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Bioceramics as the future of conservative dentistry and endodontics

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Abstract

Bioceramics, a class of biocompatible ceramic compounds engineered for medical and dental applications, have emerged as transformative materials in conservative dentistry and endodontics. Derived from compounds such as calcium silicates, calcium phosphates, zirconia, alumina, and bioactive glasses, these materials exhibit properties closely resembling biological hydroxyapatite, enabling osteoconductivity, osteoinductivity, and chemical stability in physiological environments. Their ability to release calcium hydroxide, form hydroxyapatite in situ, and integrate with dentin and bone underpins their regenerative potential.

Historically, the development of bioceramics in dentistry evolved from early alumina and zirconia applications to advanced calcium silicate–based cements like Mineral Trioxide Aggregate (MTA) and Biodentine, as well as hybrid formulations combining calcium silicate and phosphate phases. Bioactive glasses, such as Bioglass® and NovaMin®, have expanded applications in dentin hypersensitivity management, adhesive systems, and root canal obturation. Innovations like ACTIVA Bioactive Restorative and Ceramir C&B integrate bioactivity with restorative performance.

In endodontics, bioceramic sealers and repair materials—including EndoSequence Root Repair Material, BioAggregate, and TotalFill BC—offer superior sealing ability, dimensional stability, and biocompatibility. Their clinical uses span pulp capping, pulpotomy, apexification, perforation repair, retrograde fillings, and root canal obturation. Mechanical properties such as high compressive strength, radiopacity, and low solubility, combined with antibacterial effects from alkaline pH, enhance treatment outcomes.

Despite their advantages, limitations persist, including cost, handling characteristics, and limited global availability. Ongoing research focuses on improving setting times, bonding capabilities, and long-term stability while expanding accessibility.

Bioceramics represent a paradigm shift toward biologically integrated, minimally invasive dental care. Their capacity to support tissue regeneration, maintain structural integrity, and provide durable clinical performance positions them as a cornerstone in the future of conservative dentistry and endodontics

Keywords: Bioceramic material, mineral trioxide aggregate(mta), bioactive glasses, biodentine

Introduction

All solid materials can be broadly classified into four categories: metals, polymers, ceramics, and composites. In dentistry, *ceramics* are defined as inorganic, non-metallic substances composed of oxygen combined with metallic or semi-metallic elements such as aluminum, calcium, lithium, magnesium, potassium, phosphorus, silicon, zirconium, or titanium. These materials are widely used in the fabrication of porcelain crowns, metal-ceramic restorations, glass ionomer cements, and various dental prostheses [1, 2].

Biomaterials are similarly grouped into bio-metals, biopolymers, bioceramics, and biocomposites, each playing a vital role in tissue replacement and regeneration. Among these, bioceramics are specially engineered ceramic compounds synthesized through chemical processes either within the body (*in vivo*) or outside it (*in situ*). Their exceptional biocompatibility arises from their close resemblance to natural hydroxyapatite, the mineral component of bone [3, 4].

Bioceramics demonstrate both osteoconductive and osteoinductive. properties. They are non-toxic, dimensionally stable, chemically inert in biological environments, and capable of integrating with living tissues. In endodontics, these materials release calcium hydroxide when exposed to tissue fluids. This compound reacts with phosphate ions to form hydroxyapatite, which contributes to their tissue-inductive potential [3].

In restorative dentistry, the purpose of bioceramics is to restore prepared dental tissues to full biological function by creating a hard tissue structure that can withstand and transmit functional stresses. Their introduction has significantly improved the success rates of procedures such as pulp capping, pulpotomy, apexification, apicoectomy, and the repair of perforations or resorptive defects [9].

Modern bioceramic materials are designed not only to function as substitutes for human tissues but also to resorb gradually and stimulate the regeneration of natural tissues. Despite these advances, their global application remains limited due to issues of availability, cost, and accessibility.

Bioinert Materials

1. Alumina-Based Bioceramics

Alumina (aluminium oxide, Al_2O_3) represents one of the earliest and most widely accepted ceramic biomaterials, first introduced in the 1970s (first generation) and refined in the 1980s (second generation). It is the only stable oxide of aluminium and has been a technologically important ceramic throughout history. Structurally, alumina exhibits a hexagonal lattice in which aluminium ions occupy octahedral interstitial sites.

