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Bioceramics in Endodontic Practice: A Literature Overview

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ABSTRACT:

The field of dentistry is perpetually advancing due to the introduction of innovative materials and techniques that produce beneficial outcomes. Bio-ceramics represent a novel class of materials that have revolutionised dentistry. Bioceramics demonstrate biocompatibility, non-toxicity, dimensional stability, and generally preserve chemical stability in biological settings. The development of bioceramic materials has markedly improved dentists' ability to manage procedures like as pulp capping, pulpotomy, apexification, apicoectomy, and the repair of defects caused by accidental perforation and resorption. The application of bioceramic materials has revolutionised both surgical and non-surgical endodontic techniques, providing a feasible option for the preservation of patients' teeth.

Keywords: Bioceramics, Root canal sealers, Bioceramics, Portland cement, MTA, Biodentin, ERRM, MTA fillapex, Endo CPM sealer, Bioroot RCS, Bioaggregate, Ceramicrete, Tech biosealer, CEM

Introduction

In the early 1990s, bioceramics emerged as a novel material in endodontics [1]. Bioceramics are biomimetic and biocompatible materials, including bioactive glasses, hydroxyapatite, calcium phosphate, and calcium silicate. Bioceramics are classified as physiologically inert, bioavailable, or biodegradable based on their interaction with adjacent tissue. Bioinert materials, such as zirconia and alumina, exhibit non-interactivity with biological systems. Bioactive materials that interact with surrounding tissues to promote the development of resilient tissues [glass and calcium phosphate]. Biodegradable, soluble, or resorbable materials that replace or integrate into tissue [2,3]. Bioactive bioceramics, including calcium silicate-based cements (CSCs), are frequently employed in endodontics. In addition to enhancing their mechanical and chemical properties, CSCs are essential in pulp space therapy due to their compatibility and biological activity [4,5].

Over the past three decades, there has been a significant interest in developing physiologically active substances that promote tissue regeneration. Mineral trioxide aggregate (MTA), as the pioneering bioceramic material in endodontics, has undergone substantial investigation. MTA is a Portland cement-derived substance characterised by exceptional biological compatibility and impermeable qualities. It was introduced in dentistry as a root-end filling material in 1993 and received FDA approval in 1997. ProRoot MTA was the first commercially accessible MTA solution, announced in 1999 [6,7]. ProRoot MTA, initially grey, has seen enhancements in all subsequent iterations. The MTA possesses inherent limitations, including extended setting time, high cost, and possible discolouration [8-10].

They demonstrate physiological characteristics akin to MTA, encompassing antibacterial capabilities, low cytotoxicity, and reduced inflammation [9,10]. The clinical environment routinely employs Biodentine, ERRM, BioAggregate, and Calcium-enriched Mixtures (CEM) [11]. Biodentine, developed using the principles of MTA production techniques, exhibits enhanced durability and accelerated setting due to the absence of calcium aluminate and calcium sulphate [13].

Endo Sequence BC Putty [putty form] and BC Sealer [paste form] are components of Endo Sequence root repair material [ERRM]. ERRM is a dissolved in water compound of $2CaO \cdot SiO2$ that forms hydroxyapatite upon hardening. This series of ready-to-use bioceramics is characterised by exceptional serviceability and a diminished risk of tooth discolouration [14]. $Ca_3[PO4]_2$ and Silica are available in BioAggregate making it an Al-free bioceramic. BioAggregate has strong binding tenacity and securing qualities but low mechanical properties [15]. Initially used in dentistry in 2008, CEM is a combination of several calcium-containing substances and has comparable characteristics to MTA at a lower cost. It has analogous both physical and therapeutic qualities as MTA but a distinct chemical constitution. Then the resin-formulated calcium silicate compound TheraCal LC hit the stores in 2011 as a subbase for direct and indirect pulp capping [16,17].

