Review Article

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C-Root SP and Other Bioactive Sealers for Anatomically Challenging Root Canals: A Review

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ABSTRACT

Background: The root canal system is highly complex due to anatomical variations such as C-shaped canals, fins, anastomoses, isthmuses, and lateral or accessory canals, which pose challenges for effective disinfection and three-dimensional obturation. Achieving a complete and hermetic seal in these intricate morphologies is crucial for long-term periapical healing. C-Root SP, a calcium silicate–based sealer, incorporates strontium silicate instead of the conventional calcium silicate found in other bioceramic sealers, such as iRoot SP.

Objective: This review aims to evaluate the properties, mechanisms, and clinical performance of bioactive sealers, particularly C-Root SP, in obturating anatomically complex root canal systems, and to highlight their advantages over conventional and commercially available bioceramic sealers.

Methods: Relevant literature published in PubMed, Scopus, and Google Scholar was reviewed, focusing on calcium silicate–based sealers, particularly C-Root SP, which contains strontium silicate. Studies assessing obturation of complex anatomical configurations were included, with emphasis on physicochemical properties, sealing ability, adaptation to dentinal walls, and biological effects.

Results: Bioactive sealers demonstrate excellent flowability, dimensional stability, and biocompatibility. Their ability to form hydroxyapatite at the sealer dentin interface enhances chemical bonding and promotes periapical repair.

Conclusion: Superior adaptation and sealing is seen in irregular canal systems compared to traditional sealers.

Keywords: Bioactive sealer; C Root SP; c-shaped canal; calcium silicate; root canal obturation.

INTRODUCTION

The success of root canal treatment fundamentally depends on the triad of instrumentation, disinfection and three dimensional obturation of the root canal system.[1] Anatomical complexities such as C shaped

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canals, fins, anastomoses, isthmuses, and lateral or accessory canals, however, pose persistent challenges in achieving effective cleaning, shaping and obturation.[2] These intricate morphologies complicate not only instrumentation and irrigation but also the adaptation of obturation materials to obtain a proper seal. Traditional sealers often demonstrate inadequate adaptation to canal walls, higher solubility especially with zinc oxide or calcium hydroxide based sealers, and lack of bioactive properties, compromising longterm periapical healing.[3] With the advent of calcium silicate based sealers, desirable physicochemical and biological properties with high alkalinity, sustained calcium ion release, formation of hydroxyapatite, dimensional stability even in moist environments, and improved biocompatibility have been achieved.[4,5] Systematic reviews indicate that premixed calcium silicate–based sealers meet many ISO standards for sealers and may perform similarly or better than conventional materials in vitro, although limitations such as solubility and retreatability still remains.[6] This review mainly aims to study and evaluate the properties, mechanisms and clinical performance of bioactive sealers. Literature were searched using relevant mesh term in PubMed, Scopus, and Google Scholar focusing on calcium silicate–based sealers, particularly C-Root SP.

Evolution and Advantages of Bioceramic Materials

Bioceramic sealers typically consist of tricalcium or dicalcium silicate, calcium phosphate or other bioceramic phases/bioactive materials that hydrate in the presence of moisture and form a stable bioactive matrix. They offer exceptional biocompatibility, low cytotoxicity are promote hydroxyapatite deposition at the sealerdentin interface, thereby enhancing chemical bonding and sealing ability.[5,7] Their hydrophilic nature, antibacterial effect due to high PH, enhanced flow, dimensional stability, chemical bonding with dentine and slight expansion on setting (rather than shrinkage) improves adaptation of sealer to the complex anatomy of root canals.[2-3,8] . With these sealers, there is a paradigm shift in obturation from the classical guttapercha based to sealer based obturation in endodontics. This shift allows for simpler techniques such as the single cone method while maintaining obturation quality comparable to traditional methods. [9]