Mechanical Properties
- **Young's modulus:** ~380 GPa
- **Compressive strength:** ~4000 MPa
- **Bond strength:** 300–400 GPa
- **Hardness:** 2000–3000 HV
- **Density:** ≥ 3.9 g/cm³

Physical Characteristics
- Alumina ceramics are known
- High hardness and abrasion resistance
- Excellent wear performance
- Favorable frictional behavior due to surface energy and smoothness

Biocompatibility and Cytotoxicity
- **Indirect contact studies (Noiri *et al.*):** Implants placed in rabbit eye sockets for eight weeks showed no rejection. By week four, fibroblast proliferation and vascular invasion were observed, and by week eight, tissue ingrowth occurred without adverse reactions.

- **Direct contact studies (Yuhta *et al.*):** Blood compatibility tests on sputter-deposited alumina films revealed activation of the intrinsic coagulation pathway but acceptable platelet reactivity under controlled oxygen pressure.

- **Cytotoxicity tests:** Single-crystal alumina in L-cell cultures demonstrated colony formation and survival rates comparable to controls, confirming non-toxicity and safety for bone marrow implantation.

Applications
- Used in conservative dentistry as alumina–nanocomposites
- Available in powder and liquid forms

Processing Techniques
- **Spark plasma sintering (Yao *et al.*):** Fabrication of Al_2O_3–Ni nanocomposites
- **Hot pressing (Sekino *et al.*):** Al_2O_3–NiO mixtures consolidated under 30 MPa at 1450 °C
- **Colloidal processing (Díaz *et al.*):** Al_2O_3–Mo nanocomposites with improved fracture toughness

Additional Mechanical Property
- **Fracture toughness:** ~3.84 MPa·m½

Limitations
Despite significant progress, further research is required to optimize alumina's long-term performance in biomedical applications [30].

2. Zirconia-Based Bioceramics
Zirconium oxide (zirconia) was first applied in medicine in 1969 for orthopedic implants. Today, it is considered a promising biomaterial due to its superior mechanical strength and fracture toughness, largely attributed to its transformation toughening mechanism.

Mechanical Properties
- **Young's modulus:** 150–200 GPa
- **Compressive strength:** ~2000 MPa
- **Bond strength:** 200–500 GPa
- **Hardness:** 1000–3000 HV
- **Density:** ~6.0 g/cm³

Biocompatibility and Cytotoxicity
- Widely used in total hip replacements (THR) and other medical devices, with studies confirming excellent in *vitro* biocompatibility.
- Bone mineral density has been identified as a strong predictor of zirconia implant osteointegration.
- Trace radioelements in zirconia were evaluated for γ-ray activity, with no harmful effects reported.
- Polycrystalline zirconia tested in L-cell cultures showed no cytotoxicity.

Applications in Dentistry
- Zirconia-based dental posts are available in smooth, tapered, parallel, or hybrid
- designs. Rounded apical ends help reduce stress concentration at the root apex.
- **Composition:** Polyester matrix reinforced with ~65% zirconium.

Mechanical and Biological Features
- **Compressive strength:** Higher than conventional ceramic posts and cores (Kwiatkowski & Geller, in *vitro*).
- **Young's modulus:** Lower than pure zirconium, but still adequate.
- **Ductility:** Reduced, making the material stiffer.
- **Bonding:** Zirconia posts show poor resin–dentine bonding after thermocycling and dynamic loading (Dietschi *et al.*).
- **Biological properties:** Highly biocompatible, radiopaque, and capable of transmitting light through both root and coronal structures (Kakehashi *et al.*).

Limitations
- Surface roughness from manufacturing may enhance micromechanical interlocking but complicates bonding.
- Silanization or silicating treatments can improve adhesion initially, but hydrolysis over time weakens the bond [32].

Bioactive Materials
1. Bioactive Glasses (BAG)
The concept of *bioactive materials* was first introduced by Larry Hench in 1969. Bioactive glasses are available in different clinical forms such as powder particles, porous scaffolds, and dense constructs, depending on the intended application.

