REVIEW ARTICLE

# The Role of Bioceramic Sealers in the Healing of Apical Periodontitis: A Narrative Review

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## Abstract

Apical periodontitis (AP) is a chronic inflammatory condition affecting the periapical tissues, primarily caused by microbial infection within the root canal system. Successful healing of AP following root canal treatment (RCT) relies on effective disinfection and the establishment of a durable apical seal. Bioceramic sealers have gained increasing attention in endodontics due to their bioactivity, biocompatibility, and sealing properties. This narrative review aimed to evaluate the role of bioceramic sealers in promoting the healing of AP after RCT. A structured literature search was conducted in PubMed, Scopus, Web of Science, and Google Scholar for studies published between 2020 and 2025. Ten studies met the inclusion criteria and were narratively synthesized. The available evidence suggests that bioceramic sealers are associated with favorable periapical healing outcomes. Most clinical studies demonstrated healing outcomes comparable to or superior to those achieved with epoxy resin-based sealers. Bioceramic sealers appear to be a promising material for enhancing periapical healing following RCT; however, further well-designed clinical studies are needed to confirm their long-term effectiveness.

**Key words:** Bioceramic sealers, epoxy resin, root canal system

## INTRODUCTION

Apical periodontitis (AP) is a chronic inflammatory condition of the periapical tissues caused by pulp necrosis due to microbial invasion. Even though AP is mainly found in the oral cavity, new research indicates that it may cause systemic health problems by releasing microbial products such as lipopolysaccharides and proinflammatory cytokines like tumor necrosis factor alpha (TNF-α), interleukin (IL)-1β, and IL-6.[1] It is commonly known that AP is common around the world, especially in people who have untreated necrotic teeth. Although AP is frequently thought of just a localized problem in dental care, its possible systemic implications are becoming more widely acknowledged. Research has shown that persistent endodontic infections may share processes with periodontitis, a more well-researched condition with systemic consequences, and function as modifiable risk factors for systemic disorders.[2,3]

Periapical status has traditionally been evaluated using conventional radiographic methods, such as two-dimensional (2D) periapical and panoramic radiography. Nevertheless, the diagnostic accuracy of these modalities is limited since they only offer a 2D depiction of a three-dimensional (3D) structure and do not include the buccolingual dimension. Because cone-beam computed tomography can give high-resolution 3D image of periapical structures and remove anatomical superimposition, it has becoming widely used in endodontics. It is particularly difficult to identify AP with traditional 2D imaging because lesions limited to cancellous bone often go unreported, and periapical radiolucency usually only shows up when cortical bone involvement develops.[4,5]

Using various imaging techniques, the prevalence of AP has been examined in a number of groups. Research has consistently shown that AP is more common in teeth that have had root canal therapy (RCT), and the quality of endodontic

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treatment and coronal restorations has a significant impact on the disease's frequency. The significant global impact of AP was highlighted by a recent systematic review and meta-analysis that revealed a prevalence of almost 52% at the individual level and 5% at the tooth level.[6] In Saudi Arabia, several studies have evaluated the prevalence of AP using panoramic or periapical radiographs. However, some investigations included mixed-nationality cohorts or focused exclusively on endodontically treated teeth, limiting the generalizability of their findings.[7-9]

Root canal filling (RCF) represents a critical phase in endodontic treatment, aimed at sealing the canal system, preventing reinfection, and supporting long-term success. The prognosis of teeth that have had RCT has been found to be significantly influenced by the quality of the filling, especially its apical sealing, homogeneity, and adaptability. To reduce post-treatment illness and stop microbial leakage, an ideal apical seal is essential.[10] RCF is performed after a sterile environment is achieved during root canal treatment (RCT). RCF serves a secondary function in "entombing" leftover germs, even though its main goal is to stop new infections or reinfections. To minimize the amount of root canal sealer and establish gutta-percha (GP) as the main component of the RCF core, RCF traditionally uses lateral and vertical condensation procedures using GP.[11]

However, single-cone, "cold" methods have become more common thanks to recent developments in root canal sealers, such as the creation of hydraulic calcium silicate-based and bioceramic sealers.[12] These techniques boost the amount of sealer from standard levels using tapered GP cones. Results from clinical trials assessing this strategy were found to be comparable to those of conventional lateral condensation.[13] This is because contemporary sealers have better mechanical qualities, such as increased wettability and less shrinkage after setting. In particular, improved sealing brought about by calcium phosphate precipitation accounts for the higher clinical performance of hydraulic calcium silicate-based and bioceramic sealers.[11]