The sealer CRoot SP (Beijing CRoot Dental Medical Devices Co., Ltd.; CRoot Dental Medical) is a new strontium silicate–based sealer. CRoot SP contains strontium silicate ($SrSiO_3$) instead of the calcium silicate ($CaSiO_3$) used in other bioceramic sealers. Strontium silicate enhances osteogenic differentiation, angiogenesis and cell migration in vitro.[10,11] In vitro studies have demonstrated that CRoot SP exhibits angiogenesis, higher osteogenic potential and less cytotoxicity than the widely used epoxyresin sealer via enhanced alkaline phosphatase activity and mineralized nodule formation.[12] In antibacterial tests, CRoot SP showed superior inhibition of Enterococcus faecalis compared with conventional sealers.[10] Manufacturer data and independent lab work indicate improved flow, hydrophilicity and penetration into complex canal anatomy including lateral canals, fins and isthmuses, which theoretically supports better sealing in anatomically challenging systems.[12,13] These attributes suggest that CRoot SP may offer clinical advantages in the obturation of anatomically complex root canal systems. Given these promising features, this review seeks to synthesize current evidence on the properties, mechanisms of action, adaptation and obturation performance of bioactive sealers, particularly CRoot SP in irregular root canal anatomies, and to assess their comparative advantages over other commercially available bioceramic sealers.

Physicochemical Properties of Bioactive Sealers

The physicochemical properties of root canal sealers, such as flow, film thickness, dimensional stability, and solubility are essential for achieving

Table 1: Comparison between various sealers and their components

Sealer	Manufacturer	Composition
AH Plus	Dentsply International Inc., York, PA, USA	Paste A: bisphenol A epoxy resin, bisphenol F epoxy resin, calcium tungstate, zirconium oxide, silica, iron oxide pigments; Paste B: dibenzyldiamine, aminoadamantane tricyclodecane diamine, calcium tungstate, zirconium oxide, silica, silicone oil.[13]
IRoot SP	Innovative BioCeramix Inc., Vancouver, Canada	Tricalcium silicate, dicalcium silicate, calcium phosphate monobasic, calcium hydroxide, zirconium oxide, fillers, and thickening agents.[14,]
C-Root SP	Beijing C-Root Dental Medical Devices Co. Ltd., China	Strontium silicate, calcium phosphate, calcium hydroxide, zirconium dioxide, fillers, and thickening agents.[15]
Bioactive RCS	Safe Endo, India	Calcium silicates, calcium aluminate, calcium hydroxide, zirconium oxide, and dispersing agent.[16]
CeraSeal	Meta Biomed Co. Ltd., Korea	Tricalcium silicate, dicalcium silicate, zirconium oxide, and thickening agents.[17]
Zinc Oxide–Eugenol ZOE) based sealer	Generic formulation	Zinc oxide powder and eugenol liquid, with additives such as resin modifiers and radiopacifiers to enhance handling and sealing properties.[18]
Calcium Hydroxide based sealer	Generic formulation	Calcium hydroxide, calcium oxide, other calcium salts, resin or non-resin vehicle, and radiopacifiers.[19,20]

an effective seal. These characteristics influence adaptation to the root canal system and the long-term success of obturation.[21]

Setting Time and Working Time

C-Root SP is a premixed, injectable sealer that sets by hydration of strontium silicate particles in the presence of moisture. The setting reaction is similar to that of tricalcium silicate based sealers but results in a denser microstructure due to the formation of strontium-substituted hydroxyapatite.[12] According to the manufacturers and independent laboratory analyses, the setting time of C-Root SP ranges from 200 - 240 minutes, comparable to iRoot SP and BioRoot RCS, but longer than epoxy resin based AH Plus sealers.[13] Extended setting time provides adequate working time for clinical manipulation, though it may prolong the exposure to oral humidity prior to complete hardening.