Classification and Composition
- **45S5 (Bioglass):** 46.1 mol% SiO_2, 24.4 mol% Na_2O, 26.9 mol% CaO, 2.6 mol% P_2O_5
- **58S (sol-gel derived):** 60 mol% SiO_2, 36 mol% CaO, 4 mol% P_2O_5

- **S53P4:** 53 mol% SiO_2, 23 mol% Na_2O, 20 mol% CaO, 4 mol% P_2O_5

Setting Reaction

When BAG comes into contact with body fluids, calcium ions are released into the surrounding medium. At the same time, a silica-rich interfacial layer develops on the glass surface, which acts as a nucleation site for hydroxyapatite (HAp). The HAp layer continues to grow through the interaction of calcium, phosphate, and hydroxide ions, enabling bonding with hard tissues.

Production Methods

- **Conventional glass melting:** A mixture of oxides or carbonates is melted in a platinum crucible at 1250–1400 °C and homogenized to form glass.
- **Sol-gel processing:** Produces highly porous BAG with enhanced reactivity.

Applications in Conservative Dentistry

a. Treatment of Dentin Hypersensitivity

- **NovaMin® (GlaxoSmithKline, UK):** A fine BAG powder (~18 µm) incorporated into toothpaste.
- **Composition:** Calcium–sodium–phosphate silicate glass.
- **Mechanism:** Releases calcium and phosphate ions, raising pH and promoting precipitation of calcium phosphate, which crystallizes into hydroxyapatite. This seals dentinal tubules, reducing sensitivity.

Properties

- Hardness ~7 GPa (higher than enamel at ~3.5 GPa).
- Clinical studies (Gendreau *et al.*) showed that 5% NovaMin® toothpaste provided greater and longer-lasting relief compared to 5% potassium nitrate formulations.

b. Dental Adhesives and Restorative Materials

- **Experimental bonding systems:** Resin composites containing 5–15 wt% Bioglass® 45S5 or Zn-polycarboxylated BAG as microfillers.

- **Mechanism:** Zinc ions protect the collagen matrix from matrix metalloproteinases (MMPs) activated during acid etching, while BAG raises local pH.

Mechanical properties

- Flexural strength and modulus decreased with higher BAG content.
- ISO 4049 standards were met up to 20 wt% BAG.

Biological properties

- Antibacterial: Inhibited *E. coli* and *S. mutans* growth without reducing bond strength.
- Cytotoxicity: Some cytotoxic effects due to unreacted monomers, though comparable to commercial composites.

Applications in Endodontics

- **Resilon™:** A thermoplastic polymer root filling material incorporating BAG as filler.
- **Bio-Gutta:** Gutta-percha combined with Bioglass® 45S5, designed as a sealer-free obturation material.
- **Mechanism:** Forms calcium phosphate precipitates under moist conditions, creating self-adhesion to dentin and a tight seal.
- **Advantages:** High biocompatibility, antimicrobial effect, pH elevation, and sealing ability.
- **Polyisoprene (PI) and Polycaprolactone (PCL) composites:** Incorporation of up to 30 wt% BAG improved sealing properties, eliminating the need for separate sealers [28].

Ceramir

Ceramir C&B (Doxa Dental AB, Sweden), introduced in 2009, is a bioactive luting cement used for permanent cementation of crowns, bridges, inlays, onlays, prefabricated posts, and all-ceramic restorations.

- **Form:** Powder and liquid.
- **Composition:** Hybrid of calcium aluminate and glass ionomer components, mixed with distilled water.
- **Setting mechanism:** Combines a glass ionomer reaction with an acid–base hydraulic
- cement reaction.

Biological properties

- Exhibits a basic pH, which promotes bioactivity by forming an apatite layer in phosphate-containing environments.
- Releases calcium ions, enhancing remineralization.
- Calcium aluminate stabilizes the GIC matrix, reducing long-term ion leakage [34].

Activa Bioactive Restorative Material

ACTIVA Bioactive Restorative Glass (Pulpdent, USA) is a novel restorative system designed to mimic natural tooth properties.

