

Journal of Dermatological Case Reports

Review

Bioceramic Materials for Root Repair and Regenerative Endodontics: A Narrative Review of Current Evidence

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Keywords:

Bioceramics; Calcium Silicate; Mineral Trioxide Aggregate; Biodentine; Endosequence Root Repair Material; Root Perforation; Apexification; Regenerative Endodontics; Root Repair

Received: 13-08-2026

Accepted: 15-09-2026

Published: 06-10-2026

Abstract:

Background:

Calcium silicate-based bioceramic materials have become increasingly important in contemporary endodontics because of their biocompatibility, bioactivity, sealing ability and capacity to interact with mineralized tissues. Mineral trioxide aggregate (MTA) established the foundation for their clinical use, while newer materials such as Biodentine, BioAggregate, EndoSequence Root Repair Material (ERRM) and iRoot BP Plus have been developed to improve handling, setting characteristics and clinical versatility.

INTRODUCTION

The management of complex endodontic conditions frequently requires materials capable of providing a durable seal while simultaneously maintaining compatibility with surrounding tissues. Root perforations, external resorption defects, immature permanent teeth and periapical surgical procedures represent clinical situations in which the interaction between the repair material and biological tissues may substantially influence treatment outcome. Traditional materials such as amalgam, zinc oxide-eugenol cements and calcium hydroxide have been

progressively supplemented or replaced by calcium silicate-based materials. The development of mineral trioxide aggregate (MTA) represented a major advancement because of its sealing ability, biocompatibility and capacity to stimulate mineralized tissue formation. Subsequently, several calcium silicate-based bioceramics were introduced, including Biodentine, BioAggregate, EndoSequence Root Repair Material (ERRM) and iRoot BP Plus. These materials were developed partly to overcome limitations associated with conventional MTA,

particularly prolonged setting time, difficult manipulation and discoloration. Bioceramics are not merely passive filling materials. Their hydration reactions result in calcium-ion release and an alkaline environment, while interaction with tissue fluids can result in deposition of calcium phosphate or apatite-like phases. These processes may contribute to biological sealing and mineralized tissue formation. Recent reviews continue to identify MTA as the most extensively supported bioceramic in endodontics, while newer materials demonstrate encouraging but comparatively less established clinical evidence. The present review therefore focuses specifically on the evidence supporting bioceramic materials in **root repair and regenerative endodontics**, rather than providing a general review of all applications of dental bioceramics.

LITERATURE SEARCH

A focused narrative literature review was conducted using the authors' existing thesis/library material and supplemented by PubMed-indexed literature. The principal search concepts included combinations of:

- Bioceramic Materials
- Calcium Silicate Cement
- Mineral Trioxide Aggregate
- Biodentine
- Bioaggregate
- Endosequence Root Repair Material
- Iroot Bp Plus
- Root Perforation Repair
- Root-End Filling
- Apexification
- Regenerative Endodontics
- Root Repair

BIOLOGICAL BASIS OF CALCIUM SILICATE-BASED BIOCERAMICS

The biological behavior of calcium silicate-based bioceramics is primarily associated with their hydration reactions. Hydration of calcium silicate phases results in the formation of calcium silicate hydrate and calcium hydroxide, accompanied by calcium-ion release and an increase in pH. The released calcium ions can interact with phosphate-containing tissue fluids and contribute to precipitation of calcium phosphate and apatite-like phases at the material-tissue interface. This process is considered important for the bioactivity and interfacial sealing ability of calcium silicate materials. Their hydrophilic nature is particularly advantageous in endodontics because the clinical environment cannot always be maintained completely dry. Many bioceramic

materials can set in the presence of moisture and therefore are suitable for applications involving perforations, surgical sites and immature roots. In addition to their physical sealing properties, calcium silicate-based materials may influence cellular behavior. Studies have reported favorable effects on cell viability, proliferation, differentiation and mineralization, although these responses vary according to material composition, concentration, setting condition and experimental model. An important distinction must therefore be made between **bioactivity, repair and true regeneration**. Formation of a mineralized barrier or cementum-like tissue does not necessarily represent regeneration of a functional pulp-dentin complex.