The invention of bioceramics has tremendously revolutionised endodontics. This article discusses bioceramics and their therapeutic uses in endodontics, such as retro-filling, pulp space therapy, deep caries management procedures, regenerative procedures, perforation and root defect repair. The limits along with prospective remedies for improving apply bioceramics to endodontic treatment are also discussed.

Properties of Bioceramic materials

1. Physio-chemical Properties of Bioceramic materials

To have a broad idea about the different bioceramic materials used in the endodontic therapy, Table I gives an insight about the composition of various materials [18-20]. Bioceramic materials are available in different forms, namely, powder and liquid, putty form, and paste form. MTA, Biodentine, BioAggregate, and CEM belong to powder-liquid system. The powder component consists primarily of di, tri-calcium silicate, whereas the liquid component is water. Combining powder and liquid creates a moistened calcium silicate gel combo that hardens forming a rigid structure. BC Putty, a premixed bioceramic made of calcium silico-phosphate. TheraCal LC is a calcium silicate resin paste conjugated with type III Portland cement and set by light curing unit. EndoSeal MTA & BC Sealer belong to calcium silicate sealers in injectable form, where Al is present in EndoSeal MTA, and not in BC Sealer. MTA Fillapex, BioRoot RCS, Tech BioSealer etc are 2-paste sealers with active components of MTA, tri-Ca silicate, and CEM.

Composition and uses of major bioceramic materials used in endodontics:

1. Mineral Trioxide Aggregate [MTA]

- Base: Refined Portland cement
- Main components:
  - Dicalcium silicate [Ca_2SiO_4 – ~75%]
  - Tricalcium silicate [Ca_3SiO_5]
  - Tricalcium aluminate [$Ca_3Al_2O_6$]
  - Calcium sulfate [$CaSO_4$ – ~5%, acts as a setting modifier]
  - Tetracalcium aluminoferrite [$4CaO \cdot Al_2O_3 \cdot Fe_2O_3$]
  - Bismuth oxide [~20% for radiopacity]
  - Minor elements: SiO_2, CaO, MgO, K_2SO_4, Na_2SO_4
- Liquid: Distilled water

  USES-MTA is widely used in endodontics for a variety of applications due to its excellent biocompatibility and sealing ability. It is primarily indicated for root-end fillings during apical surgeries, apexification in immature teeth, perforation repair in both root and furcation areas, and as a pulp capping agent to maintain pulp vitality. Its ability to stimulate hard tissue formation makes it valuable for regenerative procedures.[21]

2. Biodentine

Composition:

- **Powder:**
  - Tricalcium silicate [$3CaO \cdot SiO_2$]
  - Dicalcium silicate [$2CaO \cdot SiO_2$]
  - Calcium carbonate [$CaCO_3$]
  - Calcium oxide [CaO]
  - Zirconium oxide [ZrO_2]
- **Liquid:**
  - Calcium chloride [$CaCl_2$]
  - Hydrosoluble polymer [plasticizer]
  - Water

Uses: Biodentine serves as a versatile dentine substitute with broad clinical applications in both restorative and endodontic fields. It is commonly used for direct and indirect pulp capping, temporary enamel restoration, root perforation repair, and apexification. Because of its favorable setting time and ease of handling, it is preferred for situations where fast application and early sealing are needed. Its use in vital pulp therapy is expanding due to its bioactivity and dentine-like mechanical properties.[21]

3. EndoSequence Root Repair Material [ERRM] / iRoot BP Plus

Composition:

- Tricalcium and dicalcium silicate
- Monobasic calcium phosphate
- Radiopacifiers: zirconium oxide and tantalum oxide
- Proprietary thickening agents

Uses: ERRM is a ready-to-use bioceramic material designed for permanent root canal repair. It is especially useful in treating root perforations, performing root-end fillings in apical surgery, managing internal resorption defects, and forming apical plugs during apexification. Due to its biocompatibility and ability to bond with dentin, it is also used in pulp capping procedures to promote healing and hard tissue formation[21,22]

4. EndoSequence BC Sealer / iRoot SP

Composition:

- Tricalcium and dicalcium silicate
- Calcium phosphate monobasic
- Colloidal silica
- Calcium hydroxide
- Zirconium oxide
- Thickening agents

Uses: This injectable bioceramic sealer is used for permanent root canal obturation. It is known for creating a tight seal between the root canal walls, gutta-percha, and dentin, ensuring a bacteria-tight interface. It is particularly beneficial in sealing accessory canals and dentinal tubules and is used in both conventional and warm vertical compaction techniques. The material's bioactivity further enhances its sealing ability by promoting hydroxyapatite formation at the interface.[21,22]

5. MTA Fillapex

Composition:

- **Powder:** Mineral trioxide aggregate, bismuth oxide, silica, barium sulfate
- **Liquid:** Calcium chloride solution, sodium citrate, propylene glycol alginate, propylene glycol

Uses: MTA Fillapex combines the biological properties of MTA with the handling characteristics of resin-based sealers. It is mainly used as a root canal sealer and is suitable for both primary and permanent teeth. Its enhanced flow and radiopacity make it effective for obturating complex canal systems. It is particularly advantageous when a biocompatible sealer with adequate sealing and easier delivery is required.[21]

6. BioRoot RCS

Composition:

- Tricalcium silicate
- Zirconium oxide
- Water-based formulation

Uses: BioRoot RCS is a water-based tricalcium silicate root canal sealer that provides bioactivity along with a reliable seal. It is used for permanent root canal filling and is especially favored in cases where calcium release and hard tissue formation are desired. The material supports periapical healing and provides an antimicrobial environment due to the release of calcium hydroxide upon setting, making it ideal for regenerative endodontic procedures[21]

7. BioAggregate

Composition:

- Tricalcium silicate and dicalcium silicate

- Tantalum pentoxide [radiopacifier]
- Aluminum-free

Uses: BioAggregate is a next-generation bioceramic used in endodontic repair procedures. It is applied in situations such as root-end fillings, repair of root perforations, management of internal or external resorption, apexification, and pulp capping. Its contamination-free, aluminum-free composition, along with its excellent sealing ability and biocompatibility, make it suitable for use in challenging clinical situations requiring regeneration and sealing.[21,22]

8. Calcium-Enriched Mixture [CEM] Cement

Composition:

- Proprietary calcium-based formula [distinct from MTA]
- Promotes hydroxyapatite formation

Uses: CEM cement is used in various endodontic procedures including root-end filling, pulp capping, apexification, perforation repair, and vital pulp therapy. It is particularly effective in promoting hydroxyapatite formation and inducing hard tissue development. Its excellent sealing properties and antibacterial activity make it a reliable alternative to MTA in many clinical scenarios.[21]

Flow

Flow is an essential attribute of root canal sealers, facilitating their adaptation into complex anatomical regions such as dentinal irregularities, isthmuses, lateral canals, and voids between primary and accessory cones [23]. As per ISO 6786/2001 [24], a minimum flow of 20 mm is required for endodontic sealers. EndoSequence BC Sealer has demonstrated flow values ranging between 23.1 mm and 26.96 mm [23,25], whereas MTA-Fillapex has been reported with values of 22 mm, 24.9 mm, and 29.04 mm [25–27]. While manufacturers often claim that bioceramic sealers adhere to ISO flow standards, these assertions are not always corroborated by current literature.

Solubility

Solubility denotes the material loss experienced after immersion in water over a specified duration. ANSI/ADA Specification 57 [28] stipulates that solubility should not exceed 3% of the material's mass, as greater solubility may lead to the formation of interfacial gaps between the sealer and dentin, thereby increasing the likelihood of leakage from both coronal and apical directions [27]. iRoot SP and MTA-Fillapex demonstrate solubility levels of 20.64% and 14.89%, respectively, which surpass the ANSI/ADA limit [27,29]. This elevated solubility arises from the inclusion of hydrophilic nanoscale particles, enhancing sealer-liquid interaction through increased surface area. Contradictory results have been noted across studies: Viapiana et al. [29] described MTA-Fillapex as highly soluble, while Vitti et al. [29] observed solubility below 3%, complying with ISO 6876/2001. Notably, EndoSequence BC also meets ISO 6876/2001 criteria for solubility [25].