Flowability and Film Thickness

C-Root SP demonstrates a flow value of 22–24 mm, fulfilling ISO 6876:2012 requirements (≥ 17 mm), and higher than that of AH Plus (18–20 mm) and iRoot SP (21–22 mm).[4,5] High flow, coupled with hydrophilicity, enables superior adaptation to canal walls even under moist conditions. Film thickness values for C-Root SP (= 45 µm) remain within acceptable limits, contributing to intimate contact with both dentin and gutta-percha.[14, 22] In comparative studies, C-Root SP exhibited superior flow and equivalent or better dimensional stability than iRoot SP, BioRoot RCS, and CeraSeal.[3,5]

Dimensional Stability and Solubility

A major limitation of traditional sealers, particularly zinc oxide–eugenol and calcium hydroxide–based formulations, is their tendency toward shrinkage and solubility over time. C-Root SP, in contrast, exhibits slight volumetric expansion (0.09–0.12%) upon setting due to continuous hydration and secondary formation of calcium/strontium hydroxyapatite.[16] This expansion compensates for shrinkage of gutta-percha and enhances long-term sealing. Solubility values reported for C-Root SP (≤ 2.5 %) meet ISO standards and are comparable to other calcium silicate sealers.[6] However, exposure to acidic conditions, simulating inflamed periapical tissues, may increase solubility, an observation consistent across most bioceramic materials.[3]

PH and Ion Release

C-Root SP exhibits an initial pH of 11.8 – 12.0 after mixing, maintaining high alkalinity for over seven days, which contributes to antibacterial efficacy and stimulation of mineralized tissue formation.[23] The release of Sr^{2+}, Ca^{2+}, and OH^{-} ions from the hydrated matrix creates an environment conducive to apatite nucleation at the sealer–dentin interface.[15] Strontium ions additionally activate osteoblastic differentiation and angiogenic signaling pathways via up regulation of vascular endothelial growth factor (VEGF) and osteocalcin expression.[24] These physicochemical interactions differentiate C-Root SP from purely calcium-based bioceramics.

Radiopacity

Radiopacity of sealers ensures adequate visualization of obturation quality under radiographic evaluation. According to ISO 6876:2012, root canal sealers should have a radiopacity of ≥ 3 mm aluminum equivalent (Al) for adequate visualization in radiograph.[25] It has been claimed that C-Root SP has radiopacity more than ISO requirement, due to zirconium dioxide as a radiopacifier.[13] Comparable or even slightly higher radiopacity is reported for AH Plus (8–9 mm Al) owing to the presence of calcium tungstate and zirconium oxide.[18]

Hydrophilicity and Interface Formation

Bioceramic sealers, unlike resin-based systems, utilize environmental moisture for setting, which is advantageous in humid root canals where complete desiccation is impractical. Although AH Plus epoxy resin based sealer has higher and uniform film thickness but it is not bioactive and lacks alkalinity that is essential for biomineralization.[14, 21] The hydrophilic and alkaline nature of C-Root SP promotes intimate adaptation to dentinal walls and tag-like mineral infiltration zones observed under scanning electron microscopy.[18] This interfacial layer, consisting of strontium-substituted apatite crystals, enhances micromechanical interlocking and chemical bonding, reducing micro leakage and improving periapical healing potential.[8]

Biological Properties of Bioactive Sealers

The biological properties of bioactive sealers are essential for ensuring biocompatibility, promoting tissue healing, and enhancing the success of endodontic treatment.

Cyto-compatibility and Cell Viability

Bioactive sealers, such as C-Root SP has been shown to actively stimulate regeneration through ion release and apatite deposition.[27] Numerous in vitro studies have demonstrated that calcium silicate and strontium silicate based sealers exhibit low cytotoxicity when compared with epoxy resin sealers.[28] When tested on human periodontal ligament fibroblasts, stem cells of apical papilla, and osteoblast-like cells, C-Root SP exhibited significantly higher cell viability and metabolic activity.[12] This has been attributed to the absence of epoxy resin components and the controlled release of strontium and calcium ions, which create a biologically favorable alkaline microenvironment.[2] Zhou et al.[5] reported that C-Root SP maintained over 90% cell viability after 72 hours, while AH Plus induced notable apoptotic changes in fibroblasts. The mild and sustained alkalinity (pH = 11–12) contributes to antibacterial properties without provoking the severe inflammatory responses often observed with eugenol-containing sealers.[18]

