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Research Article

Endodontic Bioceramic Sealers - Evolution and Future Directions

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Abstract

An important factor in the outcome of endodontic treatments consists in the techniques and materials used for root canal obturation. Numerous endodontic sealers have been created over the years, each with special qualities, benefits, and drawbacks. From this point of view, it can be stated that the emergence and introduction of bioceramic materials in endodontics have changed to a good extent our approach. Continuous innovations have led to successive generations and different classes of bioceramic sealers that have been increasingly used in clinical endodontics. This article reviews the latest progress in bioceramic sealers, focusing on their clinical performance, material science innovations, and the implications for future endodontic practice. These materials are discussed starting with their introduction, and then analysing their physico-chemical characteristics, clinical uses, most recent developments, potential future paths, and research suggestions.

Keywords: Biomaterials; Bioceramic Materials; Endodontic Sealer

The term "biomaterials" encompasses materials that interact with biological systems, whether they are found in nature or not and can be made from living substances or non-living components. Biomaterials are frequently used in medicine as a means of augmenting or supplicating an already existing natural function.

Recent years have seen a major evolution in endodontics, with key contributions coming from advances in equipment, biomaterials, and nanomaterials science. As a result of developments in dental materials research, biocompatible endodontic materials have been created. High biocompatibility nanoparticles can already be utilized in endodontics as medication carriers for intracanal administration, as well as root canal sealers.

As a subset of biomaterials, bioceramics can be defined as biocompatible ceramic materials that are used for the repair and reconstruction of diseased or damaged parts of tissues [1] or designed to stimulate specific cellular responses at the molecular level [2]. Specifically designed for use in medical and biological environments, bioceramics do not trigger an immune response and can favorably interact with biological tissues. Depending on the interaction with host tissues, bioceramics can be classified as quasi-bioinert, bioactive, and bioresorbable [3].

Bioceramic materials have evolved over three generations:

- **First Generation:** Inert materials, containing zirconia and alumina
- **Second Generation:** Bioactive materials, containing calcium phosphates, glasses and ceramic glasses, and calcium silicate
- **Third Generation:** Porous bioceramics, that can be used as scaffolds for cells and inducting molecules and being able to promote self-regeneration of tissues [4], containing hydroxyapatite, β-tricalcium phosphate (β-TCP), dicalcium phosphate dehydrate (DCPD), calcium phosphate [4].

The classification of bioceramics used in dentistry can be based on different criteria:

- **Tissue Interaction**: Bioinert, bioactive and biodegradable
- **Structure:** Dense and porous
- **Composition:** Calcium silicate-based (used as cements or sealers), calcium phosphate-based, mixture of calcium silicates and calcium phosphates, calcium aluminate-based.

The roots of bioceramic materials can be traced to the introduction of calcium hydroxide by B.W. Hermann in 1920, primarily for its antibacterial and healing properties, later adapted for use in apexification and pulp capping.

Modern bioceramic materials were introduced into endodontics in the 1990s, initially as retrograde obturation materials, then as root repair cements, root canal sealers, and coatings for gutta-percha cones [5].

Portland cement, created by Joseph Aspdin in 1824, was developed in England as a material to make concrete. The full name is Portland limestone cement because it resembled the stone quarried on the Isle of Portland in Dorset. It is a hydraulic cement first used in dentistry in 1878, in a case concerning plugging root canals and reported by Dr. Witte in Germany [6].

Mahmoud Torabinejad and his co-inventor, Dean White, received two U.S. patents for MTA, which was developed using Portland cement and bismuth oxide. It was first mentioned in the dental literature in 1993 and was approved by the FDA in 1998.

