTA was successful both clinically and radiographically, but the root canals showed greater obliteration with PC (24).

Limitations- Higher amount of lead and arsenic released from PC along with reports of its high solubility compared to MTA has raised questions regarding its safety with respect to the surrounding tissues (19).

Higher solubility may jeopardise the long term seal of the restoration (25).

Excessive setting expansion with PC may lead to crack formation with the tooth (19).

Biomineralization with PC is not as effective and as long term as with MTA which is critical for a bioactive material (23).

Mineral trioxide aggregate (MTA)

The first bioceramic material successfully used in endodontics was the MTA cement which was introduced by Dr. Torabinejad in 1993. It is osseoconductive, inductive and biocompatible. This material was developed and recommended initially as a root-end filling material and subsequently has been used for pulp capping, pulpotomy, apicogenesis, apical barrier formation in teeth with open apexes, repair of root perforations, and as a root canal filling material. Up to 2002, only one MTA material consisting of grey colored powder (GMTA) was available. In that year, white MTA (WMTA) was introduced as ProRoot MTA (Dentsply Endodontics, Tulsa, OK, USA) to address discoloration of tooth associated with GMTA (26). In the first form, grey color is given by iron ions, which were later removed to obtain the white form. Setting reaction is by hydration, obtaining hydrated calcium silicate and calcium hydroxide which is released over time. Its biological integration is due to the ions of Ca, which form hydroxyapatite in contact with phosphate ions present in body (8).

Difference between grey and white MTA

WMTA was found to have 54.9% less Al₂O₃, 56.5% less MgO and 90.8% less FeO than GMTA, leading to the conclusion that the FeO reduction is most likely the cause for the color change. WMTA was also reported to possess overall smaller particle size than GMTA (27).

Physical properties

Compressive strength—~40 MPa at 24 hours and ~67 MPa at 21 days.

Setting reaction- MTA sets through an exothermic reaction, requiring hydration of its powder to produce the cement paste that matures over time. Most important reactions are tricalcium silicate and dicalcium silicate reacting with water to produce calcium silicate hydrates (C-S-H) and calcium hydroxide [Ca(OH)₂]. The bioactivity of MTA is attributed to hydration of the powder causing Ca²⁺ dissolution and diffusion, reaction product formation (C-S-H and Ca(OH)₂), and further reactions resulting in apatite formation. Calcium chloride accelerates the setting reaction while sodium hypochlorite hinders the formation of calcium hydroxide.

\[
2[3\text{CaO.SiO}_2] + 6\text{H}_2\text{O} \rightarrow 3\text{CaO.2SiO}_2.3\text{H}_2\text{O} + 3\text{Ca(OH)}_2
\]

\[
2[2\text{CaO.SiO}_2] + 4\text{H}_2\text{O} \rightarrow 3\text{CaO.2SiO}_2.3\text{H}_2\text{O} + \text{Ca(OH)}_2
\]

7\text{Ca(OH)}_2 + 3\text{Ca(H}_2\text{PO}_4)_2 \rightarrow \text{Ca}_{10}((\text{PO}_4)_6(\text{OH})_2) + 12\text{H}_2\text{O} \quad (28)

Setting time- The recommended powder liquid ratio for MTA is 3:1. The setting time of grey ProRoot MTA was reported by Torabinejad et al. as 2 hr and...
45 min (± 5 min) (28, 29). Islam et al. reported final setting times of 140 min (2 h and 20 min) for WMTA, and 175 min (2 h and 55 min) for GMTA (30). The presence of gypsum is reported to be the reason for the extended setting time. In order to reduce the setting time, the effect of accelerators such as sodium phosphate dibasic (Na$_2$HPO$_4$) and calcium chloride (CaCl$_2$) have been added to products like MTA Bio and then used as a rapid-setting material (31).