BIOCERAMIC MATERIALS FOR ROOT REPAIR

Mineral Trioxide Aggregate

MTA is the most extensively studied calcium silicate-based endodontic repair material. Its initial applications included root-end filling and repair of root perforations, followed by use in apexification, vital pulp procedures and regenerative endodontic treatment. The major biological advantages of MTA include favorable biocompatibility, calcium-ion release, alkaline pH, sealing ability and stimulation of mineralized tissue formation. These characteristics have established MTA as an important reference material for root repair. However, conventional MTA has limitations including relatively prolonged setting time, difficult handling and the potential for tooth discoloration associated with certain formulations. Despite the development of newer bioceramics, MTA continues to demonstrate strong clinical support. Recent literature continues to describe it as the most widely utilized and best-supported endodontic bioceramic.

Biodentine

Biodentine is a tricalcium silicate-based material developed partly to improve upon the handling and setting characteristics of conventional MTA. It demonstrates calcium-ion release, alkaline activity and apatite-forming ability and has been investigated for perforation repair, root-end filling, pulp therapy, apexification and regenerative procedures. Its relatively favorable handling characteristics and shorter setting time make it clinically attractive. Evidence from clinical studies and systematic reviews suggests that Biodentine can provide favorable outcomes in difficult endodontic conditions. A recent systematic review evaluating Biodentine in complex endodontic lesions reported favorable clinical and radiographic outcomes, including reduction in lesion

size and progression of periapical bone regeneration during follow-up. However, the authors emphasized the need for stronger evidence before making definitive conclusions regarding its regenerative superiority.

BioAggregate

BioAggregate is a calcium silicate-based bioceramic introduced as an alternative to MTA. It contains calcium silicate components and a radiopacifying system and has demonstrated favorable biological behavior in experimental studies. Reported characteristics include biocompatibility, bioactivity, calcium-ion release and mineralized tissue formation. BioAggregate has been investigated for root-end filling and root repair. However, compared with MTA and Biodentine, the amount of high-level clinical evidence remains relatively limited. Therefore, its favorable laboratory and experimental characteristics should not be interpreted as evidence of established clinical superiority.

EndoSequence Root Repair Material

EndoSequence Root Repair Material (ERRM) is a premixed hydraulic calcium silicate-based repair material. Its composition includes calcium silicate components, calcium phosphate, radiopacifying agents and other additives. Its premixed formulation provides a major clinical advantage by eliminating chairside mixing. The material is hydrophilic and capable of setting in the presence of moisture. ERRM has been investigated for perforation repair, root-end filling, apexification and other root repair procedures. Importantly, a 2025 systematic review and meta-analysis comparing newer bioceramics with MTA in endodontic microsurgery found **no significant difference in clinical success or failure** between the materials. ERRM accounted for most of the newer bioceramics included in the analysis. Thus, ERRM can reasonably be considered a clinically useful alternative to MTA, particularly when its handling advantages are desirable, but current evidence does not justify describing it as universally superior.

iRoot BP Plus and Premixed Bioceramic Putty Materials

iRoot BP Plus represents another group of premixed calcium silicate-based repair materials. These materials are supplied in a ready-to-use putty form and have been developed for applications such as apexification, perforation repair and root-end filling. The major advantages are ease of handling, moisture-dependent setting, bioactivity and convenient delivery into confined root defects. Recent clinical literature involving iRoot BP Plus has reported favorable outcomes in vital pulp procedures, although direct

evidence specific to root repair remains less extensive than the evidence available for MTA.

BIOCERAMICS IN ROOT PERFORATION REPAIR

Root perforation establishes an abnormal communication between the root canal system and periodontal tissues. The prognosis depends on several factors, including perforation location, size, contamination, time before repair, periodontal condition and quality of the final seal. MTA has traditionally been considered a reference material for perforation repair because of its sealing ability and favorable biological response. Biodentine has emerged as a clinically relevant alternative. Experimental and clinical evidence suggests that both MTA and Biodentine can promote favorable tissue responses following perforation repair. The available systematic evidence, however, has important limitations. Many comparative studies are animal studies, sample sizes are small and protocols vary considerably. Therefore, apparent differences between materials should be interpreted cautiously. Premixed bioceramics such as ERRM and iRoot BP Plus offer additional practical advantages. Their ready-to-use formulation may facilitate accurate placement, particularly in difficult repair sites.