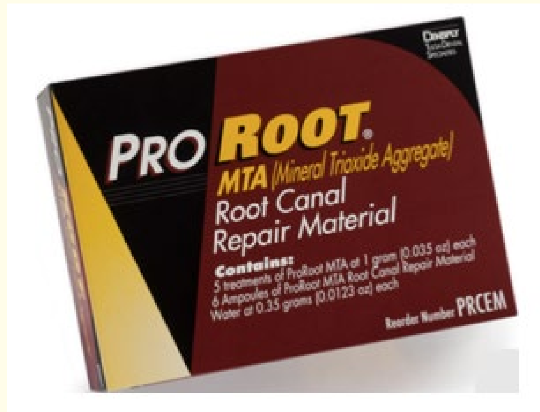

Figure 1: ProRoot MTA - Root Canal Repair Material.

The first commercial MTA product, ProRoot MTA (Dentsply Tulsa Dental Specialties, Johnson City, TN) was available starting in 1999 (Figure 1).

The original MTA formula contained Portland cement powder and radio-opacifying particles and was considered a revolutionary material for root repair and apexification.

Displaying bioactivity by forming hydroxyapatite upon contact with body fluids, MTA's success as a repair material inspired the development of other calcium silicate-based products, with more MTA formulations later introduced, primarily consisting in tricalcium silicate, dicalcium silicate, tricalcium aluminate, and tetracalcium aluminoferrite, with calcium sulfate and bismuth oxide as minor components [7].

Based on tricalcium silicate cements, a great number of various other MTA or MTA-type material formulations have been developed, encompassing three generations.

MTA Angelus (Angelus, Londrina, Brazil/Clinician's Choice, New Milford, CT), containing different amounts of tricalcium and dicalcium silicate than ProRoot MTA (2001).

Figure 2: MTA Angelus.

MTA Plus was introduced by Avalon Biomed in 2011, and showed better reactivity and prolonged ability to release calcium and increase local pH to alkaline values compared to ProRoot MTA.

NeoMTA Plus (Avalon Biomed), introduced for clinical use in 2013, and available since 2015, contains tricalcium silicate, dicalcium silicate, tantalum oxide, calcium sulfate and silica, without bismuth oxide.

Figure 3: NeoMTA Plus (Avalon Biomed).

MTAFlow (Ultradent Products Inc, South Jordan, Utah) is a hydraulic repair cement for direct pulp-capping application, released in 2015.

Figure 4: MTA Flow.

Endocem MTA (Maruchi, Wonju, Korea).

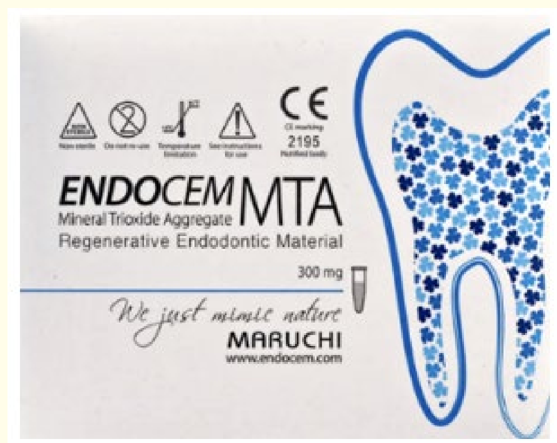

Figure 5: Endocem MTA.

Apart the MTA related products, different bio-ceramic materials have been gradually developed for endodontics, such as.

Biodentine (Septodont), composed of a powder containing tricalcium silicate, dicalcium silicate, calcium carbonate, calcium oxide, iron oxide shade, and zirconium oxide and a liquid containing calcium chloride, water, and a water reducing agent.

Figure 6: Biodentine.

BioAggregate (Verio Dental Co. Ltd., Vancouver, Canada), composed of nano particle sized tricalcium silicate, tantalum oxide, calcium phosphate, silicon dioxide. It is aluminum-free.

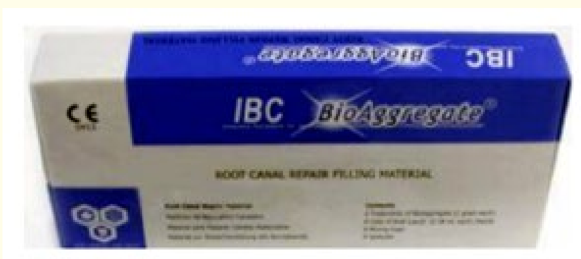

Figure 7: BioAggregate.