**pH**-Hydrated MTA products have an initial pH of 10.2, which rises to 12.5 three hours after mixing (27).

**Pushout bond strength**-The retentive strength of MTA is significantly less than that of glass ionomer or zinc phosphate cement and, thus, it is not considered to be a suitable luting agent. Studies have shown that a 4-mm thickness of MTA (apical barrier) offered more resistance to displacement than a 1-mm thickness (32). Aggarwal V et al. found the push-out bond strength of MTA after 24 hours to be ~5.2 ± 0.4 MPa (33). The strength significantly increased to 9.0 ± 0.9 MPa after the samples were allowed to set for 7 days.

**Flexural strength**-According to Walker et al., placement of moist cotton pellet over the setting MTA for 24 hours showed significant increase in flexural strength, i.e. ~14.27±1.96 MPa (34).

**Porosity**-The amount of porosity in mixed cement is related to the amount of water added to make a paste, entrapment of air bubbles during the mixing procedure, or the environmental acidic pH value (35).

**Microhardness**-Less humidity, low pH values, the presence of a chelating agent and more condensation pressure might adversely affect MTA microhardness (36).

**Sealing ability**-The majority of the dye and fluid filtration studies suggest that MTA materials overall allow less microleakage than traditional materials when used as an apical restoration while providing equivalent protection as a ZOE preparation when used to repair furcation perforations. GMTA and WMTA were shown to provide equivocal results compared against gutta-percha when used as a root canal obturation material in microleakage studies. No significant leakage is observed when at least 3 mm of MTA remained after root-end resection. However, significantly more leakage is seen when 2 mm or less thickness of MTA remained after root-end resection (27).

**Particle size**-The physical properties of cement might be influenced by crystal size. Smaller sized particles increase surface contact with the liquid and lead to greater early strength as well as ease of handling. Some particles of MTA are as small as 1.5 mm, which is smaller than the diameter of some dentinal tubules. WMTA has finer particles in comparison to GMTA. Particle sizes might affect the handling characteristics of these materials (19).

**Biocompatibility**-MTAs are non-mutagenic and non-neurotoxic and do not produce a side effect on microcirculation. Both animal and human investigations have confirmed the encouraging role of MTA on the production of signalling molecules. MTA is found to have anti-inflammatory effects on pulp tissue and cementoconductive, cementoinductive and osteoconductive effects have been confirmed (36).

**Advantages**-Forms Calcium Hydroxide that releases calcium ions for cell attachment and proliferation

- Creates an antibacterial environment by its alkaline pH
- Modulates cytokine production
- Encourages differentiation and migration of hard tissue–producing cells and
  - Forms Hydroxyapatite (or carbonated apatite) on the MTA surface and provides a biologic seal (36).

**Limitations**-Long setting time (37, 38)

- Difficult handling and high cost
- Potential tooth discoloration (39).

- Absence of a known solvent for this material (40), and
- Difficulty of its removal after placement (36).

**Biodentine**

‘Biodentine’ is a calcium silicate based product which became commercially available in 2009 (Septodont, Saint Maur des Fosses, France). The material is formulated using the MTA-based cement technology and the improvement of some properties of these types of cements, such as physical qualities and handling.

**Setting reaction**- The setting reaction of Biodentine is similar to MTA with the formation of calcium silicate hydrate gel (C–S–H) and calcium hydroxide. However, calcium carbonate acts as a nucleation site for calcium-silicate-hydrate gel, thereby reducing the duration of the induction period, leading to a faster setting time and enhancing the
Bioceramics in endodontics

Microstructure. The hydrosoluble polymer reduces the viscosity of the cement and improves handling (41).

Setting time—The working time of Biodentine is up to 6 minutes with an initial setting period of 9–12 minutes and final setting time of 45 minutes. This shorter setting time is an improvement compared to other calcium silicate materials. This is due to the addition of calcium chloride to the mixing liquid. Calcium chloride has also been shown to result in accelerated setting time for MTA (42).