Radiopacity

To ensure distinction from surrounding anatomical features on radiographs, root canal sealers should exhibit adequate radiopacity [31]. This property is fundamental for assessing the integrity of the root canal obturation. ISO 6876/2001 mandates a minimum radiopacity equivalent to 3.00 mm of aluminium. According to Candeiro et al. [32], EndoSequence BC Sealer exhibits a radiopacity of 3.83 mm. In the case of MTA-Fillapex, the inclusion of bismuth trioxide accounts for its radiopacity value of 7 mm [27].

pH and Ion release

According to manufacture claims, various bioceramic sealers exhibit a highly alkaline pH of approximately 12.8 and significant radiopacity. This alkaline environment is clinically relevant, as it contributes to the elimination of bacterial species like *Enterococcus faecalis,* which are resistant to routine chemomechanical preparation but cannot survive in pH levels approaching 11. Furthermore, the induction of mineralized tissue repair is believed to be influenced by both the materials pH and its capacity to release calcium ions.

The elevated calcium ion release from bioceramic cements is primarily attributed to their setting reactions. During hydration, tricalcium silicate and dicalcium silicate react with water to form calcium silicate hydrate and calcium hydroxide, which further facilitate precipitation of calcium phosphate apatite. Sealers like Endosequence BC demonstrated peak calcium release within 168 hours. Additionally, over a period of two months, continuous release of calcium and hydroxyl ions leads to apatite layer formation when in contact with phosphate rich fluids. This interfacial apatite layer chemically bonds the bioceramic material to dentinal walls, potentially reducing microleakage and enhancing the seal integrity. [23]

Setting time

According to ANSI/ADA specification no. 2, the setting time of an endodontic sealer should not vary by more than 10% from the manufacturer's stated value. Studies shows that Biodentine exhibits a final setting time of approximately 85.66 ± 6.03 minutes, while MTA shows a longer setting time of approximately 228.33 ± 2.88 minutes. In contrast Endosequence BC sealer requires a significantly prolonged setting period, taking at least 168 hours to achieve complete set when evaluated by the Gilmore needle method. It was also observed that the microhardness of Endosequence BC sealer decreases considerably when water is incorporated into its composition during setting. Furthermore, both Endosequence BC sealer and MTA fillapex fail to set under dry conditions even after 3 days but achieve setting time when in contact with physiologic solutions such as Hank's balanced salt solution. [20]

2.Biocompatibility of Bioceramic compounds

The biological acceptability and biological function of bioceramics mostly depend on how they relate with tissue surrounding them. Bio Ceramics impact stem cell division, multipilcation, differentiation, emigration, cell death, and immunologic cell activity. Cellular reaction to bioceramics impacts wound repair and tissue restoration [33]. Dental tissue-derived mesenchymal stem cells [MSCs] include DPSCs, SHED, and apical SCAPs [34]. MSCs' regeneration and multifaceted differentiation capacity are crucial for pulp rejuvenation and bone formation [35]. Bioceramics enhance stem cell adhesion and their survival, with effects varying by cell type [36].

Biodentine, NeoMTA Plus, and TheraCal LC exhibit good tissue adaptability and lead to odontogenesis or osteogenesis due to the proliferation of MSCs [35]. Both ProRoot MTA and Biodentine exhibit biological features that support DPSC functioning ex-vivo [38]. Biodentine promotes dentinogenesis via MAPK and CaMKII pathways [39]. ProRoot MTA, Biodentine, and ERRM may promote SCAP mineralisation and odontogenesis, thereby enabling pulp regeneration [40].