Composition

- Bioactive ionic resin matrix
- Shock-absorbing resin component
- Reactive glass ionomer fillers

Setting reaction

- Engages in continuous ion exchange with saliva and tooth structure.
- Releases and recharges calcium, phosphate, and fluoride ions.
- Responds dynamically to pH fluctuations in the oral cavity.
- Forms a chemical bond to tooth surfaces, sealing against microleakage.

Properties

- Strong, esthetic, and durable, with mechanical performance comparable to composites but with added bioactivity.
- Inhibits enamel demineralization adjacent to orthodontic brackets more effectively than non-fluoride releasing controls [20].

Biodegradable Materials

1. Calcium Silicate–Based Bioceramic Materials

1.1 Calcium Silicate–Based Cements

a. Mineral Trioxide Aggregate (MTA)

- **Introduction:** Mineral Trioxide Aggregate (MTA) was first developed by Mahmoud Torabinejad at Loma Linda University, California, in 1993. It was the first bioceramic cement successfully applied in endodontics, recognized for its osseoconductive, inductive, and biocompatible properties.

Form

- Fine hydrophilic powder, packaged in single-use 1 g sachets.
- Available as Grey MTA and White MTA.

Composition

- Portland cement (~75%)
- Bismuth oxide (~20%)
- Calcium oxide (50–75 wt%)
- Silicon oxide (15–20 wt%)
- Gypsum (~5%)

Setting Reaction

- Hydration of tricalcium and dicalcium silicate produces calcium hydroxide and calcium silicate hydrate gel, creating an alkaline environment.
- Tricalcium aluminate reacts with calcium phosphate to form calcium sulphoaluminate.
- Calcium ions diffuse through dentinal tubules, with concentration increasing as curing progresses.

Setting Time

- **Torabinejad *et al*.:** ~2 h 45 min (Grey MTA)
- **Islam *et al*.:** ~2 h 55 min (Grey MTA), ~2 h 20 min (White MTA)

Mechanism of Action

- Releases calcium ions that promote cell adhesion and proliferation.
- Alkaline pH creates an antibacterial environment.
- Hydroxyapatite (or carbonated apatite) forms on the surface, providing a biological seal.

Properties

- **Solubility:** Higher water/powder ratio increases solubility and porosity (Fridland & Rosado).
- **Compressive strength:** 40 MPa at 24 h; 67.3 MPa at 21 days (Torabinejad). Grey MTA stronger than White.
- **Flexural strength:** 14.27 MPa after 24 h with two-sided moisture (Walker).
- **Microhardness:** Greater in 5 mm thickness than 2 mm (Matt).
- **Radiopacity:** Equivalent to 7.17 mm aluminum (Torabinejad).
- **Microleakage:** Excellent sealing ability (Torabinejad).
- **Marginal adaptation:** 4 mm thickness ensures sealing; expansion improves adaptation (Shipper, Valois).
- **Biocompatibility:** Non-mutagenic, low cytotoxicity, stimulates bone cell activity (Kettering, Koh).
- **Bioactivity:** Promotes odontoblastic differentiation and reparative dentin (Laurent).

Applications

- Pulp capping
- Pulpotomy
- Apexogenesis
- Apical barrier formation in immature teeth
- Repair of root perforations
- Root canal filling material

Limitations

- Tooth discoloration (especially with Grey MTA)
- Prolonged setting time [1].

b. Biodentine

Introduction: Biodentine is a biocompatible, non-toxic calcium silicate cement developed as an improvement over MTA, with enhanced handling and physical properties [9].

Form:

- Supplied in capsules containing pre-measured powder and liquid.

Composition

- **Powder:** Tricalcium silicate (core), dicalcium silicate, calcium carbonate, iron oxide (shade), zirconium oxide (radiopacifier)
- **Liquid:** Calcium chloride (accelerator), hydrosoluble polymer (reducing agent)

Setting Reaction

- Hydration releases Ca^{2+}, OH^-, and silicate ions.
- Forms calcium silicate hydrate gel and calcium hydroxide, raising pH.
- Gel encapsulates unreacted particles, limiting water penetration and slowing further reaction.