Compressive strength—There is a sharp increase in the compressive strength reaching more than 100 MPa in the first hour. The mechanical strength continues to improve to reach more than 200 MPa at 24h which is more than the value of most Glass Ionomers. Biodentine has the capacity to continue improving with time over several days until reaching 300 MPa after one month. This value becomes quite stable and is in the range of the compressive strength of natural dentin (297 MPa) (43).

Elastic modulus - 22.0GPa, very similar to that of dentin at 18.5GPa (44).

Microhardness - After 2 hours, the hardness of Biodentine was 51 VHN and reached 69 VHN after 1 month. The reported micro hardness values for natural dentin are in the range of 60-90 VHN (43).

Sealing ability—The micromechanical adhesion of Biodentine is caused by the alkaline effect during the setting reaction which causes organic tissues to dissolve out of the dentin tubule. The alkaline environment between Biodentine and hard tooth substance clears a path through which the dentin substitute mass can enter the exposed opening of the dentin canaliculi. This enables Biodentine to be keyed to the dentine by means of innumerable microscopic cones, creating a stable anchorage with a sealing, bacteria-tight effect (44).

Push Out Bond Strength—Biodentine has more push-out bond strength than MTA at 24 hrs. Blood contamination affected the push-out bond strength of MTA Plus irrespective of the setting time. A favourable feature of Biodentine was that blood contamination had no effect on the push-out bond strength, irrespective of the duration of setting time (44).

Flexural strength—The value of the bending obtained with Biodentine after 2 hours was 34 MPa as compared with other materials such as 5-25 MPa for Conventional Glass Ionomer Cement; 17-54 MPa for Resin modified GIC and 61-182 MPa for Composite resin (19). Hence it was concluded that the bending resistance of Biodentine is superior to conventional GIC, but still much lower than the composite resin (42).

Antibacterial activity and pH—Calcium hydroxide ions released from cement during setting phase of Biodentine increases pH to 12.5 which inhibits the growth of microorganisms and can disinfect the dentin (43).

Biocompatibility—Biodentine is non-toxic and has no adverse effects on cell differentiation and specific cell function. It increases TGF-B1 (growth factor) secretion from pulp cells which causes angiogenesis, recruitment of progenitor cells, cell differentiation and mineralization (42).

Advantages of Biodentine over MTA

Consistency ensures improved handling which is better suited to the clinical use than MTA.

Exhibits better mechanical properties than MTA.

Does not require a two-step restoration procedure as in the case of MTA.

As the setting is faster, there is a lower risk of bacterial contamination than with MTA (42).

Experimental calcium alumino-silicates

EndoBinder (45)

A new calcium aluminate-based endodontic cement, called EndoBinder (Binderware, São Carlos, SP, Brazil), has been developed with the intention of preserving the properties and clinical applications of MTA eliminating its negative characteristics. EndoBinder is produced with high levels of purity, eliminating traces of free magnesium oxide (MgO) and calcium oxide (CaO), which are responsible for the undesired expansion of the material, and ferric oxide (Fe₂O₃), which is responsible for tooth darkening. Among recent materials, EndoBinder presented satisfactory tissue reaction; it was biocompatible when tested in subcutaneous tissue of rats.

Generex A (45)

Generex A (Dentsply Tulsa Dental Specialties, Tulsa, OK, USA) is a calcium-silicate-based material that has some similarities to ProRoot MTA but is mixed with unique gels instead of water used for
MTA. Generex A material has very different handling properties in comparison to MTA. Generex A mixes to a dough-like consistency, making it easy to roll into a rope-like mass similar to intermediate restorative material.

**Capasio (45)**

Capasio (Primus Consulting, Bradenton, FL, USA) is composed primarily of bismuth oxide, dental glass and calcium alumino-silicate with a silica and polyvinyl acetate-based gel. A recent study found that Capasio and MTA promote apatite deposition when exposed to synthetic tissue fluid thus had the mineralization capacity. The same researchers also concluded that when used as a root-end filling material, Capasio is more likely to penetrate dentinal tubules. Another study compared Generex A, Generex B, Capasio along with Ceramicrete-D (magnesium phosphate based) using primary osteoblasts. Generex A was the only new generation endodontic material that supported primary osteoblast growth. No material besides MTA facilitated nodule formation. Only Generex A and MTA allowed cell growth and proliferation throughout the experiment.