BIOCERAMICS FOR ROOT-END FILLING AND ENDODONTIC MICROSURGERY

Root-end filling requires a material capable of providing an effective seal while remaining compatible with periapical tissues. MTA became widely accepted for this purpose because of its favorable sealing and biological characteristics. Newer bioceramic materials have subsequently been introduced, particularly premixed putties and hydraulic calcium silicate cements. The important clinical question is whether these newer materials actually provide superior clinical outcomes. Current evidence does not demonstrate this conclusively. A 2025 systematic review and meta-analysis identified five comparative studies involving newer bioceramics, predominantly ERRM, and found no significant difference in success or failure compared with MTA. The authors concluded that newer bioceramics were not conclusively superior, although their handling characteristics may make them attractive clinically. Similarly, a 2025 systematic review of bioceramics in retrograde apical surgery concluded that MTA and newer bioceramic putties demonstrate favorable clinical performance but emphasized the need for additional long-term controlled studies. Therefore, the principal advantage of newer materials may currently be **clinical convenience rather than proven superiority in healing**.

APEXIFICATION AND IMMATURE PERMANENT TEETH

Immature permanent teeth with necrotic pulps present a particular challenge because their roots have thin dentinal walls and open apices. Traditional apexification with calcium hydroxide requires prolonged treatment. Calcium silicate-based materials allow formation of an artificial apical barrier and may reduce treatment time. MTA has extensive evidence supporting its use in apexification. Premixed bioceramics such as ERRM and iRoot BP Plus provide an alternative with simplified handling. The current evidence suggests that calcium silicate-based materials can provide predictable apical barrier formation. However, apexification primarily produces **apical repair and closure rather than continued biological root maturation**. This distinction is important because regenerative endodontic procedures have subsequently been developed to potentially allow continued root development.

BIOCERAMICS AND REGENERATIVE ENDODONTICS

Regenerative endodontics aims to restore, as far as possible, the biological functions of the pulp-dentin complex rather than simply filling the root canal space. The biological characteristics of calcium silicate-based materials make them attractive for regenerative procedures. Their calcium-ion release, alkalinity and interaction with hard tissues may influence stem/progenitor-cell behavior and mineralized tissue formation. MTA has been widely used as a coronal barrier in regenerative endodontic procedures. Biodentine has also attracted interest because of its biological properties and handling characteristics. A recent randomized clinical study comparing Biodentine and MTA as pulp-space barrier materials during regenerative endodontic procedures reported significant periapical healing in both groups. At 18 months, there was no significant difference between the materials in periapical lesion healing or recovery of tooth sensibility. This finding is important because it suggests that Biodentine may provide a clinically acceptable alternative to MTA in selected regenerative procedures. Nevertheless, the evidence should be interpreted carefully. Positive sensibility responses and radiographic healing do not by themselves demonstrate histologically confirmed regeneration of a normal pulp-dentin complex. A recent systematic review of calcium silicate-based cements in regenerative applications also identified MTA and Biodentine among the most frequently investigated materials, while emphasizing variability in experimental conditions and cellular responses. Thus, the future role of bioceramics in regenerative endodontics may extend beyond their function as

sealing materials toward materials capable of modulating the local biological environment.

The current literature therefore supports a **material-specific rather than “one material fits all” approach**. MTA remains appropriate when extensive clinical evidence is prioritized. Biodentine may be selected when improved handling and setting characteristics are desirable. Premixed materials such as ERRM and iRoot BP Plus may offer practical advantages in difficult clinical situations. However, the presence of bioactivity alone should not be used to claim superiority. Material selection should consider the clinical indication, defect characteristics, moisture conditions, handling requirements, operator experience and available evidence.