Alternative quality control methods during RCT, such as the culture test used during the focused infection era, may have resulted from the uncertainty in outcome caused by periapical healing latency. In addition to the fact that RCT had already gained widespread acceptance, the test lost favor in modern practice since the procedure was thought to impair cost-effectiveness. In ordinary practice, the immediate (and occasionally the final) outcome assessments at the end of the treatment are the radiographic evidence of technically perfect root-filling and the post-operative absence of clinical signs and symptoms.[14] Due to their high sealing capacity and bioactivity, bioceramic sealers have become more and more popular in recent years. Nevertheless, there are still a few high-caliber comparative studies that directly assess how well they work in comparison to conventional sealers in both primary RCTs and retreatment instances (re-RCTs). Because previous filling materials might complicate retreatment methods and affect results, there is a large evidence gap.[10]

Bioceramic materials are biocompatible ceramic materials designed to interact with biological systems, which are primarily used in medicine and dentistry to replace or regenerate damaged hard tissues.[15] Bioceramic materials in endodontics mainly interact with dental pulp and the surrounding tissues of the tooth and root canal system, which are best suited for mechanical qualities and biocompatibility.[16] Since mineral trioxide aggregate (MTA) was first introduced as a bioceramic in 1993, bioceramics have revolutionized endodontics by offering ways to rebuild and repair damaged dental tissues in order to restore their original functionality.[17]

The market for bioceramics was estimated to be worth USD 7.4 billion in 2023. The root canal sealer market segment is anticipated to develop at a compound annual growth rate of 3.6%, from USD 2.41 billion in 2024 to USD 3.25 billion by the end of 2032. Endodontic applications, including root canal fills, sealants, and regenerative endodontic procedures, are the main drivers of the market's expansion. Materials like calcium silicates (CaSi), such as MTA, bioactive glasses, and other CaSi, have demonstrated the capacity to encourage the regeneration and healing of injured tooth tissue thanks to recent advancements.[18]

## PATHOPHYSIOLOGY OF AP

### Microbial etiology

Through a variety of strategies, including modulating immune cell death, invasive pathogenic bacteria frequently suppress immune cell activity in order to survive and spread across periapical tissues. There is evidence that *Enterococcus faecalis*, which is thought to be the main cause of persistent AP and failed root canal therapies, affects macrophage apoptosis in a concentration-dependent way. In developing bone marrow stem cell-derived macrophages, prolonged exposure to *E. faecalis* suppresses apoptotic signaling at low multiplicity of infection.[19] Furthermore, early infection at high multiplicity of infection suppresses apoptosis by blocking caspase-3 activation through the PI3K/Akt pathway.[20] On the other hand, caspase-dependent apoptosis in macrophages is regularly triggered by high-concentration *E. faecalis* infections.[21]

This biphasic reaction points to a bacterial survival strategy that involves postponing host cell apoptosis during early colonization to aid in adaption and spread, and subsequently encouraging apoptosis to allow for bacterial discharge and the spread of periapical inflammation. Furthermore, *E. faecalis* causes periapical bone resorption by inducing osteoblast apoptosis through both intrinsic and extrinsic mechanisms.[22-24] Other endodontic infections exhibit similar

processes. For instance, *Fusobacterium nucleatum*, which was isolated from human necrotic tooth pulp, causes lymph node cells to undergo apoptosis mediated by the tumor necrosis factor receptor p55.[25]

## Molecular mechanism of regulated cell death (RCD)

- Apoptosis is a highly preserved type of RCD that preserves the integrity of the plasma membrane while exhibiting unique morphological and biochemical characteristics, such as cell shrinkage, nuclear condensation, chromatin condensation and margination, and the production of apoptotic bodies.[26] This programmed cell death mechanism is divided into intrinsic apoptosis (mediated by mitochondrial signals) and extrinsic apoptosis (controlled through death receptor-driven processes) based on the different origins of apoptotic stimuli.[27]
- Necroptosis serves as a pivotal driver of inflammatory amplification and osteolytic destruction in AP, operating through regulated necrosis that releases danger-associated molecular patterns (DAMPs) and proinflammatory cytokines to exacerbate periapical bone resorption. In particular, Dai *et al*. found widespread macrophage infiltration in periapical lesions, where macrophage markers CD68 and F4/80 co-localized with the necroptosis executioner protein MLKL. This geographical correlation suggests that inflammatory cascades in periapical tissues are directly amplified by macrophage necroptosis.[28]
- Pyroptosis, a lytic and highly proinflammatory form of RCD, serves as a central driver of periapical bone destruction in AP by orchestrating inflammasome-mediated cytokine release, osteoclast hyperactivation, and feedforward inflammatory amplification.[29]
- PANoptosis has been shown to exacerbate inflammatory responses in periapical tissues. *F. nucleatum* infection triggers ZBP1-mediated PANoptosis in macrophages, characterized by the release of abundant inflammatory cytokines.[30]
- Autophagy serves as a pivotal immunomodulator in AP, dynamically modulating inflammatory responses and cellular homeostasis through context-dependent activation or suppression. While overexpression of regulator of G protein signaling 10 activates TFEB-mediated autophagy, which suppresses macrophage infiltration and bone resorption, reduced TFEB-mediated autophagy worsens inflammation in AP, as demonstrated by increased production of IL-1β, IL-6, and TNF-α in lipopolysaccharide-stimulated macrophages.[31]