**Quick-Set (45)**

Recently, Capasio powder has been refined and renamed as Quick-Set (Primus Consulting), and the cationic surfactant was removed from the liquid gel component, which was thought to interfere with cytocompatibility. In a contemporary research using odontoblast-like cells, Quick-Set and MTA exhibited similar cytotoxicity profiles. They possess negligible in vitro toxicological risks after time-dependent elution of toxic components.

**Root-end filling material using epoxy resin and Portland cement (EPC) (45)**

EPC, a novel composite made from a mixture of epoxy resin and Portland cement, was found to be a useful material for root-end filling, with favorable radio-opacity, short setting time, low microleakage and clinically acceptable low cytotoxicity.

**Calcium phosphate based bioceramics (46)**

It was reported that a triple calcium phosphate compound used in a bony defect promoted osteogenesis or new bone formation. In 1971, Hench (47) developed a calcium-and-phosphate-containing glass ceramic, referred to as Bioglass, and showed that it ‘chemically’ bonded with the host bone through acalium phosphate-rich layer.

**Classification**—Based on porosity – Dense or porous

**Based on resorbability** – Non-resorbable (Hydroxypatite), Resorbable (β-TricalciumPhosphate)

**Compressive strength**—Porous- 30-170 MPa, Dense- 120-917 MPa.

**Uses**

Bone substitute or bone graft material
Pulp-capping materials
Active restorative materials containing ACP as filler encapsulated in a polymer binder was developed which stimulated the repair of tooth structure because of releasing significant amounts of calcium and phosphate ions in a sustained manner (48).

**Limitations**—The main limitation of the calcium phosphate ceramics is their lack of strength, causing them to have fatigue fracture and to fail in load-bearing situations (46).

**Mixture of calcium silicates and calcium phosphates**

**Bioaggregate**

BioAggregate (Verio Dental Co. Ltd., Vancouver, Canada) is composed of nano particle sized tricalcium silicate, tantalum oxide, calcium phosphate, silicon dioxide and presents improved performance compared with MTA. Tricalcium silicate is the main component phase, tantalum oxide is added as a radiopacifier and it is free of aluminium (12).

**Setting reaction**—On hydration, the tricalcium silicate produces calcium silicate hydrate and calcium hydroxide. The former is deposited around the cement grains, while the latter reacts with the silicon dioxide to form additional calcium silicate hydrate. This results in reduction of calcium hydroxide in the aged cement. MTA Angelus reacts in a similar fashion; however, since it contained no additives, the calcium hydroxide was still present in the aged cement (49).

**Biocompatibility**—Bioactivity was demonstrated by deposition of hydroxyapatite. The tantalum oxide as
opposed to bismuth oxide was inert, and tantalum was not leached in solution (49).

**Differences between MTA and Bioaggregate—**

As opposed to MTA Angelus, BioAggregate does not contain aluminium and contains additives such as calcium phosphate and silicon dioxide. MTA Angelus exhibited the presence of aluminium, while BioAggregate had phosphorus.

BioAggregate exhibits high calcium ion release early, which is maintained over the 28-day period as opposed to MTA Angelus, which demonstrated low early calcium ion release which increased as the material aged.

Reactivity of BioAggregate was slower when compared to MTA (49).

BioAggregate is more biocompatible, has better sealing ability, higher fracture and acidic resistance than MTA (50).

BioAggregate exerts a greater potential to induce odontoblastic differentiation and mineralization than that of MTA in pulp capping (51).

**Ceramicrete**

Ceramicrete is a self-setting phosphate ceramic developed at the Argonne National Laboratory, Illinois, USA, that sets in an ambient condition formed by acid-base reaction between an acid phosphate (KH₂PO₄) and a negligible soluble basic metal oxide (calcined MgO). More recently, a biocompatible, radiopaque Ceramicrete-based dental/bone material has been created by incorporating hydroxyapatite powder and cerium oxide radiopaque filler into the phosphosilicate ceramic.