EndoSequence Root Repair Material (ERRM - Brasseler USA, Savannah, GA) is a hydrophilic calcium silicate material that forms hydroxyapatite after solidification.

Figure 8: EndoSequence Root Repair Material.

Due to their excellent biocompatibility, ability to promote tissue healing, and minimal shrinkage properties, a wide range of endodontic clinical settings have made extensive use of bioceramics materials:

- Indirect and direct pulp capping
- Partial pulpotomy
- Apexogenesis
- Apexification
- Pulp chamber floor and root perforations repair
- Retrograde filling
- Root resorption management
- Internal resorption repair
- Regenerative endodontics

The history of endodontic bioceramic sealers primarily centers around the development of Mineral Trioxide Aggregate (MTA), which is considered the first widely used bioceramic material in endodontics. Although not intended for use as a sealant, MTA was the first major step in the use of bioceramic materials in endodontics due to its biocompatible properties.

Initial formulations of MTA had a coarse particle size, making them unsuitable for use as a conventional root canal sealer, prompting further research to develop finer and more flowable bioceramic compositions. The evolution of bioceramic sealers was focused on research on developing new bioceramic sealers with improved handling characteristics and sealing abilities.

Bioceramic-based sealers can create bonds between the dentin and core filling materials, such as bioceramic impregnated or coated gutta-percha points [8].

Root canal obturation first used bioceramic based sealers once their first generation was introduced in 2010, emerging as an injectable, premixed material with excellent sealing properties and bioactivity: MTA-Fillapex (Angelus, Londrina, Parana, Brazil) [9]. It is a hydraulic tricalcium silicate-based sealer containing MTA, resins, bitmuth trioxide, nanoparticulated silica and pigments.

Figure 9: Angelus MTA Fillapex Smartmix Root Canal Endodontic Sealer.

The last almost two and a half decades have brought important advancements, concerning improved handling properties, setting times, and radiopacity while maintaining bioactivity. Sealers became more compatible with single-cone techniques, reducing procedural time and enhancing efficiency.

The evolution of bioceramic sealers in endodontics reflects advancements in material science aimed at improving the biological and sealing properties of root canal obturation materials.

This new range of endodontic sealers has revolutionized root canal therapy by offering enhanced biological and physicochemical properties compared to traditional sealers. These materials, primarily composed of calcium silicate-based compounds, have gained prominence due to their biocompatibility, bioactivity, and ability to form hydroxyapatite upon contact with body fluids, promoting a strong seal and tissue healing.

Recent innovations in their formulation have further improved their handling characteristics, setting times, and antimicrobial properties, addressing key limitations of earlier products.

The history of bioceramic sealers reflects a shift towards biologically active materials that not only seal the root canal system but also promote healing and regeneration.

Advancements in nanotechnology and material science have also enabled the development of bioactive nanoparticles and modified bioceramic compositions, enhancing sealers' flow, adaptability, and sealing abilities.

Additionally, the incorporation of improved delivery systems has streamlined clinical applications, making them more user-friendly and efficient. These advances not only optimize treatment outcomes but also align with the growing demand for minimally invasive and biologically oriented endodontic therapies.

Any root canal obturation comprises a solid core and an endodontic sealer, acting synergistically to achieve a compact, tight root canal filling.

Endodontic sealers play numerous and important roles, such as:

- Prevention or minimization of micro infiltrations
- Blocking of possible residual microorganisms at the level of the dentinal canals
- Antimicrobial role
- Filling the existing micro spaces between the core root canal obturation material and the parietal walls of the root canals
- Lubricating role, facilitating the introduction of gutta-percha points

Qualities of an ideal sealer include:

- Ease of application
- Sufficiently long setting time
- Adherence to the root canals walls
- Biocompatibility
- Without polymerization shrinkage, possibly showing a minimum expansion
- Chemically stability
- Non-resorbable
- Insolubility in tissue fluids
- Radiopacity
- Bacteriostatic/bactericidal character
- Not inducing discoloration
- Nonimmunogenic, nonmutagenic, noncarcinogenic
- Easy removal for endodontic retreatment.