Osteogenic and Angiogenic Potential

A distinct advantage of C-Root SP lies in the incorporation of strontium silicate, which enhances osteogenic and angiogenic activities.[24] Strontium ions are known to stimulate osteoblast differentiation and proliferation while inhibiting osteoclast activity, thereby facilitating bone formation and reducing resorption.[29] Study found that strontium can enhance in vitro angiogenesis due to enhanced pro-angiogenic capacity, leading to increased developmental vascularization, neovascularization and bone regeneration in some animal models.[24] In vitro study found the release of calcium silicate based bioceramic sealers can stimulate the release of angiogenic growth factor such as vascular endothelial growth factor (VEGF) and platelet-derived growth factor, thus enhancing the possible neovascularization and periapical tissue regeneration.[30, 31] These effects have been corroborated by scratch-wound and migration assays showing that C-Root SP conditioned media accelerates fibroblast and endothelial cell migration by 30–40% relative to control media.[32]

Bioactivity and Hydroxyapatite Formation

When immersed in simulated body fluid (SBF), C-Root SP rapidly forms a dense layer of strontium-substituted hydroxyapatite (Sr-HA) within 3–5 days, indicating strong mineral nucleation capability.[33] Scanning electron microscopy (SEM) and energy-dispersive X-ray (EDX) analysis reveal crystalline deposits rich in Ca, Sr, P, and O elements that are chemically bonded to dentinal walls.[4] This mineral layer facilitates a chemical bond between the sealer and dentin, promoting micromechanical interlocking through tag-like structures.[8] Such mineral infiltration zones enhance the sealing integrity, resist bacterial penetration, and support the formation of a biologically compatible interface conducive to periapical healing.[16] In terms of bioactivity, C-Root SP hence, demonstrates equal or superior bioactivity and osteogenic response in vitro.[5]

Inflammatory reaction and Cytotoxicity

Animal implantation studies indicate that bioceramic sealers induces minimal inflammatory infiltration and is encapsulated by a thin fibrous capsule within 7–14 days, followed by signs of tissue regeneration.[34] The alkaline environment discourages bacterial survival and endotoxin activity, while the released calcium and strontium ions modulate macrophage polarization toward an M2 regenerative phenotype.[35] Cytotoxicity analysis demonstrated that bioceramic sealers, including C-Root SP and iRoot SP, exhibited lower cytotoxicity than the epoxy resin–based sealer AH Plus, promoted new bone formation at 12 weeks (compared with no or minimal bone formation with AH Plus), and that C-Root SP showed superior biocompatibility and the lowest cytotoxicity among the evaluated calcium silicate sealers.[36]

Although calcium and strontium share similar intracellular transport pathways, strontium has a greater affinity for the bone matrix during mineralization and, unlike calcium, reduces osteoclastic activity and bone resorption; therefore, the strontium silicate present in C-Root SP promotes bone formation, decreases bone resorption, and enhances bone mass by maintaining balanced bone turnover.[37] In simulated body fluid, it has been found that strontium silicate-based sealer such as C Root SP could induce hydroxycarbonate apatite formation, which is closer to natural hydroxyapatite.[38] This bio mineralization, chemical adhesion (via ion exchange) and micromechanical interlocking provides a biologically stable interface less susceptible to degradation than purely mechanical bonds seen with resin sealers.[3,6]

On comparing cytotoxicity and osteogenic potential of C Root SP, iRoot SP and AH Plus Bioceramic sealer with AH plus on MC3T3-E1 pre-osteoblasts, strontium silicate-based sealer (C Root SP) was found to have favorable biological response and enhanced osteogenic activity than calcium silicate-based sealers.[39] The Sr^{2+}/Ca^{2+} ion ratio influences apatite morphology, with higher Sr content leading to finer crystalline deposits and faster nucleation kinetics.[37] Strontium silicate-based sealers (e.g., C-Root SP) demonstrates differences in alkaline phosphatase activity and mineralized nodule formation leading to enhanced bio functional properties for periapical tissue repair due to presence of strontium when compared with other calcium silicate-based sealers.[39]. The unique strontium-based chemistry of these sealers, provides unique advantages in terms of cellular response and healing potential, distinguishing it from other calcium silicate-based materials.[30, 39, 40]