**Setting time—**The Ceramicrete-based material has an initial setting time of 6 min and a final setting time of 12 min. It can also be rolled into a sausage-like formation for easier manipulation with dental instruments and sets under water with minimal washout.

**Sealing ability—**A modified version of the material (Ceramicrete D) was introduced by mixing the powder with deionized water. The sealing ability of Ceramicrete D was reported to be favorable. In another study by Leal et al. (52), two endodontic bioceramic repair cements (Bioaggregate and Ceramicrete D) displayed similar leakage results to white MTA when used as root-end fillings materials. Ceramicrete D had significantly lower glucose penetration.

Physical and chemical analyses showed that the clinical handling and washout resistant of the Ceramicrete D were superior to those of MTA; however, it was weaker, less radiopaque, and initially more acidic than Generex A and Capasio.

**Calcium enriched mixture (10)**

Asgary et al. introduced new endodontic cement in 2008 to combine the superior biocompatibility of MTA with appropriate setting time (less than 1 h), handling characteristics, chemical properties, and reasonable price (53). This newly formulated biomaterial, named calcium-enriched mixture (CEM) cement (BioniqueDent, Tehran, Iran), was made using different calcium compounds.

**Setting reaction—**The manufacturer claimed that the mixed paste of CEM is not sticky; it does not tend to adhere to the applicator and can be easily condensed by the operator. In addition, some calcium compounds in CEM such as calcium sulfate and calcium silicate may cause a slight expansion of the material through continuous hydration after initial setting of the material and further crystalline maturation. CEM comprises water-soluble calcium and phosphate ions and forms hydroxyapatite after setting.

**Sealing ability—**Its sealing ability as a root-end filling material was comparable with MTA. However, CEM showed superior sealing ability compared to MTA in presence of saliva contaminations (54).

**Antibacterial activity—**Antimicrobial properties of CEM against gram-negative, gram-positive, and cocci/bacilli bacteria were compared with MTA and calcium hydroxide (CH) using agar diffusion test. Results showed comparable antibacterial effects with CH and significantly better results than MTA (55).

**Biocompatibility—**In addition, recent studies in cell culture revealed its cytotoxicity to be within acceptable range, suitable biocompatibility and ability to induce hard tissue formation. The results of in vivo studies on dogs showed that as pulp capping materials, MTA and CEM showed similar favorable biological outcomes, and both better than CH especially in terms of inducing the formation of the dentinal bridge (56).

**EndoSequence Root Repair Material/irootSP/irootBP (10)**

Recently, a new root repair material has been introduced to the market, namely, EndoSequence Root Repair Material (ERRM; Brasseler, Savannah, GA). It is also available as iRoot SP injectable root canal sealer and iRoot BP Plus putty root canal filling and repair material.

**Composition—**According to the manufacturer, it is composed of calcium silicate, monobasic calcium phosphate, zirconium oxide, tantalum oxide and filler agents and is available as paste in preloaded syringes and also in a moldable putty form.
Setting time- According to the manufacturer’s instructions, it has a working time of 30 min and a setting reaction initiated by moisture with a final set achieved approximately 4 hrs thereafter.

Sealing ability- Sealing ability of this novel material was compared with MTA was compared by Hirschberg CS et al. using a bacterial leakage model and it was concluded that samples in ERRM group leaked significantly more than those in MTA group (57).

Antibacterial activity- Antibacterial activity of ERRM was compared with MTA, and results demonstrated similar antimicrobial properties during their setting reaction against ten clinical strains of E faecalis (58).

Biocompatibility- ERRM material did not exhibit cytotoxic effects on human gingival fibroblasts when compared with MTA Angelus and Intermediate Restorative Material (59).

