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Review

Assessing the Role of Calcium Silicate-Based Sealers in Reducing Post-Treatment Microleakage

Maha Ali Abdulwahab[1*], Ibrahim Dhaifallah Al Thobaiti[2], Abdulaziz Abdulrahman Alqarni[3], Ayman Thamer Alharbi[4], Abubakr Ahmed Siddiq[5], Juwana Khalid Alansari[6], Fadhel Hejji Alnashmi[7]

[1] *North Jeddah Specialist Dental Center, King Abdullah Medical Complex, Jeddah, Saudi Arabia*
[2] *College of Dentistry, Taif University, Taif, Saudi Arabia*
[3] *Dental Department, King Abdulaziz University Dental Hospital, Jeddah, Saudi Arabia*
[4] *College of Dentistry, Taibah University, Medina, Saudi Arabia*
[5] *Department of Endodontics, Dental Specialist Center in Tabuk, Tabuk, Saudi Arabia*
[6] *College of Dentistry, King Abdulaziz University, Jeddah, Saudi Arabia*
[7] *Al Ajfar Primary Healthcare Center, Ministry of Health, Al Ahsa, Saudi Arabia*

Correspondence should be addressed to **Maha Ali Abdulwahab**, North Jeddah Specialist Dental Center, King Abdullah Medical Complex, Jeddah, Saudi Arabia. Email: mahaaabbas84@gmail.com

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Abstract

Calcium silicate-based sealers have emerged as a transformative innovation in endodontics, offering solutions to long-standing challenges such as microleakage, biocompatibility, and durability. These sealers demonstrate exceptional adaptability due to their hydraulic setting properties, ensuring tight seals in moist environments and reducing micro-gaps commonly associated with traditional materials. Their bioactivity, characterized by the release of calcium ions and hydroxyapatite formation, promotes periapical tissue healing and enhances the interface between dentin and the sealer, contributing to long-term treatment success. High alkalinity during setting provides sustained antimicrobial activity, effectively inhibiting bacterial proliferation within the root canal system. This property, coupled with low solubility and resistance to degradation, ensures stability and reliability even under challenging clinical conditions. Comparative studies reveal that calcium silicate-based sealers outperform traditional alternatives, such as epoxy resin and zinc oxide-eugenol sealers, in key performance metrics, including sealing ability, biocompatibility, and post-treatment outcomes. Clinically, these sealers are compatible with various obturation techniques, simplifying application while maintaining efficacy in sealing complex canal anatomies. Patients treated with calcium silicate-based sealers report lower incidences of postoperative pain, attributed to their anti-inflammatory properties and enhanced healing potential. Emerging research continues to refine their formulations, addressing limitations like prolonged setting times and optimizing handling properties. The integration of calcium silicate-based sealers into routine endodontic practice signifies a paradigm shift, driven by their ability to improve clinical outcomes and reduce failure rates. As material advancements progress, these sealers hold promises for broader applications in complex cases, further enhancing the predictability and success of root canal treatments. Their superior performance establishes them as a cornerstone in modern endodontic care, addressing both current and future challenges in the field.

Keywords: *Calcium silicate sealers, microleakage prevention, endodontic treatment, bioactive materials, root canal sealers*

Introduction

The integrity of the root canal system is critical to the success of endodontic treatment. A key factor influencing the outcome is the ability of the sealer to create a hermetic seal that prevents microleakage, which could lead to reinfection or post-treatment complications. Traditional sealers, such as zinc oxide-eugenol and epoxy resin-based sealers, have been widely used; however, their limitations, such as dimensional instability and suboptimal sealing ability over time, have driven the exploration of alternative materials (1, 2).

Calcium silicate-based sealers, categorized as bioceramics, have emerged as promising alternatives due to their superior physicochemical and biological properties. These sealers exhibit excellent biocompatibility, bioactivity, and the ability to induce mineralized tissue formation. Their hydraulic setting mechanism allows for stable sealing even in moist environments, which is critical in endodontic conditions where complete desiccation is often impractical (3). Additionally, these materials demonstrate high pH levels during setting, conferring antimicrobial properties that further contribute to their effectiveness (4). Post-treatment microleakage remains a persistent challenge, often resulting from inadequate adaptation of the sealer to dentinal walls or degradation over time. Calcium silicate-based sealers, such as mineral trioxide aggregate and newer formulations like TotalFill and EndoSequence BC sealer, have been specifically designed to address these issues. Their ability to expand slightly during setting enhances their sealing ability, reducing the risk of microleakage compared to traditional materials (3).