## Host immune response

Pattern recognition receptors, like Toll-like receptors, are found on the membranes of epithelial and immune cells, including macrophages and dendritic cells, and are involved in host immunological activation. These receptors detect microbial motifs or DAMPs and start signaling cascades that encourage the production of proinflammatory mediators like TNF-α, IL-1β, and IL-6. Neutrophils are drawn to the infection site by these cytokines. Neutrophils are quickly released from the bone marrow into the bloodstream upon detecting infection or tissue damage, and they are then drawn to the afflicted areas.[32,33]

They use a variety of antimicrobial strategies there, such as phagocytosis, degranulation, reactive oxygen species (ROS) generation, and neutrophil release. They use a variety of antimicrobial strategies there, such as phagocytosis, degranulation, ROS generation, and neutrophil release. In addition, neutrophils can support immunological suppression and the resolution of inflammation by contributing to an anti-inflammatory phenotype marked by the release of IL-10 and CCL2. On the other hand, certain neutrophils display hyperinflammatory profiles in chronic inflammatory conditions, generating proinflammatory cytokines like IL-12 and chemokines like CCL3 and CCL4. These mediators exacerbate tissue deterioration by activating additional immune cells.[34]

Macrophages play a more critical role in the innate immune response and tissue destruction. Proinflammatory cytokines are released by activated macrophages, which intensify the inflammatory response and stimulate additional immune cells. In addition, they release catabolic enzymes such as prostaglandins and MMPs, which promote extracellular matrix degradation and cause periodontal disease.[35,36] In addition, B cells contribute to the development of disease and the adaptive immune response. They develop into plasma cells, which release antibodies, mainly immunoglobulin G, which can attach to periodontal bacteria and help remove them.[37]

## Factors influencing healing

1. Patient-related factors: One of the main elements affecting periodontal healing after regenerative periodontal therapy is post-operative plaque control. The results of periodontal regeneration are more influenced by the self-performed plaque control. In terms of improved clinical attachment level (CAL) gain, patients with high levels of plaque management benefit more than those with low levels. Optimal levels of plaque management were primarily responsible for the long-term stability of periodontal regeneration. Smoking is thought to be a potential negative predictor since it hinders the healing of periodontal wounds and raises the risk of infection following surgery, which leads to less favorable regeneration. Smokers' regenerative results were much worse than those of non-smokers.[38]
2. Tooth-associated factors: The amount of clinical attachment and bone acquired at 1 year is significantly

impacted by the depth of the intrabony component of the lesion. Deeper defects showed a noticeably greater degree of clinical improvement. However, it was found that the regenerating capability of shallow and deep lesions was equal in a multicenter controlled trial. The width of the intrabony component is another significant morphological feature of the defect. CAL and bone gain at 1 year were significantly lower for broader lesions than for narrower abnormalities.[39,40] In periodontal regenerative therapy, the importance of tooth vitality has been regarded as a relevant aspect. The healing response after periodontal regenerative therapy is not negatively impacted by successfully root canal-treated teeth, and there are no appreciable variations between vital and root canal-treated teeth in the stability of the attachment level gain after regenerative therapy.[41]

3. Surgery-associated factors: Blood clot stabilization is crucial during the early stages of wound healing because it offers a framework for cell migration and/or proliferation. However, weakened wound stability may result in poor fibrin clot adhesion to the root surface, which could cause the lengthy junctional epithelium to develop and degrade the results of regenerative therapy. During the initial weeks following surgery, maintaining wound stability appears to be crucial. Inhibit the series of biological processes that lead to periodontal regeneration when wound stability is compromised due to wound dehiscence.[38]