Uses of Bioceramics

Prosthetic uses- implants, prosthesis, prosthetic devices, coatings to improve the biocompatibility of metal implants (52).

Surgical uses – joint replacements, fill surgical bone defects, alveolar ridge augmentation, sinus obliteration, and correction of orbital floor fracture.

Endodontic uses- sealers, obturation, perforation repair, retrograde filling, pulpotomy, resorption, apexification, regenerative endodontics.

Restorative uses- Dentin substitute, pulp capping, dentin hypersensitivity, dentin remineralization (3, 6).

Conclusion

While MTA was the benchmark in bioceramic materials, material advances have constantly tried to overcome disadvantages and improve its properties. Bioceramics now have a wide array of applications both in endodontics and restorative dentistry. An up-to-date knowledge of these new bioactive materials is essential to ensure the selection of the most suitable material in different clinical situations.

Source of funding
None declared.

Conflict of interest
None declared.

References
1. Shenoy A, Shenoy N. Dental ceramics: An update. J Conserv Dent 2010;13(4):195-203.
2. Nasseh A. The rise of bioceramics. Endod Practice 2009;2:17-22.
3. Jain P, Ranjan M. The rise of bioceramics in endodontics: A review. Int J Pharm Bio Sci 2015;6(1):416-422.
4. Best SM, Porter AE, Thian ES, Huang J. Bioceramics: Past, present and for the future. J Eur Ceram Soc 2008;28:1319-1327.
5. Hench L, Wilson J. An introduction to bioceramics. Singapore: World Scientific, 1993.
6. Prati C, Gandolfi MG. Calcium silicate bioactive cements: Biological perspectives and clinical applications. Dent Mater 2015;31(4):351-370.
7. Utneja S, Nawal RR, Talwar S, Verma M. Current perspectives of bio-ceramic technology in endodontics: Calcium enriched mixture cement - review of its composition, properties and applications. Restor Dent Endod 2015;40(1):1-13.
8. Jitaru S, Hodisan I, Timis L, Lucian A, Bud M. The use of bioceramics in endodontics - literature review. Clujul Med 2016;89(4):470-473.
9. Tanomaru-Filho M, Viapiana R, Guerreiro-Tanomaru JM. From mta to new biomaterials based on calcium silicate. Odontos-Int J Dent Sci 2015;17(1):10-14.
10. Ghoddusi J. Material modifications and related materials. Berlin Heidelberg: Springer, 2014.
11. Viola NV, Tanomaru Filho M, Cerri PS. MTA versus portland cement: Review of literature. Rev Sul-bras Odontol 2011;8(4):446-452.
12. Parirokh M, Torabinejad M. Calcium silicate–based cements in mineral trioxide aggregate: Properties and clinical applications. Hoboken, NJ, USA: John Wiley & Sons, 2014.
13. Lenherr P, Allgayer N, Weiger R, Filippi A, Attin T, Krastl G. Tooth discoloration induced by endodontic materials: A laboratory study. Int Endod J 2012;45(10):942-949.
14. Vivian RR, Zapata RO, Zeferino MA, Bramante CM, Bernardineli N, Garcia RB, Hungaro Duarte MA, Tanomaru Filho M, Gomes de Moraes I. Evaluation of the physical and chemical properties of two commercial and three experimental root-end filling materials. Oral Surg Oral Med Oral Pathol Oral Radiol Endod 2010;110(2):250-256.
15. Formosa LM, Mallia B, Camilleri J. A quantitative method for determining the antiwashout
Bioceramics in endodontics

characteristics of cement-based dental materials including mineral trioxide aggregate. Int Endod J 2013;46(2):179-186.

16. Formosa LM, Mallia B, Bull T, Camilleri J. The microstructure and surface morphology of radiopaque tricalcium silicate cement exposed to different curing conditions. Dent Mater 2012;28(5):584-595.