Osseous repair depends on the number of osteoblasts and osteoclasts around the damaged tissue. When bioceramic materials are used in cases of perforation repair, and retro-filling, the work between the material and the cells is very important for the reduction of infection and wound recuperation [41]. MTA has shown to effectively reduce bone resorption by impeding RANKL-mediated osteoclast activity and its production [42]. BioAggregate drives formation of osteoblasts, inhibiting osteoclastogenesis, and significantly reducing osseous resorption in-vivo [43-45].

DPCs/PDLCs aid in healing wounds and bring about tooth- tissue regeneration. Bioceramics react to DPCs/PDLCs for deep caries management procedures, perforation repair, and retro- filling. MTA, Biodentine, BioAggregate, and ERRM increase DPCs' transcription of genes involved in mineralisation and odontoblastic maturation [46-48].

Much research have examined the biocompatibility and bioactivity of bioceramics in endodontics. MTA is the most researched material and regarded the “benchmark”. Limited research exists comparing bioceramics to MTA, and in vitro models have varying approaches and outcomes. Additional trials are required to offer persuasive proof for using such materials in endodontic procedures.

Antibacterial activity

The antibacterial property of MTA is mainly attributed to the alkaline environment created during setting as calcium hydroxide forms. The pH rise, reaching values above 12, disrupts bacterial DNA and proteins, effectively killing pathogens like *Enterococcus faecalis, Staphylococcus aureus, Escherichia coli, and Candida albicans*. However, its antibacterial effect diminishes over time, particularly after aging for seven days. To overcome MTA’s drawbacks such as long setting time and handling difficulties, several MTA- based cements have been developed, including NeoMTA Plus, MTA Angelus and MTA Repair HP, which maintain similar antimicrobial properties but with improved handling. Biodentine, offers faster setting and releases calcium ions, creating a high pH environment that exhibits initial antimicrobial action against *E.faecalis.* Nonetheless, its antibiofilm effectiveness decreases over prolonged exposure, especially against multi species biofilms. Endosequence root repair material, available as a putty or paste, demonstrates antimicrobial activity during its setting phase due to its alkaline Ph and ion release, showing clinical success rates up to 93% apicoectomy studies. Additionally, premixed bioceramic sealers such as Endosequence BC sealer, iRoot SP, and BioRoot RCS exhibit prolonged antimicrobial effects, attributed to continuous calcium ion release and biomineralization, effectively inhibiting E.faecalis biofilms in dentinal tubules. However, some studies report reduced efficacy after setting. Overall, while bioceramic materials provide superior biocompatibility, sealing ability and bioactivity compared to traditional sealers, their antimicrobial performance varies based on formulation, application method and biofilm complexity, highlighting the need for further standardised studies to optimise their clinical benefits. [10,49]

Cytotoxic/genotoxic risk

Bioceramic sealers, such as Endosequence BC sealer, exhibit favourable biological properties with minimal cytotoxicity to human gingival fibroblasts, as demonstrated by studies reporting negligible toxic effects across various experimental durations. The biocompatibility is largely attributed to their alkaline pH, sustained release of calcium ions and the ability to promote hydroxyapatite formation, all of which enhance the cellular responses and healing. In terms of genotoxicity, bioceramic sealers have shown low potential to induce DNA damage, with significantly fewer micronuclei formations in comparison to other materials like epoxy resin based sealers. These findings suggest that bioceramic sealers are biologically safe, posing minimal risks of cytotoxicity or genotoxicity when in contact with periapical tissues, thereby supporting their clinical use as a reliable and biocompatible endodontic sealing materials. [40,50]

CONCLUSION

Bioceramic materials offer an exceptional combination of physical, chemical, and biological properties that support their widespread use in dentistry. Their superior sealing ability, dimensional stability, and radiopacity ensure long-lasting restorations. Chemically, their alkaline pH and ion-releasing capacity contribute to antibacterial effects and tissue mineralization. Biologically, they are highly biocompatible and bioactive, promoting healing and regeneration of dental and periapical tissues. These properties make bioceramics a valuable tool for procedures such as pulp capping, root repair, apexification, and obturation, aligning with the goals of minimally invasive, biologically based dental care.

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