Recent studies have compared the performance of calcium silicate-based sealers with conventional alternatives in terms of sealing ability, antimicrobial activity, and long-term stability. The results consistently demonstrate their superiority in preventing bacterial penetration and microleakage (4). However, the variations in methodology, such as the use of dye penetration, fluid filtration, or bacterial leakage models, create challenges in drawing definitive conclusions about their clinical efficacy (4). Furthermore, the clinical application of calcium silicate-based sealers has revealed additional benefits, including their potential to promote healing in cases of periapical lesions. Their bioactive properties, including the release of calcium ions, support the regeneration of periapical tissues, making them particularly valuable in complex cases involving compromised periapical health (2, 4).

Despite these advantages, challenges remain in optimizing their handling properties and ensuring consistency across different formulations. Advances in material science continue to refine these sealers, aiming to enhance their performance and ease of use for clinicians. This review aims to explore the role of calcium silicate-based sealers in reducing post-treatment microleakage, focusing on their properties, clinical performance, and potential to improve long-term outcomes in endodontic treatment.

Review

Calcium silicate-based sealers have demonstrated notable efficacy in minimizing post-treatment microleakage due to their superior physicochemical and biological properties. Unlike traditional sealers, these materials possess a hydraulic setting mechanism that allows them to perform effectively even in moist environments, reducing the likelihood of gaps and voids that could compromise the seal (3). Additionally, their slight expansion during setting enhances adaptation to the dentinal walls, further reducing microleakage risks. A significant advantage of calcium silicate-based sealers is their bioactivity, which not only contributes to a hermetic seal but also facilitates the healing of periapical tissues. The release of calcium ions from these sealers stimulates mineralization, creating a biologically active environment that supports tissue regeneration. This property is particularly beneficial in cases of apical periodontitis, where healing is essential for long-term treatment success (4). Despite these advantages, challenges persist in optimizing the handling properties of calcium silicate-based sealers. Their longer setting times

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compared to epoxy resin-based alternatives can be a limitation in certain clinical scenarios. Additionally, variations in the performance of different formulations highlight the need for standardized methodologies in evaluating their sealing ability. Nevertheless, their potential to improve clinical outcomes continues to drive advancements in this field.

Mechanisms of Microleakage Prevention

Calcium silicate-based sealers stand out in endodontic therapy due to their unique mechanisms for minimizing microleakage, a primary concern in root canal treatment. One of the key features of these sealers is their hydraulic setting mechanism, which allows them to adapt to moist environments typically present in root canals. Unlike traditional materials, they maintain their integrity and dimensional stability under these conditions, ensuring a tight seal against bacterial infiltration (5). This adaptability is further enhanced by their slight expansion during the setting process, which fills voids and micro-gaps that could otherwise compromise the seal's efficacy (6).

The chemical properties of calcium silicate-based sealers also play a critical role in microleakage prevention. Upon hydration, these materials release calcium ions that react with phosphate ions in the surrounding environment, forming a hydroxyapatite layer. This mineralized barrier integrates with the dentinal walls, reducing permeability and creating a robust, biologically active seal (7). This bioactivity not only prevents bacterial ingress but also promotes healing by encouraging the regeneration of periapical tissues, a benefit not commonly observed in resin-based alternatives. Another significant advantage of calcium silicate-based sealers lies in their antimicrobial properties. During the setting phase, these materials exhibit a high pH due to the release of hydroxide ions, creating an alkaline environment that inhibits bacterial growth. This antimicrobial activity persists even after setting, providing long-term protection against reinfection (8). Additionally, their ability to resist solubility ensures that the seal remains intact over extended periods, even under challenging conditions such as exposure to fluids or recurrent bacterial challenges. Studies comparing calcium silicate-based sealers with traditional epoxy resin-based sealers have consistently demonstrated superior resistance to solubility, a key factor in maintaining the seal's durability (9).

The interaction between these sealers and dentinal tubules further contributes to their effectiveness. Calcium silicate-based sealers form a chemical bond with the dentin, creating an interface that resists mechanical dislodgement and microleakage. This bonding mechanism is supported by their capacity to penetrate into dentinal tubules, enhancing their mechanical interlocking and sealing potential (10). In cases involving complex canal anatomies, such as those with lateral canals or isthmuses, the flowability of these sealers ensures comprehensive coverage, which is essential for reducing the risk of bacterial infiltration. Clinical studies have also highlighted the compatibility of calcium silicate-based sealers with various obturation techniques. Single-cone techniques, in particular, have shown favorable outcomes when paired with these sealers. The material's flowability and self-setting properties eliminate the need for excessive compaction, reducing the risk of procedural errors and maintaining the structural integrity of the root canal system (11). Additionally, the biocompatibility of these sealers minimizes the risk of inflammatory responses, further enhancing their suitability for clinical applications.