Antibacterial and Antifungal Activity

C-Root SP exhibits inherent antimicrobial properties due to its sustained release of hydroxyl ions (OH^-), maintaining an alkaline environment (pH = 12) that is lethal to Enterococcus faecalis, Candida albicans, and Streptococcus mutans.[1] Unlike antibiotic-containing materials, its antibacterial activity is not dependent on chemical agents but rather on high pH and osmotic stress, minimizing the risk of resistance development.[33] Time-kill assays demonstrated a 99.5% reduction in E. faecalis within 24 hours of exposure to C-Root SP, comparable to iRoot SP and superior to AH Plus.[4] Additionally, the alkalinity supports neutralization of endotoxins such as lipopolysaccharides (LPS), further promoting periapical healing.[8]

Interfacial Adaptation, Penetration, Bond Strength, and Sealing Ability of C-Root SP

C-Root SP achieves a durable, gap-free seal at the dentin–gutta-percha interface, ensuring effective three-dimensional obturation through the synergistic effects of its strontium-enriched bioactive composition, fine particle size, and hydrophilic nature.[30] Scanning electron microscopy (SEM) and confocal laser scanning microscopy (CLSM) analyses have demonstrated that C-Root SP exhibits superior adaptation to root dentin compared with epoxy resin based AH Plus and other calcium silicate based sealers.[6] The hydrophilicity of C-Root SP enables it to wet the dentinal surface even in the presence of residual moisture, forming a continuous layer with minimal interfacial gaps.[3] Tag-like mineral infiltration zones (MIZs) have been observed along the dentin sealer junction composed of strontium-substituted hydroxyapatite crystallites.[5] These MIZs, measuring approximately 2–5 µm, indicate partial ion exchange and bio mineralization within the dentinal tubules, contributing to both micromechanical interlocking and chemical adhesion.[39]

Push-out and micro tensile bond strength tests reveal that C-Root SP achieves bond strengths comparable to or exceeding those of other bioceramic sealers. Average push-out values range from 3.5–4.8 MPa for C-Root SP, similar to iRoot SP (3.2–4.5 MPa) and greater than AH Plus (2.8–3.2 MPa). This enhanced adhesion is primarily due to the formation of chemical bonds via calcium and strontium ions reacting with phosphate groups in dentin, producing an ion-exchange layer.[12] Additionally, the nanometric particle size (< 2 µm) facilitates penetration into dentinal tubules, increasing the effective bonding area.[41] Increased bonding has been shown by bioceramic sealers due to its bioactive interaction with dentin. Upon hydration, calcium silicate-based sealers release calcium ions, which react with phosphate ions from dentinal fluid forming calcium-phosphate rich interfacial layer. This mineral infiltration zone enhances chemical bonding between dentin and sealer resulting in superior sealing ability and better resistance to dislodgement. Moreover, due to its hydrophilic nature, it will set better in dentinal canal walls with deeper penetration into tubules resulting in better interfacial adaptation compared to epoxy resin-based sealers.[42]

Calcium silicate-based sealers maintain stable push out bond strength after simulated thermo cycling indicating that these sealers have good resistance to degradation under thermal aging and temperature changes similar to oral environment. This stability is due to their bioactive interfacial bonding and hydrophilic nature.[43]

Sealing Ability and Microleakage

Micro-CT and dye penetration studies have consistently shown lower apical and coronal microleakage with C-Root SP compared to conventional sealers.[24] The slight expansion during setting contributes to improved sealing efficiency, while the formation of apatite layer at the interface further reduces leakage pathways.[33,38] In vitro studies report comparable sealing ability between single-cone and warm vertical compaction techniques when bioactive sealers are used.[8,44] Clinical evidence further supports similar success rates across obturation techniques.[9]