Present day bioceramic-based sealers are divided based on their primary chemical composition into two main categories: calcium silicate-based and calcium phosphate-based. Other fillers can also be added to improve the physicochemical characteristics [10].

Bioceramic sealers are biocompatible, nontoxic, antibacterial, hydrophilic, chemically stable, easy to use, have a quick and non-shrinkage prone setting, have very good sealing ability, and do not cause a significant inflammatory response if an overfill occurs [11].

Continuous innovations include enhanced chemical bonding to dentin and gutta-percha, reduced shrinkage for improved dimensional stability and higher radiopacity for better visualization in radiographs.

The evolution of applications is visible in numerous directions:

- Bioactivity and healing. Bioceramic sealers introduced the concept of promoting healing rather than just sealing. They form hydroxyapatite, facilitating tissue regeneration and reducing inflammation.
- The use of single-cone technique. The rise of bioceramic sealers popularized the single cone obturation technique, simplifying the obturation process without compromising the seal of the root canal obturation.
- Regenerative endodontics. Bioceramic sealers have become central to regenerative procedures like apexogenesis and apexification, where bioactivity and minimal cytotoxicity are critical.
- Combination with bioceramic-impregnated gutta-percha. Recent innovations include bioceramic-coated and impregnated gutta-percha points, which enhance the chemical bond between the sealer and the root canal obturation material.

Figure 10: EndoSequence Bioceramic Impregnated and Coated Gutta-Percha Points (Brasseler).

Figure 11: Bio GP Points - Bioceramic Impregnated (Sure-endo).

Figure 12: Total Fill Bioceramic Gutta Percha Points (FKG).

The use of bioceramic materials as root canal sealers has two main advantages: the first one is found in their biocompatibility, which prevents the surrounding tissues from rejecting them; the second is found in them containing calcium phosphates, which improve the bond of the sealer to the root canal dentin. Bioceramic sealers can evenly close the gaps between the dentin walls and the endodontic obturation material and are able to close the dentinal tubules. The bond between the endodontic sealant and the intracanal dentin is essential to properly adapt the dentin-sealant interface [12,13].

The two types of present day bioceramic sealers are calcium-silicate based sealers (MTA based and non-MTA based) and calcium phosphate-based sealers.

While most bioceramic sealers are primarily composed of calcium silicate, which plays a crucial role in the bonding process, the exact mechanism of how bioceramic-based sealers bond to root dentin is not perfectly explained. A combination of factors has been proposed:

- Diffusion of sealer particles into dentinal tubules, thus creating mechanical interlocking bonds
- Infiltration of the sealer's mineral content into the intertubular dentin, resulting in the creation of a zone of mineral infiltration produced after the denaturation of collagen fibers with a strong alkaline sealer
- A partial reaction of phosphate with calcium silicate hydrogel and calcium hydroxide is produced in the presence of the dentin's moisture and leads to the formation of hydroxyapatite along the mineral infiltration zone and the creation of a strong bond with the tooth structure [11].

Intracanal moisture has a negative impact on handling conventional sealers and their adhesion to dentinal walls. Calcium silicate-based root canal sealers, on the contrary, need water to initiate the hydration reactions that are the basis of the whole process, and their biological properties.

When introduced into the root canal, calcium silicate-based root canal sealers are involved in a succession of hydration reactions triggered by the dentin moisture, followed by a precipitation one [14].