17. Massi S, Tanomaru-Filho M, Silva GF, Duarte MA, Grizzo LT, Buzalaf MA, Guerreiro-Tanomaru JM. Ph, calcium ion release, and setting time of an experimental mineral trioxide aggregate-based root canal sealer. J Endod 2011;37(6):844-846.

18. Asgary S, Parirlokh M, Eghbal MJ, Brink F. Chemical differences between white and gray mineral trioxide aggregate. J Endod 2005;31(2):101-103.

19. Parirlokh M, Torabinejad M. Mineral trioxide aggregate: A comprehensive literature review--part i: Chemical, physical, and antibacterial properties. J Endod 2010;36(1):16-27.

20. Shahi S, Rahimi S, Hasan M, Shiezaadeh V, Abdolahimi M. Sealing ability of mineral trioxide aggregate and portland cement for furcal perforation repair: A protein leakage study. J Oral Sci 2009;51(4):601-606.

21. Fayazi S, Ostad SN, Razmi H. Effect of proroot mta, portland cement, and amalgam on the expression of fibronectin, collagen i, and tgfbeta by human periodontal ligament fibroblasts in vitro. Indian J Dent Res 2011;22(2):190-194.

22. D’Anto V, Di Caprio MP, Ametrano G, Simone M, Rengo S, Spagnuolo G. Effect of mineral trioxide aggregate on mesenchymal stem cells. J Endod 2010;36(11):1839-1843.

23. Dreger LA, Felippe WT, Reyes-Carmona JF, Felippe GS, Bortoluzzi EA, Felippe MC. Mineral trioxide aggregate and portland cement promote biomineralization in vivo. J Endod 2012;38(3):324-329.

24. Sakai VT, Moretti AB, Oliveira TM, Fornetti AP, Santos CF, Machado MA, Abdo RC. Pulpotomy of human primary molars with mta and portland cement: A randomised controlled trial. Br Dent J 2009;207(3):E5; discussion 128-129.

25. Borges AH, Pedro FL, Miranda CE, Semenoff-Segundo A, Pecora JD, Filho AM. Comparative study of physico-chemical properties of mta-based and portland cements. Acta Odontol Latinoam 2010;23(3):175-181.

26. Emine ST, Tuba UA. White mineral trioxide aggregate pulpotomies: Two case reports with long-term follow-up. Contemp Clin Dent 2011;2(4):381-384.

27. Roberts HW, Toth JM, Berzins DW, Charlton DG. Mineral trioxide aggregate material use in endodontic treatment: A review of the literature. Dent Mater 2008;24(2):149-164.

28. Torabinejad M, Hong CU, McDonald F, Pitt Ford TR. Physical and chemical properties of a new root-end filling material. J Endod 1995;21(7):349-353.

29. Zapf AM, Chedella SC, Berzins DW. Effect of additives on mineral trioxide aggregate setting reaction product formation. J Endod 2015;41(1):88-91.

30. Islam I, Chng HK, Yap AU. Comparison of the physical and mechanical properties of mta and portland cement. J Endod 2006;32(3):193-197.

31. De-Deus G, Reis C, Brandao C, Fidel S, Fidel RA. The ability of portland cement, mta, and mta bio to prevent through-and-through fluid movement in repaired furcal perforations. J Endod 2007;33(11):1374-1377.

32. Malhotra N, Aggarwal A, Mala K. Mineral trioxide aggregate: A review of physical properties. Compend Contin Educ Dent 2013;34(2):e25-32.

33. Aggarwal V, Singla M, Miglani S, Kohli S. Comparative evaluation of push-out bond strength of proroot mta, biodentine, and mta plus in furcation perforation repair. J Conserv Dent 2013;16(5):462-465.

34. Walker MP, Diliberto A, Lee C. Effect of setting conditions on mineral trioxide aggregate flexural strength. J Endod 2006;32(4):334-336.

35. Torabinejad M, Parirlokh M. Mineral trioxide aggregate: A comprehensive literature review--part II: Leakage and biocompatibility investigations. J Endod 2010;36(2):190-202.