Retreatment Considerations

Although calcium and strontium silicate sealers have outstanding sealing ability and enhanced adhesion to dentine, retreatment becomes a challenge compared to cases with conventional sealers. Study showed that the no instrumentation technique or irrigating solutions can completely remove bioceramic sealers from root canals during retreatment. Ultrasonic are effective in removing sealers from straight portion of the canal but inhumes and deep dentinal tubules often remained sealed. Moreover, solvents like chloroform and orange oil can soften gutta percha but not the bioceramic sealers.[45] However when compared with conventional syringe irrigation, passive ultrasonic irrigation or activation with XP Endo finisher files in presence of chelating agents like 17% EDTA improves the removal of bioceramic materials during retreatment. Single cone obturation with bioceramic sealers provide balanced flow, adhesion and effective sealing for long term stability. Hence for enhanced bond strength and adequate sealing, these sealers are excellent options although comprehensive cleaning during re treatment needs multimodal protocols and is a challenge.[47]

Clinical Performance, Handling Characteristics and Biomechanical Implications

In vitro study showed bioceramic sealers such as C-Root SP has low cytotoxicity, good but favorable flow, and adequate sealing ability, making it easy for clinicians to place it even in narrow or curved canals.[48] C root SP is available in premixed formulation with homogenous consistency and no mixing errors similar to other premixed bioceramic sealers. These sealers are dimensionally stable or slightly expand, in moist environment due to its hydrophilic nature and hydraulic setting reaction unlike resin based which may shrink on setting.[10] Moreover bioceramic sealers have high alkaline PH and ion release for favorable antimicrobial activity, rapid periapical healing and dentine remineralization.

A randomized controlled trial (RCT) showed success rate of 91-95% when non-surgical root canal treatment was done using C Root SP in older patients, irrespective of the obturation techniques used with reduced post-operative pain in single cone obturation technique.[49] From a biomechanical perspective, bioceramic sealers form a mineral infiltration zone at the dentin interface due to calcium or strontium ion release and apatite formation resulting in improved interfacial adaptation and distribution of stresses along the root canal walls. These improved interfacial adaptation and bioactivity can enhance fracture resistance reinforcing root structure.[48]

Radiographic and Clinical Healing Outcomes

Radiographic evaluations serve as essential indicators of clinical success. Several prospective and retrospective clinical studies have assessed calcium silicate-based sealers in human subjects, although specific long-term data on C-Root SP remain limited. A RCT study found C Root SP used in various obturation technique, similar clinical success rate and reduction in periapical index score at 1 year compared to iRoot SP.[49] Moreover, a retrospective analysis showed that periapical extrusion of bioceramic sealers does not negatively affect the clinical or radiographic healing and success rate remain high irrespective of extrusion or not.[50] Periapical studies further confirm the biocompatibility and potential bone induction capability of C Root SP in vivo.[36] Although prospective and retrospective studies have assessed calcium silicate based sealer in human studies, specific long term data on C Root SP remain scarce to the date.

Challenges with Bioceramic Sealers

Although bioceramic sealers possess several advantages, the lack of standardized protocols for evaluating bioactivity limits comparison among studies, as current ISO and ANSI/ADA standards assess only basic physicochemical properties.[48] Variations in storage media and obturation techniques further influence physicochemical behavior and sealing performance.[1] Advanced methods such as micro-CT, spectroscopy, and nanoindentation may improve material evaluation. Biocompatibility is affected by ion release, pH, and dopants such as strontium, which enhances osteogenesis but may alter mineralization if released excessively.[39] Although animal studies and molecular evidence support their regenerative potential, long-term human clinical data remain limited.[27,36] Moisture-dependent setting and thermal changes during warm obturation may also adversely affect their properties.[1,37]

Future Research Directions

Future research on C-Root SP should focus on long-term, multicenter randomized controlled trials using standardized evaluation protocols and clinically relevant outcomes to validate its performance against conventional sealers. Further studies should investigate the molecular mechanisms of strontium-mediated biomineralization, optimize material properties through nanotechnology and controlled ion release, and develop improved retreatment strategies. Advanced imaging techniques such as micro-computed tomography and artificial intelligence, together with cost-effectiveness, patient-reported outcome studies, and interdisciplinary research, will be essential for developing next-generation smart bioactive sealers with enhanced regenerative potential.

Conflict of Interest: Authors Declare No Conflict of Interest

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