Table 1. Major Calcium Silicate-Based Bioceramics Used for Root Repair

Material	Important Characteristics	Major Applications	Current Evidence
MTA	Biocompatible, bioactive, calcium-ion release, excellent sealing	Perforation repair, root-end filling, apexification, regenerative procedures	Strongest clinical evidence
Biodentine	Faster setting, improved handling, bioactive	Root repair, root-end filling, apexification, regenerative procedures	Promising clinical evidence
BioAggregate	Calcium silicate-based, bioactive, biocompatible	Root-end filling, perforation repair	Mainly experimental/limited clinical evidence
ERRM	Premixed, hydrophilic, moisture-setting	Root repair, perforation repair, apexification, microsurgery	Promising; increasing clinical evidence
iRoot BP Plus	Premixed putty, convenient placement, bioactive	Apexification, root-end filling, perforation repair	Promising but comparatively limited evidence

COMPARATIVE EVIDENCE AND CLINICAL IMPLICATIONS

Table 2. Current Interpretation of Evidence

Clinical Application	MTA	Biodentine	ERRM / iRoot BP Plus	Evidence Interpretation
Perforation repair	Strong evidence	Promising	Promising	MTA remains benchmark
Root-end filling	Strong evidence	Good experimental/clinical evidence	Promising	No proven superiority of newer materials
Apexification	Strong evidence	Promising	Promising	Bioceramics facilitate artificial apical barrier
Regenerative endodontics	Extensive experience	Increasing evidence	Emerging evidence	Functional regeneration remains unproven
Handling	More difficult	Improved	Excellent due to premixed forms	Newer materials offer practical advantage
Setting characteristics	Relatively prolonged	Faster	Convenient moisture-dependent setting	Newer formulations address MTA limitations
Long-term clinical evidence	Extensive	Moderate	Limited-moderate	Major evidence gap for newer products

LIMITATIONS OF CURRENT EVIDENCE

Several limitations should be recognized when interpreting the current literature. First, a substantial proportion of evidence originates from **in vitro and animal studies**. Although these studies are valuable for understanding biological mechanisms, they cannot completely predict clinical healing. Second, commercially available bioceramics differ in composition, particle size, radiopacifier and additives. Therefore, results obtained with one product cannot automatically be generalized to all calcium silicate-based materials. Third, clinical studies use heterogeneous outcome measures, including radiographic healing, symptoms, tooth retention, mineralized tissue formation and cell responses. Finally, many studies describe calcium-ion release, apatite formation or mineralization as evidence of regeneration. These outcomes demonstrate bioactivity but do not necessarily prove regeneration of a functional pulp-dentin complex. Future clinical research should therefore use standardized outcome measures and longer follow-up periods.

FUTURE PERSPECTIVES

The next generation of endodontic bioceramics should aim to combine the established biological advantages of calcium silicate materials with improved physical

and clinical properties. Important areas of development include:

1. **Reduced setting time** without compromising biological activity.
2. **Improved mechanical properties** and resistance to dissolution.
3. **Enhanced antimicrobial activity** without increasing cytotoxicity.
4. Improved dimensional stability and adhesion to dentin.
5. Development of materials capable of **controlled ion and bioactive molecule release**.
6. Greater understanding of interactions with stem/progenitor cells.
7. Development of biomaterials specifically designed for regenerative endodontics.

The ultimate objective should not simply be the formation of an apical barrier or mineralized tissue, but restoration of a functional tissue environment capable of supporting vascularization, neural development and continued dentin formation. Recent reviews similarly emphasize the need for controlled clinical studies before newer bioceramics can be considered established replacements for MTA.

CONCLUSION

Calcium silicate-based bioceramics have substantially changed contemporary endodontic root repair. Their favorable biocompatibility, bioactivity, calcium-ion release, alkaline activity and sealing properties make them particularly suitable for perforation repair, root-end filling and management of immature permanent teeth. **MTA remains the most extensively validated bioceramic and continues to represent the clinical benchmark.** Biodentine provides improved handling and setting characteristics with increasingly supportive clinical evidence. Premixed materials such as ERRM and iRoot BP Plus offer important practical advantages and promising biological behavior. Current evidence does not establish a universal superiority of newer bioceramics over MTA. Instead, these materials should be regarded as clinically useful alternatives whose selection should be based on the specific clinical indication and available evidence. In regenerative endodontics, bioceramics have an important role as biologically compatible sealing materials and potential modulators of tissue response. Nevertheless, mineralization, apical closure and radiographic healing should not automatically be interpreted as true regeneration. Future research should therefore move toward **well-designed randomized clinical trials, standardized outcome measures and long-term evaluation of functional regenerative outcomes**.

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