Properties

- **Setting time:** 9–12 min (manufacturer); shortest among tricalcium silicate cements (Grech *et al*.).
- **Density & porosity:** Comparable to iRoot BP Plus and Ceramicrete.
- **Compressive strength:** 100 MPa (1 h), 200 MPa (24 h), 300 MPa (1 month) — similar to dentin (297 MPa).
- **Flexural strength:** 34 MPa after 2 h.
- **Microhardness:** 51 VHN (2 h), 69 VHN (1 month); superior to BioAggregate and IRM (Goldberg *et al*.).
- **Radiopacity:** Exceeds ISO 6876:2001 minimum of 3 mm Al.
- **Microleakage:** High pH and ion release stimulate mineralization, forming a mineral infiltration zone.
- **Marginal adaptation:** Good micromechanical adhesion; MTA and IRM superior in root-end fillings (Soundappan *et al*.).
- **Bond strength:** Low initially; final composite restoration should be delayed >2 weeks (Hashem *et al*.).
- **Biocompatibility:** Comparable to MTA; less toxic than GIC (Zhou *et al*.). Promotes pulp cell proliferation (Pérard *et al*.).
- **Bioactivity:** Stimulates odontoblastic differentiation, mineralization, and reparative dentin (Laurent *et al*.).

c. Portland Cement (PC)

Introduction: Portland cement is the primary component of MTA and shares many of its beneficial properties. It is used in endodontics where preservation of pulp vitality is critical.

Form:

- Supplied as powder and liquid (distilled water).

Composition

- **Alite:** Tricalcium silicate (Ca_3SiO_5)
- **Belite:** Dicalcium silicate (Ca_2SiO_4)
- **Aluminate:** Tricalcium aluminate ($Ca_3Al_2O_6$)
- **Ferrite:** Tetracalcium aluminoferrite (Ca_2AlFeO_5)
- **Classification (by composition):**
- **Type I:** High tricalcium silicate
- **Type II:** Low tricalcium aluminate (<8%)
- **Type III:** Higher tricalcium silicate, finer particles, high early strength
- **Type IV:** Lower tricalcium aluminate
- **Type V:** Lower tricalcium aluminate

Setting Reaction

- Hydraulic reaction occurs when mixed with water.
- Hydration of tricalcium and dicalcium silicate produces calcium silicate hydrate (C-S–H) gel and portlandite ($Ca(OH)_2$).
- The porous, negatively charged C–S–H promotes calcium phosphate nucleation and apatite-like crystal formation.
- SEM studies reveal unhydrated grains, portlandite crystals, ettringite needles, cracks, and voids.
- Optimal water/powder ratio: 0.3–0.6.

Properties

- **Setting Time:** Initial and final setting times are approximately 180 and 240 minutes.

- **Compressive Strength:** Increases progressively with time. After 28 days, both ordinary and white Portland cement demonstrate lower strength compared to MTA (Islam *et al.*).

- **Push-Out Bond Strength:** Improved by biomineralization, particularly with additives such as calcium chloride.

- **Sealing Ability:** Effective in sealing perforations, comparable to MTA in leakage prevention. Slight expansion (0.47% in white PC, 0.45% in grey PC) enhances sealing.

- **Solubility:** Lower than MTA, with <3% weight loss in 24 hours and <1% in Hank's Balanced Salt Solution (HBSS) over 28 days.

- **Biocompatibility & Cytotoxicity:** Initially, severe inflammatory infiltration may occur, but this subsides over time, with only mild recurrence later. PC is more biocompatible than glass ionomer, calcium hydroxide, and zinc oxide cements. It shows low cytotoxicity toward multiple cell lines, including human endothelial cells.

- **Bioactivity & Regenerative Potential:** Promotes pulp regeneration, mineralization, and hard tissue barrier formation through odontoblast activation. Animal studies confirm osteoconductivity, with osteogenesis observed in intraosseous sites. PC also enhances mineral density in carious dentin, indicating strong remineralization potential.