36. Parirlokh M, Torabinejad M. Mineral trioxide aggregate: A comprehensive literature review--part III: Clinical applications, drawbacks, and mechanism of action. J Endod 2010;36(3):400-413.

37. Funteas UR, Wallace JA, Fochtman EW. A comparative analysis of mineral trioxide aggregate and portland cement. Aust Dent J 2003;29(1):43-44.

38. Makkar S, Vashisht R, Kalsi A, Gupta P. The effect of altered ph on push-out bond strength of biodentine, glass ionomer cement, mineral trioxide aggregate and theracal. Serb Dent J 2015;62(1):7-13.

39. Camilleri J. The chemical composition of mineral trioxide aggregate. J Conserv Dent 2008;11(4):141-143.
40. Macwan C, Deshpande A. Mineral trioxide aggregate (mta) in dentistry: A review of literature. J Oral Res Rev 2014;6:71-74.
41. Malkondu O, Karapinar Kazandag M, Kazazoglu E. A review on biodentine, a contemporary dentine replacement and repair material. Biomed Res Int 2014;2014:160951.
42. Singh H, Kaur M, Markan S, Kapoor P. Biodentine: A promising dentin substitute. J Interdiscipl Med Dent Sci 2014;2:140.
43. Arora V, Nikhil V, Sharma N, Arora P. Bioactive dentin replacement. J Dent Med Sci 2013;12:51-57.
44. Ranjan M. Review on biodentine-a bioactive dentin substitute. J Dent Med Sci 2014;13(1):13-17.
45. Saxena P, Gupta SK, Newaskar V. Biocompatibility of root-end filling materials: Recent update. Restor Dent Endod 2013;38(3):119-127.
46. LeGeros RZ. Calcium phosphate materials in restorative dentistry: A review. Adv Dent Res 1988;2(1):164-180.
47. Hench LL. Bioceramics: From concept to clinic. J Am Ceram Soc 1991;74(7):1487-1510.
48. Skrtic D, Antonucci JM, Eanes ED, Eichmiller FC, Schumacher GE. Physicochemical evaluation of bioactive polymeric composites based on hybrid amorphous calcium phosphates. J Biomed Mater Res 2000;53(4):381-391.
49. Camilleri J, Sorrentino F, Damidot D. Characterization of un-hydrated and hydrated bioaggregate and mta angelus. Clin Oral Investig 2015;19(3):689-698.
50. Tuloglu N, Bayrak S. Comparative evaluation of mineral trioxide aggregate and bioaggregate as apical barrier material in traumatized nonvital, immature teeth: A clinical pilot study. Niger J Clin Pract 2016;11(4):332-335.
51. Asgary S, Akbari Kamrani F, Taheri S. Evaluation of antimicrobial effect of mta, calcium hydroxide, and cement. Iran Endod J 2007;2(3):105-109.
52. Asgary S, Parirokh M, Eghbali MJ, Ghoddusi J. Sem evaluation of pulp reaction to different pulp capping materials in dog’s teeth. Iran Endod J 2006;1(4):117-123.
53. Hirschberg CS, Patel NS, Patel LM, Kadouri DE, Hartwell GR. Comparison of sealing ability of mta and endosequence bioceramic root repair material: A bacterial leakage study. Quintessence Int 2013;44(5):e157-162.
54. Lovato KF, Sedgley CM. Antibacterial activity of endosequence root repair material and proroot mta against clinical isolates of enterococcus faecalis. J Endod 2011;37(11):1542-1546.
55. Martinez-Cortes M T-MC, Rosales C, Uribe-Querol E. Cytotoxicity assessment of 3 endodontic sealing cements used in periapical surgery. Revista Odontologica Mexicana 2017;21(1):e40-e48.

Corresponding Author:
Srinidhi Surya RAGHAVENDRA
Dept of Conservative Dentistry & Endodontics, Sinhgad Dental College and Hospital, Pune, Maharashtra, India.
Phone:+91 9372342232
e-mail: srinidhi73@gmail.com