## EVOLUTION OF ROOT CANAL SEALERS

Following the establishment of a sterile environment during RCT, RCF is carried out. RCF serves a secondary function in "entombing" leftover germs, even though its main goal is to stop new infections or reinfections. To minimize the amount of root canal sealer and establish GP as the main component of the RCF core, RCF traditionally uses lateral and vertical condensation procedures using GP. However, single-cone, "cold" methods have gained popularity because to recent developments in root canal sealers, such as the creation of hydraulic calcium silicate-based and bioceramic sealers.[11]

### Conventional sealers

Grossman established the ideal root canal sealer's qualities, which are still used as a standard for evaluating materials. His standards state that the ideal sealer should: demonstrate an appropriate viscosity during mixing to provide successful adhesion to the canal walls during setting; create a hermetic seal; be radiopaque so that radiographic images can be seen; be made into an extremely fine powder so that it can be easily combined with a liquid; do not shrink when setup and keep your dimensions stable.; Prevent tooth structure discoloration; be bacteriostatic or at the very least not encourage bacterial growth; have a setting time that is slow enough to permit clinical manipulation; Be non-irritating to periapical tissues, insoluble in tissue fluids, and soluble in a widely accessible solvent to make removal easier if needed.[42] No single product presently meets all of these ideal requirements, despite continuous progress in material science. There are many commercially available endodontic sealers, and their chemical makeup and clinical efficacy vary greatly.[43]

1. Zinc oxide eugenol (ZOE)-based sealer: Since their creation, ZOE has been a standard in endodontics due to its long-term efficacy. Zinc oxide powder and eugenol liquid, an essential oil made from cloves, are components of ZOE sealers. Eugenol and zinc oxide combine to generate an amorphous gel when added to damp root dentin. A stiff matrix is created in the gel by the remaining zinc oxide particles. Teeth have become darker as a result of certain of these powder-liquid sealers that contain silver in the powder component (Kerr formula).[44]
2. Glass ionomer-based sealers: A fine silicate glass powder is combined with polyacrylic and related acids to create glass ionomer sealer products. They combine to create an ionomer by forming repeating subunits of inorganic ions and organic monomers. In dentistry, these materials are utilized for restoratives and cements. Fluoride is released by glass ionomer cement sealer KT-308 (GC, Tokyo, Japan) to attach to tooth structure and prevent decay, but this product is no longer sold.[44]
3. Silicone-based sealers: Silicone-based sealers are made of polymethyvinylsiloxane, which contains a platinum salt and polymethylhydrogensiloxane. The polymer is formed via an addition reaction between vinyl groups and hydrosilyl groups connected to the polydimethylsiloxane chain. Silicone-based sealers include GuttaFlow, GuttaFlow 2, and RoekoSeal (Coltene/Whaledent). While GuttaFlow 2 and RoekoSeal are auto-mix, GuttaFlow is triturator-mixed and needs a single master cone.[45]
4. Methacrylate resin-based sealers: There are four generations of methacrylate resin-based sealers, each of which reflects improvements in clinical performance and formulation. Methacrylate-based sealers outperform silicone and zinc oxide-based sealers in terms of resistance to vertical root fracture when paired with Resilon. Methacrylate resin-based sealers have certain drawbacks despite their many benefits. Their cytotoxicity is the biggest worry. Research has shown that toxicity ranges from moderate-to-severe and tends to worsen with time.[46,47]
5. Epoxy resin-based sealers: Due to their notable physicochemical and mechanical qualities, such as satisfactory adhesion to dentin, a tight apical seal, sufficient flow characteristics and film thickness, low solubility, long-term dimensional stability, relatively low toxicity, and antibacterial performance, epoxy resin-based sealers are now widely used. However, in order to overcome drawbacks like prolonged setting times, modest solubility, or restrictions on flow and dimensional

stability, it is constantly necessary to improve their physicochemical and mechanical qualities through the creation of optimum formulations.[48]

6. Calcium hydroxide-based sealers: Due to their advantageous biological and physicochemical characteristics, calcium hydroxide-based endodontic sealers make up a significant class of root canal obturation materials. Strong alkalinity (pH~12.5) in calcium hydroxide ($Ca(OH)_2$) is the basis for its antibacterial action and capacity to neutralize bacterial endotoxins. In addition, it stimulates the creation of hard tissue, which aids in periapical healing.[49] These sealers are especially useful in situations involving large periapical lesions or during endodontic retreatment procedures due to their well-known high biocompatibility and osteogenic and cementogenic potential.[50]
7. Bioceramic sealers: The most recent generation of root canal obturation materials are bioceramic sealers, which stand out for their attractive physicochemical characteristics, strong bioactivity, and biocompatibility. Their main constituents are CaSi, which undergo a hydration process when they come into contact with moisture. This reaction releases calcium and hydroxyl ions and forms hydroxyapatite (HAp) at the interface with surrounding tissues. This process actively promotes periapical healing and tissue regeneration in addition to guaranteeing a tight closure of the root canal system. Bioceramic sealers differ from conventional epoxy and calcium hydroxide-based sealers in that they are hydrophilic, do not shrink while setting, and function well in damp conditions.[51,52]