Applications

- Repair of root perforations and resorption defects
- Pulpotomy procedures
- Vital pulp therapy

Limitations

- Requires further modification to optimize properties for root repair.
- Clinical applicability, reliability, and cost-effectiveness must be addressed before routine use in daily practice.

d. ProRoot MTA

Overview: ProRoot MTA is a specialized root canal repair material designed as an improvement over conventional cement. Its strong affinity for dentinal walls ensures predictable healing outcomes.

Form:

- Supplied as powder with pre-measured purified water for mixing.
- Available in white and grey shades, packaged in 0.5 g and 1 g treatment boxes.

Composition

- White Portland cement (WPC)
- Bismuth oxide (Bi_2O_3)

Properties

- **Hydration Process:** Mixing with liquid produces a colloidal gel that gradually solidifies, forming a dense, impermeable barrier.

- **Setting Time:** Approximately 3 hours; slower setting allows improved handling.

- **Biocompatibility:** Highly compatible with living tissues, stimulating reparative dentinogenesis and periapical healing.

Clinical Applications

- Root-end filling material
- Apical plug during apexification
- Repair of root perforations
- Direct pulp capping
- Pulpotomy in pediatric patients

Precautions

- Store in a dry environment to prevent premature hydration.
- Use immediately after mixing to avoid dehydration.
- In esthetic areas, consider restorative materials and surface exposure to minimize discoloration.
- Avoid direct skin contact to prevent irritation or allergic reactions.
- If extended working time is required, cover with moist gauze to prevent evaporation.

1.2 Calcium Silicate–Based Sealers

a. Endo CPM Sealer (EGEO, Argentina)

Composition

- **Powder:** Silicon dioxide, calcium carbonate, bismuth trioxide, barium sulfate, propylene glycol alginate, sodium citrate
- **Liquid:** Calcium chloride in saline solution

Properties
- Radiopacity equivalent to 6 mm aluminum (Guerreiro-Tanomaru *et al.*).
- Suspension pH >11, higher than MTA-Fillapex.
- Less resistant to leakage compared to other sealers [40].

Biological Properties
- Freshly mixed Endo CPM exhibits antibacterial activity against Staphylococcus aureus and Streptococcus mutans, with inhibition zones maintained after setting [40].

b. MTA Fillapex

Form

Composition
- Natural resin, salicylate resin, diluted resin, bismuth trioxide, silica nanoparticles, pigments

Properties
- **Radiopacity:** ~7 mm Al
- **Setting time:** ~19.3 minutes
- **Flow:** Reported between 22–29 mm
- Causes minimal crown discoloration, not clinically perceptible
- **Retreatment:** Comparable to AH Plus in terms of residual material, dentin removal, and working length time

Biocompatibility & Cytotoxicity
- Lowest biocompatibility among calcium silicate sealers
- Significant cytotoxicity due to salicylate resin, which prolongs setting and increases dissolution of toxic byproducts

c. BioRoot™ RCS

Form
- Powder and liquid system

Composition
- **Powder:** Tricalcium silicate, zirconium oxide, excipients
- **Liquid:** Calcium chloride solution with excipients

Properties
- **Working time:** ~10 minutes
- **Setting time:** ~4 hours
- **Radiopacity:** ~5 mm Al
- Strong adhesion to dentin and gutta-percha
- **Hydrophilic:** continues sealing in moist conditions
- **Pure mineral formulation:** resin-free, monomer-free, no shrinkage, no staining
- Excellent flowability, sealing auxiliary canals

Biocompatibility
- No cytotoxic effects reported; highly biocompatible

d. TotalFill BC

Form
- Syringe paste and fast-set putty

Composition
- Zirconium oxide (35–45%)
- Dicalcium silicate (7–15%)
- Tricalcium silicate (20–35%)
- Calcium hydroxide (1–4%)
- Fillers

Properties
- Setting time: ~2 hours (syringe paste), ~20 minutes (fast-set putty)

Biocompatibility
- Excellent tissue compatibility
- Non-cytotoxic, ensuring safety for periapical tissues [36, 37].

2. Calcium Phosphate–Based Bioceramic Materials

a. Sankin Apatite Root Canal Sealer (Types I, II, and III)
- **Form:** Supplied as powder and liquid.

