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Bioceramic a futuristic boon in endodontics - A review

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***Abstract*---**Background**:** The ultimate goal of root canal treatment is prevention or healing of apical periodontitis. The use of biologically active materials to seal root canal systems has been extensively proposed in contemporary endodontics to realise this goal. There are several commercial formulations of bioceramics available based on minor variations in composition which could have potentially important changes in properties in the clinical situation. This narrative review serves to provide brief information on the different formulations of bioactive ceramics that are available to a dentist. Aim**:** To give an overview of bioceramics used in endodontics, their classification, advantages and disadvantages. This review also gives insights about each biomaterial in detail and its use in endodontics. Review Results: Continuous innovations have led to bioceramics showing a variety of applications in both endodontic and restorative

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dentistry. While MTA was the benchmark in bioceramics materials, material advances have constantly tried to overcome disadvantages and improve its properties. Conclusion: Bioceramics now have a wide array of applications both in endodontics and restorative dentistry. However, considering the biological advantages of bioceramics materials, their use in multiple paradigms of endodontic therapy appears to be the future. Clinical Significance: It is important for clinicians to understand that in the world of continuous innovation, successful outcome of root canal treatment can be achieved.

***Keywords*---**Biomaterial, Bioceramic, Endodontics.

Introduction

A biomaterial is a substance that has been engineered to take a form which, alone or as part of a complex system, is used to direct, by control of interactions with components of living systems, the course of any therapeutic or diagnostic procedure, in human or veterinary medicine.[1]

During the past 30- 40 years there has been a major advance in the development of medical materials and this has been in the innovation of ceramic materials for skeletal repair and reconstruction. The materials within this class of medical implant are often referred to as “Bioceramics”.[2] It is defined as a type of biomaterial with optimal biocompatibility that is used for medical and dental purposes. Newly developed techniques and technology allow the majority of skilled dentists to produce stellar endodontic results.[3] In general, all solids are divided into four major groups of materials: metals, polymers ceramics and composites. Similarly, all biomaterials are also divided into the same major groups: bio-metals, biopolymers, bio-ceramics and bio-composites. All of them play very important roles in replacement and regeneration of human tissues.[4]

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.[5,6]

There has been an increasing trend towards the application of bioceramics in medical and dental fields. In bone tissue engineering, they have been used as bone surrogates, bone implants and as a composition of artificial joints. They are also used in making artificial heart valves. In dentistry, they are widely used as compositions of implants and periodontal surgeries, i.e. for alveolar ridge augmentation.[8] Since 1993, the field of endodontics has seen a huge influx of this category of materials with a wide array of applications. The first endodontic use of this class of materials was in the form of Mineral Trioxide Aggregate (MTA), used for perforation repair and root end filling.[9-11] An extensive literature search on Medline revealed 1958 articles on MTA as on September 15, 2016. In general, it has been widely noted that MTA has excellent biocompatibility and sealing ability owing to its bioactive nature. This material is now considered the gold standard for direct pulp capping, perforation repair, root-end filling and apexification.[7] Nevertheless, MTA does have disadvantages including long setting time, low cohesive strength and poor handling properties.[12] The possibility of biocompatibility issues due to heavy metal leaching[13] and coronal discoloration[14,15] have also been reported.

Table 1
Different Types of Bioceramics used in Endodontics

Calcium-silicate based	Calcium-phosphate based	Mixture of Calcium silicate and Calcium Phosphates	Experimental calcium alumino slilicates
● Cements: MTA, Portland cement, biodentine, ProRoot MTA, Endocem MTA ● Sealers: Endo CPM sealer, MTA Fillapex, BioRoot RCS, TechBiosealer and EndoCem.	● Tricalcium phosphate	● EndoSequence Root Repair Material (ERRM) ● Bioceramic Root Repair Material ● EndoSequence BC Sealer ● Total Fill, Bioaggregate ● Tech Biosealer	● Generex A ● Capasio ● Quick-set ● Root end filling material using epoxy resin and Portland cement

Review Results

Characteristics of an optimal material for endodontic use:[7]

1. A short setting time can help facilitate a tight seal between the root canal system and the periodontium, while a long setting time may result in difficulties with maintaining consistency of the mixture.
2. High compressive strength of a root repair material could enable it to withstand loads tending to deformation and shrinkage.
3. An alkaline pH and calcium ion release are desired during the setting reaction of any material that is permanently sealed in the root canal.
4. An ideal root canal filling and sealing material should have a certain degree of radiopacity to be clearly visible on radiographs.
5. Lack of solubility is a desired characteristic for root-end filling materials and materials used for perforation repair.
6. The material should be compatible with surrounding hard and soft tissues.

Bioceramic materials used as Cements

Table 1 gives the classification of the Biocermaic materials used in endodontics.