## COMPOSITION AND PROPERTIES OF BIOCERAMIC SEALERS

More than 10 years ago, bioceramic materials based on calcium phosphate and silicate were introduced to the market. Their superior physicochemical and biological qualities have drawn attention. Endodontic bioceramics' physicochemical characteristics are carefully chosen to satisfy particular needs in the root canal environment. First and foremost, biocompatibility is an essential characteristic that guarantees these materials won't cause harmful responses in nearby tissues.[16,53] Next, accurate radiographic visualization during procedures and post-treatment monitoring depend on radiopacity.[54] Furthermore, many endodontic bioceramics have high solubility; however, this solubility is regulated for particular uses. Beneficial ions like calcium and silicate, which have antibacterial qualities and can encourage the development of mineralized tissue, can be gradually released when solubility is controlled5. Excessive solubility, however, can present long-term difficulties.[55]

Premature material deterioration could threaten long-term solubility, resulting in the loss of the root canal seal's structural integrity. When the solubility rate is excessively fast, this issue is particularly pertinent. If endodontic bioceramics are not properly regulated, their durability may be adversely affected, which could impact the treatment's efficacy. Strategies for improving the composition of bioceramics were put into practice to reduce any long-term problems. Higher-quality products have been made possible by the development of bioceramic cements with regulated solubility that also allow for the advantageous release of ions without sacrificing the material's structural stability.[55,56]

Bioceramic materials are perfect for a variety of applications in the endodontic environment in addition to having the aforementioned qualities. When they come into direct contact with various tissues, these inorganic compounds have the ability to react actively. Due to their superior biocompatibility and bioactivity, they stimulate the development of HAp, which enables tooth repair with a fairly similar physical structure. MTA and bioceramic cements stand out among these materials due to their special qualities and particular uses that make them crucial to dental practice.[57]

In addition to a variety of products on the market, bioceramic cements, which are made of ceramics such as calcium silicate and tricalcium phosphate, offer a broader range of uses, such as pulp capping, canal filling, and perforation repair.[16] Nanoparticles, or particles with diameters in the nanometer range, are frequently found in bioceramic cements. The flowability and adaptability of bioceramic cements in intricate root canals are enhanced by the presence of nanoparticles. Nanoparticles can improve the material's ability to penetrate anatomical features and microfissures, increasing the efficiency of sealing.[58]

### Bioactive potential

Mineralized tissue can develop as a result of bioceramic materials interacting with surrounding tissues. The release of calcium hydroxide causes this formation, which results in the induction of a mineralized barrier. Calcite crystals are created when hydrated calcium silicate and calcium ion release interact with carbon dioxide in tissue, resulting in the creation of mineralized tissue and the deposition of fibronectin. This process gives the material bioactivity by causing cells to differentiate into fibroblasts, odontoblasts, and cementoblasts. Furthermore, bioceramic's alkaline pH creates an environment that is hostile to harmful microbes and favorably promotes bone neoformation and tissue repair.[59,60]

Dental areas with root perforations can be restored thanks to the bioactivity of bioceramic sealers. However, these bioactive materials can perform a stable connection when utilized as a retrograde filling material. By depositing calcium silicate and HAp in an interfacial layer that forms between the biomaterial and the dentin tubules, this connection is made with live tissues. Since direct contact with the applied material encourages the formation of apatite crystals in these

other areas, this interfacial layer also causes the cementum and periodontal ligament to remineralize.[57] In addition, bioceramic materials were developed for use as endodontic sealants. Long-term usage of MTA Fillapex sealer (Angelus) was shown to boost alkaline phosphatase (ALP) enzyme activity and mineralized nodule formation, increasing its bioactivity after setting.[61] One of the plasmatic membrane's enzymes linked to the mineralization process is ALP, which is also one of the primary markers of osteoblast activity.[62]

## MECHANISM OF ACTION IN HEALING

There are a number of theories for calcium silicate-based sealers, despite the fact that the precise process by which bioceramic sealers adhere to root dentin is still unclear.