Composition
- **Powder:** Type I contains α-tricalcium phosphate and hydroxyapatite; Type II includes 30% iodoform; Type III contains 5% iodoform.
- **Liquid:** Polyacrylic acid dissolved in water.

Biological Properties
- In *vitro* studies (Telli *et al.*) confirmed that Sankin apatite is biocompatible [40].

b. Capseal (Types I and II)
- **Form:** Powder and liquid system.

Composition
- **Powder:** Tetracalcium phosphate (TTCP), dicalcium phosphate anhydrous (DCPA), Portland cement (grey in Type I, white in Type II), zirconium oxide, and other additives.
- **Liquid:** Hydroxypropyl methylcellulose in sodium phosphate solution.

Properties
- Both Capseal I and II demonstrated strong sealing ability, with Capseal II performing comparably to AH Plus.

Biological Properties
- Induce less tissue irritation and inflammation than many other sealers.
- Shon *et al*. reported low cytotoxicity and the ability to promote periapical healing by modulating periodontal ligament cell activity and enhancing osteoblast differentiation [41].

c. Nanoseal Plus
- **Overview:** An experimental sealer composed of **hydroxyapatite nanoparticles** (40–60 nm).

Properties
- Rod-shaped nanoparticles penetrate dentinal tubules and accessory canals, ensuring effective sealing [39].

3. Mixed Calcium Silicate– and Calcium Phosphate–Based Bioceramic Materials

a. iRoot SP

- **Form:** Syringe with dispenser.
- **Composition:** Zirconium oxide, calcium silicates, calcium phosphate monobasic, calcium hydroxide, fillers, and thickening agents.

Properties

- **Radiopacity:** ~3 mm Al
- **Flow:** ~26 mm
- **Setting time:** 4–10 hours (average ~4 h)
- **Film thickness:** ~25 µm
- **Solubility:** ~11%
- **Retrievability:** Can be removed using conventional retreatment techniques with gutta-percha, or with piezoelectric ultrasonics under water spray.

Applications & Biological Properties

- Comparable to Endosequence BC Sealer, with similar sealing and bioactive behavior [20].

b. Endosequence BC Sealer

- **Form:** Injectable syringe.
- **Composition:** Zirconium oxide, calcium silicates, calcium phosphate monobasic, calcium hydroxide, fillers, and thickening agents (meets ADA Specification No. 57:2000).
- **Working/Setting Time:** 4 hours working time; 4–10 hours setting time (ISO 6876:2001).

Interaction

- Setting depends on moisture from dentinal tubules; no additional moisture is required in the canal.

Biological Properties

- Excellent biocompatibility and osteoinductive potential due to similarity with natural hydroxyapatite.
- Acts as a **resorbable scaffold**, gradually replaced by regenerating tissue.
- Antibacterial effect through in situ precipitation, which entraps bacteria.

c. ERRM (Endosequence Root Repair Material)

- **Form:** Syringe and putty.
- **Composition:** Nanoparticles of tricalcium silicate, dicalcium silicate, calcium phosphate monobasic, amorphous silicon dioxide, and tantalum pentoxide.

Physical Properties:

- **Compressive strength:** 50–70 MPa
- **Setting time:** ~2 hours
- Radiopacity: Excellent, due to tantalum pentoxide

Biological Properties

- High pH (>12.5), strong resistance to washout, no shrinkage during setting, and excellent tissue compatibility.

Applications

- Used for pulp capping, root canal repairs, and apicoectomy retro-fillings.
- Advantages noted in clinical reports: easy handling, convenient syringe delivery, multiple clinical uses, and no mixing required.

d. BioAggregate

- **Form:** Powder and liquid system (Verio Dental Co. Ltd., Vancouver, Canada).
- **Composition:** Aluminum-free cement containing nanoparticle tricalcium silicate (main component), tantalum oxide (radiopacifier), calcium phosphate, and silicon dioxide.

Performance

- Releases calcium ions at high levels early, sustained for up to 28 days (in contrast to MTA, which shows delayed release) [9, 13].