Calcium-Silicate Based Materials:

1. **ProRoot MTA** (Dentsply Tulsa Dental, Tulsa, OK, USA): ProRoot MTA is considered a prototype of bioceramics in endodontics. It was developed and first introduced in Loma Linda University, USA in 1993, and was patent registered in 1995. The white ProRoot MTA or tooth-colored

ProRoot MTA was later developed in 2002. ProRoot MTA is one of the most widely researched endodontic materials, including short- and long-term treatment outcome studies.[10-12,16-21] ProRoot MTA has been shown to demonstrate the least cytotoxicity and leakage compared with other materials, and has been proven to induce osteogenesis and cementogenesis.[22,23] The compressive strength of MTA was about 40 MPa at 24 hours and 67.3 MPa at three weeks.[16] Clinical applications of ProRoot MTA in endodontics included pulp protection in vital pulp therapy, perforation and resorption repair, apexification, revascularization and root end filling during apicectomy.[24]

2. **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.[25] PC shows antibacterial and antifungal properties similar to MTA against *Enterococcusfaecalis*, *Micrococcus luteus*, *Staphylococcus aureus*, *Staphylococcus epidermidis, Psuedomonasaeruginosa* and *Candida albicans*. However, its limitation of higher amount of lead and arsenic release along with reports of its high solubility compared to MTA has raised questions regarding its safety with respect to the surrounding tissues.[26]

3. **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, apexogenesis, apical barrier formation in teeth with open apex 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.[27]

4. **MTA Plus and NeoMTA Plus:** With an increasing body of evidence demonstrating the biomineralisation properties of tricalcium silicates, the application of MTA logically extended to being used as root canal sealers.[7] ProRoot MTA and MTA Angelus were not intended to be applied as root canal sealers. A new group of cost-effective materials (MTA Plus and NeoMTA Plus) were introduced into the market for all conceivable applications of bioactive ceramic materials (vital pulp therapy, apexification, root end filling, perforation repair, resorption management and root canal sealer. While the basic composition of MTA Plus is similar to that of the original MTA, there are two main differences: the powder of MTA Plus is finer and it is recommended that the MTA powder be mixed with a proprietary water-based gel when the material is to be used as a root canal sealer)[28,29] This gel contains film forming polymers and accelerators but no salts. Currently, three variants of this material are available: Gray MTA Plus, MTA Plus and NeoMTA Plus.

5. **Biodentine:** It 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.[30] 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.[31] 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.[32] Biodentine exhibits better mechanical properties than MTA as well as lower setting time and does not require two-step restoration.[31]

Experimental Calcium Alumino-Silicates:[33,34]

1. **Endobinder:** 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.

2. **Generex A:** 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.

3. **Capasio:** 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.

4. **Quickcset**: 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 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.

Calcium Phosphate Based Bioceramics

In 1971, Hench[35] developed a calcium-and-phosphate-containing glass ceramic, referred to as Bioglass, and showed that it 'chemically' bonded with the host bone through a calcium phosphate-rich layer. 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.[36] 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.[37]

Mixture of Calcium Silicates and Calcium Phosphates:

1. **Bioaggregate:** It 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.[38]
   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.[39]

2. **EndoSequence Root Repair Material/ IrootSP/ IrootBP:** 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.[40] Its antibacterial activity was compared with MTA, and results demonstrated similar antimicrobial properties during their setting reaction against ten clinical strains of E faecalis.[41]

3. **Calcium-Enriched Mixture:** 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.[42] Antimicrobial properties of CEM against gram-negative, gram-positive, and cocci/bacilli bacteria are better compared to MTA and calcium hydroxide.[43]

Discussion

Apart from use of bioceramics as cements, they are also used as root canal sealing materials. These sealers provide certain advantages as they are exceedingly biocompatible, nontoxic, antibacterial, hydrophilic, chemically stable and do not shrink on setting. Although some limitations are also present such as release of higher amount of lead and arsenic, excessive setting expansion, etc.[3]

Gutta-percha in combination with various types of root canal sealers has been the dominant root canal filling since mid-nineteenth century. However, with an increasing knowledge of root canal anatomy as well as the simplified matched cone obturation techniques, one relies on the sealer for providing a suitable seal which is oftentimes considered elusive.[44]

Recently, nano-particle bioceramic impregnated and coated gutta-percha points (Endosequence BC Gutta-Percha) have been developed to be used with Endosequence BC sealer under a "hydraulic condensation technique". Advantages of this technique are: The remaining moisture in the canal and the natural moisture in the dentine enhances setting of the cement as the bioceramic sealer is highly hydrophilic; high pH above 12 of the sealer prior to setting gives rise to its antimicrobial properties; the sealer does not shrink but slightly expands, and it is insoluble in the presence of tissue fluids, thus allowing more amount of the sealer to be coated over the gutta-percha[45]

Clinical Significance

Since the introduction of the first bioceramic material, MTA, in the 1990s, bioceramic cements have increasingly taken on many important tasks in endodontic treatment. Bioceramic cements have become de facto materials of choice in the treatment of teeth with open apexes, accidental or resorption perforations, pulp capping, retrograde fillings, and as high quality sealing materials in regenerative endodontics. Staining of tooth structure and slow setting times have been some of the potential downsides of the bioceramic cements, depending on the clinical situation. New BC materials seem to show improvement with regard to these challenges. While experimental research has produced promising data on the biological and mechanical characteristics of bioceramic cements, long-term clinical studies are needed to confirm the promising potential shown in clinical experience and in vitro studies.

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