1. Tag-like structures form next to an interfacial layer known as the "mineral infiltration zone," where collagen in the surrounding dentin is broken down by alkaline byproducts from the hydration of calcium silicate cement. High concentrations of calcium ($Ca^{2+}$), hydroxide ($OH^-$), and carbonate ($CO_3^{2-}$) ions can diffuse across the porous network that this breakdown produces, encouraging further mineralization in that region.[63]
2. Alongside the previously identified mineral infiltration zone, HAp crystals are formed when dentin moisture is present due to the interaction between calcium and phosphate.[64]
3. Bioceramics produce porous powders composed of nanocrystals with a diameter of one to three nanometers, which successfully prevent germs from adhering. Their antibacterial qualities are further enhanced by their high alkaline pH.[63]
4. They possess inherent osteoinductive potential because they can take in osteoinductive materials when there is a bone healing process in proximity.[65]
5. It serves as a regenerative framework made of biodegradable lattices that provide a framework that progressively disintegrate while the body restores tissue. The capacity to have good radiopacity, form a chemical bond with the tooth structure, and produce an excellent airtight seal.[65]

## BIOCOMPATIBILITY AND CYTOTOXICITY

Two of the most crucial factors in assessing sealer performance are biocompatibility and cytotoxicity. In addition to being minimally harmful to host tissues, a sealer should promote cellular activity and tissue regeneration, particularly when dental tissue-derived stem cells are present. While biocompatibility refers to a material's capacity to live with surrounding biological systems without causing detrimental effects, cytotoxicity refers to a material's tendency to damage or impair the function of essential cells, like periodontal ligament stromal cells. Newer biomaterials, especially calcium silicate-based bioceramics, which are thought to be more advantageous than conventional epoxy resin- or zinc oxide-based sealers due to their bioactivity and regenerating potential, have been developed in an effort to increase biocompatibility.[66]

The capacity of a substance to encourage a biological response with a decreased inflammatory reaction that results in structural and functional tissue restoration is known as biocompatibility. An apatite layer may form at the material-tissue interface as a result of interactions between a bioactive material and living tissue. Following endodontic treatment, periapical tissue repair is anticipated to be aided by the biocompatibility and bioactivity of bioceramic endodontic sealers. Based on the measurement of calcium precipitation, the von Kossa method assesses calcium deposition. Using immunohistochemistry to identify proteins like osteocalcin, a peptide released by osteoblasts during bone formation, the induction of mineralized deposits can be evaluated.[67]

Calcium hydroxide and calcium silicate hydrate, which have numerous therapeutic uses, including ready-to-use materials that set with moisture in dentin and surrounding tissues, are promoted by calcium silicate materials. Due to their superior biological qualities and bioactivity, new endodontic sealers based on calcium silicate are being developed.[68,69] A bioceramic root canal sealer that is ready to use is called NeoSealer Flo (NeoFlo, NuSmile, Houston, TX, USA). The producer claims that it exhibits antibacterial action, dimensional stability, biocompatibility, and the capacity to create HAp. NeoFlo releases physiologically active ions like calcium and phosphate and has suitable physicochemical characteristics. Comparing it to EndoSequence BC, the clinical success rate for obturated cases was 96.5% as opposed to 94.9%. The reduction of inflammatory cells and the reorganization of connective tissue indicate that NeoSealer Flo and the associations with cetrimide are biocompatible and have bioactive potential, even if the addition of cetrimide to NeoSealer Flo increased the inflammatory response.[70]

Bio-C Sealer (BC, Angelus, Londrina, Paraná, Brazil) is a ready-to-use bioceramic endodontic sealer with biocompatibility and bioactive potential that comes in a single syringe. Alkalinization capacity, sufficient flow, radiopacity, and volumetric stability are all present in BC. More radiopacity than TotalFill BC Sealer is found in AH Plus (AHP, Dentsply DeTrey GmbH, Konstanz, Germany), an endodontic sealer based on epoxy resin with zirconium oxide and calcium tungstate. AHP is regarded as biocompatible and causes an initial inflammatory response that gradually diminishes. Nevertheless, AH Plus lacks bioactivity.[71,72]

The Fédération Dentaire Internationale and the International Standard-ISO advocate the examination of biomaterials implanted into subcutaneous connective tissue as a controlled methodology for assessing the degree of irritability of dental materials. This makes it possible to accurately evaluate the reactions brought on by the substance and describe the

kind, size, and duration of the lesions. In addition, research employing biomaterial implantation in subcutaneous tissues shows noteworthy outcomes concerning the impact of various endodontic materials on biomineralization indicators and inflammation. To improve the clinical efficacy of these materials and to comprehend the mechanisms driving periapical tissue healing and regeneration, research into tissue responses and the bioactive potential of bioceramic endodontic sealers is essential.[70]