Setting Reaction

- Hydration of tricalcium silicate produces calcium silicate hydrate and calcium hydroxide.
- Calcium hydroxide reacts with silicon dioxide to form additional calcium silicate hydrate, reducing free calcium hydroxide in aged cement.

Properties

- Alumi
- num-free formulation
- Excellent biocompatibility
- Optimal working and setting times
- Easy handling and manipulation
- Pure white, tooth-colored powder

Biocompatibility

- Highly compatible with periradicular tissues [13].

Indications

- Repair of root perforations and resorption defects
- Apexification procedures
- Direct pulp capping

Applications

- Nanotechnology-based particles react with water to form bioactive, aluminum-free ceramics.
- Hydrophilic powder promotes cementogenesis and creates a hermetic seal within the root canal.[6]

4. Experimental Calcium Aluminosilicate–Based Bioceramic Materials

a. AH Plus® Bioceramic Sealer

- **Form:** Supplied as a pre-loaded paste in an air-tight syringe.

Composition

- 5–15 wt% tricalcium silicate (core setting component)
- Zirconium dioxide (radiopacifier)
- Dimethyl sulfoxide (DMSO) as a non-reactive diluent to improve flow
- Lithium carbonate (setting accelerator)
- Additional ingredients: bentonite clay, polyvinyl alcohol, and polyvinyl pyrrolidone

Modified Form: AH Plus Jet®, delivered in mixing syringes for direct application into canal orifices.

- **Setting Reaction:** Hydration of tricalcium silicate produces calcium silicate hydrate and calcium hydroxide. The latter elevates pH, inducing hydroxyapatite (HA) formation.

Properties

- Radiopacity: ~7.5 mm Al
- Flow: ~26 mm
- Setting time: 2–4 h (average 19.78 h reported)
- Film thickness: ~25 µm
- Solubility: ~11%
- Easier to retrieve compared with other calcium silicate and ZOE-based sealers
- More radiopaque than most conventional bioceramic sealers
- Energy Dispersive X-Ray Spectroscopy (EDS) confirmed increasing calcium and phosphorus at the surface, verifying bioactivity
- High alkaline pH enables complete elimination of *Enterococcus faecalis* within 24 h of direct contact

Biological Properties: In *vitro* comparisons with EndoSequence BC sealer and AH Plus resin-based sealer showed no cytotoxicity and similar cell proliferation/migration, confirming good biocompatibility.

b. Generex A (Dentsply Tulsa Dental Specialties, USA)

- **Composition:** Calcium silicate, specialized gels, and hydroxyapatite.
- **Properties:** Exhibits strong resistance to washout, high compressive strength, and good radiopacity.
- **Applications:** Designed for retrograde fillings and perforation repair.
- **Biological Findings:** In comparative studies with Generex B, Capasio, and Ceramicrete-D (magnesium phosphate-based), Generex A was the only new-generation endodontic material (besides MTA) that supported **primary osteoblast growth** [13].

c. Capasio (Primus Consulting, USA)

- **Composition:** Primarily bismuth oxide, dental glass, and calcium aluminosilicate, combined with a silica and polyvinyl acetate-based gel.

Properties

- Demonstrates mineralization potential by promoting apatite deposition when exposed to synthetic tissue fluid.
- Shows greater ability than MTA to penetrate dentinal tubules when used as a root-end filling material.

Quick-Set (Primus Consulting, USA)

- **Overview:** A refined version of Capasio powder, marketed as Quick-Set. The liquid gel formulation was modified by removing the cationic surfactant, which had been linked to reduced cytocompatibility.

- **Biological Properties:** In studies with odontoblast-like cells, Quick-Set and MTA demonstrated similar cytotoxicity profiles.

- Both materials showed negligible toxicological risks after time-dependent elution of residual components [13].

Conclusion

Bioceramics have transformed surgical and non-surgical endodontics, offering superior properties and conservation of tooth structure. Despite advantages, challenges remain—slow adoption, limited guidelines, and need for improved antimicrobial profiles. Expanding research and clinical collaboration can accelerate innovation, ensuring bioceramics become the preferred, globally standardized materials for diverse dental applications.

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