- the hydration reactions:

(a) $2[3CaO.SiO_2] + 6H_2O \rightarrow 3CaO.2SiO_2.3H_2O + 3Ca(OH)_2$

(b) $2[2CaO.SiO_2] + 4H_2O \rightarrow 3CaO.2SiO_2.3H_2O + Ca(OH)2$

- the →precipitation reaction:

(c) $7Ca(OH)_2 + 3Ca(H_2PO_4)_2 \rightarrow Ca10(PO_4)6(OH)_2 + 12H_2O$

Recent years have brought the appearance of an impressive number of bioceramic sealers which are currently in clinical use:

- MTA Fillapex Automix - Bioceramic Root Canal Sealer (Angelus)
- BIO-C Sealer ION+ Ready-to-use Bioceramic Root Canal Sealer (Angelus)
- MTA-BIOSEAL Root Canal Sealer (Itena Clinical)
- BioRoot Flow (Septodont)
- BioRoot RCS, Mineral-based Root Canal Sealer (Septodont)
- ZenSeal Bioceramic Root Canal Sealer (Kerr)
- EndoCeramic Premixed RTU Bioceramic Sealer
- ActaCal Sealer - calcium-silicate-based MTA root canal sealer
- RE-GEN™ Bioactive Endo Sealer (Vista Dental Products)
- Dia-Root™ Bio Sealer (DiaDent)
- Meta Biomed CeraSeal Calcium Silicate Based Bioceramic Sealer
- C-Root SP Injectable Root Canal Bioceramic Sealer
- N Root SP Injectable Root Canal Bioceramic Sealer (ENP)
- EdgeBioCeramic Sealer (EdgeEndo)
- Suppra Bio-Ceramic RCS – Root Canal Sealer (SUPPRA)
- Seal-fx BC Sealer (Rident)
- Endosequence BC Sealer Hi Flow Bioceramic Root Canal Sealing Material (Brasseler)
- Bioseal Bioceramic Endodontic Sealer (EDS)
- X-ROOT Bioceramic Root Canal Sealer (Easyinsmile)
- ApexSil Cal Non-eugenol, Calcium Hydroxide Based Polymeric Bioceramic Sealer
- Rootfyx Bioceramic Root Canal Sealing Material (MAARC Dental)
- One-Fil Calcium-Silicate Based Bioceramic Root Canal Sealer (MDCLUS)
- NeoSEALER Flo Bioactive Bioceramic Root Canal Sealer (Avalon Biomed)
- Komet BioSeal (Komet)
- AH Plus Bioceramic Sealer (Dentsply Sirona)

Figure 13: MTA-BIOSEAL Root Canal Sealer (Itena Clinical).

Figure 14: ZenSeal Bioceramic Root Canal Sealer (Kerr).

Figure 15: EdgeBioCeramic Sealer (EdgeEndo).

Figure 16: Endosequence BC Sealer (Brasseler).

A sealer-based obturation with the help of bioceramic sealers helps in creating very few voids inside the root canal space. So, achieving a good hermetic seal in the apical third of the tooth becomes easier. Furthermore, since the bioceramic sealer expands slightly on or after setting, it further prevents chances of percolation of fluids or contamination into the tooth.

On the other hand, one of the main setbacks of bioceramic sealers consists in the difficulty in removal during retreatment, especially at the apical third [14].

Current trends of development include:

- The Use of hybrid sealers combining bioceramic and resin properties (e.g., AH Plus Bioceramic Sealer - Dentsply Sirona)
- Improved handling, faster setting times and better flowability for clinical convenience
- Broader applications: expanding use in surgical endodontics and regenerative procedures.

Figure 17: AH Plus Bioceramic Sealer (Dentsply Sirona).

The increasingly broader use of bioceramic sealers led to development and introduction in clinical practice of special bioceramic nanoparticles impregnated or coated gutta-percha points.

The future of endodontic bioceramic sealers looks promising, with experts predicting they will become increasingly prevalent in root canal treatments due to their biocompatible nature, ability to promote tissue regeneration, and potential for improved clinical outcomes compared to traditional sealers, leading to more conservative treatment approaches while maintaining high success rates; however, further research is needed to optimize their properties and address potential limitations like setting time and retreatment challenges.

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