## CLINICAL APPLICATIONS OF BIOCERAMIC MATERIALS

Bioceramic materials come in a variety of forms, including putties, sealers, and pastes, and are frequently employed in endodontics. Root-end filling, vital pulp therapy, apexification, regenerative endodontic therapy, perforation repair, and root defect repair are among the procedures that frequently employ putties. During RCT, pastes like BioRoot RCS and BC Sealer are primarily utilized as sealing agents. Due to these materials' superior physical and biological qualities, which make them simpler to employ even for inexperienced doctors, they have grown in favor.[73] There are two types of bioceramic sealers: a premixed formulation that solidifies when it comes into contact with moisture from the surrounding tissues, and a powder–liquid formulation that needs to be manually mixed, making it technique-sensitive and perhaps causing inconsistent handling. By lowering the possibility of error, premixed sealers provide the benefit of a uniform texture and easier handling during clinical operations.[63]

Excellent biocompatibility, reduced cytotoxicity, increased cell attachment, and the presence of calcium phosphate, which strengthens the binding between the sealer and root dentin, are the benefits of using bioceramic materials as root canal sealers. In addition, some research indicates that these sealers may promote bone regeneration in the surrounding area if they are inadvertently pushed past the root tip (apical foramen) during filling or perforation repair. *In vitro* research has demonstrated that bioceramic materials, particularly when combined with GP cones coated or impregnated with bioceramic, can increase the fracture resistance of teeth that have received RCT.[74]

Numerous endodontic sealers, including iRoot SP, EndoSequence BC, Totalfill BC, and others, have been created over time, each with special qualities, advantages, and disadvantages. The clinician's experience, preferences, and the particular qualities of the material are all important considerations when choosing a sealer. The single-cone approach, cold lateral condensation, warm vertical compaction, and carrier-based procedures are some of the obturation processes utilized with sealers. These techniques aim to provide a more durable and secure seal by increasing the amount of GP employed while reducing the amount of sealer. The single-cone method is the simplest and most direct of them.[75,76]

## RETREATMENT AND HANDLING CONSIDERATIONS

Complete debridement of the root canal system, removal of germs and diseased or necrotic pulp tissue, and closure of the canal space are all necessary for endodontic therapy to be successful in preventing infection and reinfection of the pulp cavity. Over 90% of RCTs are successful when done correctly. Endodontic failures are still possible, though, and they can be caused by overextended fillings, incomplete debridement, poor obturation, missing canals, or secondary infections brought on by coronal leaks. The most advised and successful course of treatment in these situations is non-surgical orthograde retreatment.[77]

Retreatment's main goal is to remove all filling materials to properly disinfect the canal area and enable re-obturation.[78] Retreatment can be difficult because leftover obturation materials, especially in dentinal tubules, lateral canals, and canal ramifications, can contain germs and block irrigants and medications, preventing periapical healing.[79] Thus, a key component of a successful retreatment is the retrievability of RCF materials.[80] The classic sealers have a few drawbacks, including shrinking upon setting, being washed up in the presence of tissue fluids, and potentially causing an inflammatory reaction to the periapical tissue if extruded beyond the apical foramen, which might negatively impact the outcomes of RCT.[81]

Many of the drawbacks of conventional sealers have been addressed by the introduction of bioceramic-based sealers, which are mostly made of CaSi, thanks to recent developments in material science. They are the perfect option for endodontic therapy due to their greater biocompatibility with periapical tissues and the presence of calcium phosphate, which creates a crystalline structure similar to that of bone and natural dentin. These materials have exceptional bioactivity, antibacterial qualities, and dimensional stability. They also have the special capacity to set in the presence of moisture, which is a natural part of the root canal environment. Due to these benefits, a number of premixed calcium silicate-based sealers, including CeraSeal, Prashanti Bioceramic Sealer, and MTA Fillapex (which blends MTA with resin), have become more well-liked in clinical practice due to their simplicity of use and promising clinical performance.[77]

## ADVANTAGES AND LIMITATIONS

It is to be noticed that due to their remarkable biocompatibility, bioactivity, and sealing qualities, calcium silicate-based bioceramic sealers such as EndoSequence BC Sealer, TotalFill BC, and BioRoot RCS have become

increasingly popular in endodontics. Superior sealing and periapical healing are facilitated by their hydrophilic nature and capacity to produce HAp in situ. However, during non-surgical endodontic retreatment, their beneficial chemical and physical interactions with dentinal structures pose significant hurdles.[82] Interface and Retention of Material-Dentin: HAp -like crystals are deposited along with the formation of a mineral infiltration zone in the dentin by bioceramic sealers. This leads to chemical bonding and micromechanical interlocking with dentinal tubules, making their total removal during retreatment more difficult Table 1.[83]

While retrieval in straight canals was enhanced by ultrasonics and photon-induced photoacoustic streaming methods, residual material remained in complex anatomies. Furthermore, popular solvents that work well against GP and resin-based sealers, including eucalyptol or chloroform, do not considerably soften bioceramics. Retreatability is also influenced by the obturation technique. In contrast to cold lateral compaction, warm vertical compaction changes the physical characteristics of bioceramic sealers, increasing hardness and impeding subsequent removal, according to a systematic micro-computed tomography review. The material may become more embedded in the canal walls due to expansion or degradation of the crystalline matrix caused by heat.[63]

### Instrumentation force and torque

Compared to conventional sealers, mechanical retreatment in bioceramic-filled canals produces distinct stress profiles. Even while apical forces were reduced, substantial residues persisted, especially in the apical third, according to an *in vitro* investigation employing XP-endo Shaper.[63] Bioceramic sealers needed more activation techniques and a longer instrumentation time to achieve satisfactory cleanliness, although torque and coronal forces were similar to those observed with AH Plus sealer retreatments.[84]

## FUTURE PERSPECTIVES

Bioceramic sealers offer a promising future in endodontics due to their biological compatibility, sealing ability, and regenerative properties. However, further material development can enhance their performance.[85] Without sacrificing physical integrity, adding nanomaterials such as silver nanoparticles has shown improved mechanical qualities and increased antibacterial activity.[86] Despite these developments, handling issues still exist. To guarantee simplicity of use and predictable results, material uniformity, flow, and retrievability after retreatment continue to be issues that call for innovation.[87] Furthermore, there is a dearth of long-term clinical data assessing outcomes, including dimensional stability, periapical healing, and interaction with host tissues, despite the fact that numerous formulations have demonstrated positive short-term effects.[88]

Cost is still another crucial factor. The broad use of bioceramic sealers is restricted by their high cost and limited accessibility in areas with lower incomes. Affordable, scalable formulations

**Table 1:** Examples of root canal sealers[43]

| Type of sealers | Advantages | Disadvantages | Composition |
|---|---|---|---|
| Zinc oxide-eugenol-based | Antimicrobial, resorbable when overextended, removable | Cytotoxicity, porosity, shrinkage | Zinc oxide, eugenol, barium sulfate, thymol iodide, eugenol, etc. |
| Glass ionomer-based | Chemical bonding to dentin, low shrinkage, low solubility, and fracture resistance | Short-term antimicrobial, difficult retreatment | Glass powder, polycarboxylic acids, tartaric acid |
| Silicone based | Good biocompatibility, dimensional stability | Lack of antibacterial activity, cost | Gutta-percha powder, silicone oil, polydimethylsiloxane |
| Methacrylate resin-based | Adhesion, monoblock potential, fracture resistance | Cytotoxicity, residual monomers, gaps, and cost | Urethane dimethacrylate (UDMA), triethylene glycol dimethacrylate (TEGDMA), polymethyl methacrylate (PMMA), methyl methacrylate (MMA), and 4-methacryloyloxyethyl trimellitate anhydride (4-META) |
| Epoxy resin-based | Good sealing, low shrinkage, and dimensional stability | Moderate biocompatibility, no bioactivity | Epoxy resin, amine adducts, zirconium dioxide |
| Calcium hydroxide-based | Alkaline pH, biocompatibility, hard tissue induction | Solubility, weaker sealing | Calcium hydroxide, calcium oxide, bismuth oxide, resin components |
| Bioceramic based | Bioactivity, no shrinkage, chemical bonding to dentin | Difficult to remove, neurotoxicity risk | Tricalcium silicate, dicalcium silicate, calcium phosphate, zirconium oxide, tricalcium aluminate DMSO |

DMSO: Dimethyl sulfoxide

that maintain their biological and physical performance should be the focus of future research. In addition, these sealers work well with straightforward obturation methods like the single-cone technique, which lowers operator variability and promotes productive operations.[86,88] Their use is growing beyond root canal obturation to include specifications, pulp capping, and perforation repair, underscoring their significance in regenerative therapies. To completely determine the therapeutic utility and safety of these materials, future clinical research should concentrate on multicenter trials, uniform evaluation criteria, and prolonged follow-up periods.[85,87]

## CONCLUSION

Bioceramic sealers appear to be promising materials for enhancing the healing of AP after RCT. The included studies suggest favorable clinical, radiographic, and biologic outcomes, but more high-quality long-term randomized trials are still needed before definitive conclusions can be made.

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