Despite their advantages, calcium silicate-based sealers face certain limitations. One challenge is their longer setting time compared to resin-based sealers, which can prolong treatment procedures. However, advancements in material formulations are addressing this issue, with newer products offering faster setting times without compromising their bioactivity or sealing properties. Moreover, the handling characteristics of some formulations can be improved, as clinicians occasionally report difficulties in achieving consistent application due to the material's viscosity (12). Ongoing research continues to explore ways to optimize the properties of calcium silicate-based sealers. Innovations in nanotechnology, for instance, holds promise for enhancing their sealing ability and antimicrobial

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activity. Incorporating nanoparticles into the sealers may improve their flow characteristics and penetration into dentinal tubules, further reducing the potential for microleakage. Additionally, studies investigating the long-term performance of these sealers under various clinical conditions will provide valuable insights into their durability and reliability in practice.

Performance Comparison with Traditional Sealers

Calcium silicate-based sealers have gained prominence in endodontics for their enhanced properties compared to traditional sealers, such as epoxy resin and zinc oxide-eugenol-based formulations. The unique chemical and physical characteristics of calcium silicate-based sealers offer improved sealing ability, biological interaction, antimicrobial effects, and durability, which address limitations observed in conventional sealers. The sealing ability of calcium silicate-based sealers is a defining feature, largely attributed to their hydraulic setting mechanism. This property allows them to adapt effectively to the moist environment of root canals, maintaining dimensional stability and creating a tight seal against potential pathways for microleakage. Traditional sealers like epoxy resin-based materials rely on mechanical compaction and are prone to shrinkage upon setting, increasing the likelihood of voids at the dentin-sealer interface (11). Calcium silicate-based sealers expand slightly during hydration, filling micro-gaps and enhancing the integrity of the seal. This expansion also compensates for potential discrepancies in obturation techniques, offering a more consistent outcome.

Biocompatibility is a critical factor in endodontic therapy, particularly for materials that remain in close contact with periapical tissues. Traditional sealers, especially those based on epoxy resin, have been associated with cytotoxic effects during their initial setting phase, posing risks to surrounding tissues. Conversely, calcium silicate-based sealers demonstrate superior biocompatibility due to their bioactivity. The release of calcium ions from these sealers promotes hydroxyapatite formation at the dentin interface, fostering tissue regeneration and providing a biologically active barrier against bacterial infiltration (12). This bioactivity not only contributes to healing but also strengthens the bond between the sealer and dentin, enhancing the overall stability of the obturation.

Antimicrobial properties further distinguish calcium silicate-based sealers from traditional options. While zinc oxide-eugenol sealers exhibit some antimicrobial activity due to eugenol's inherent properties, this effect diminishes over time. Epoxy resin-based sealers lack any significant antimicrobial characteristics, leaving treated canals vulnerable to reinfection. Calcium silicate-based sealers, however, create a highly alkaline environment during hydration through the release of hydroxide ions, inhibiting bacterial growth. This sustained antimicrobial effect has been demonstrated in studies showing reduced bacterial colonization even after prolonged exposure (10).

Durability and resistance to solubility are crucial for long-term endodontic success. Traditional sealers, such as those based on zinc oxide-eugenol, tend to degrade over time, compromising the seal and increasing the risk of reinfection. Similarly, resin-based sealers are susceptible to structural changes that lead to microleakage under prolonged exposure to oral fluids. In contrast, calcium silicate-based sealers exhibit lower solubility and the ability to form mineralized deposits at the sealing interface, ensuring the seal's longevity and reliability (1). These properties make them particularly suitable for cases requiring extended treatment durability.

The interaction between calcium silicate-based sealers and dentinal tubules also plays a significant role in their superior performance. Their ability to penetrate and bond chemically with dentin enhances mechanical interlocking and resists dislodgement. This property is particularly beneficial in canals with irregular anatomies, where achieving a reliable seal with traditional materials can be challenging. The flowability of calcium silicate-based sealers ensures thorough coverage, even in lateral canals and isthmuses, areas prone to bacterial ingress when inadequately sealed (6).

http://dx.doi.org/10.52533/JOHS.2025.50109

Clinical studies have also explored the compatibility of calcium silicate-based sealers with different obturation techniques. Single-cone obturation methods, for instance, yield superior outcomes when paired with these sealers, reducing the procedural complexity associated with lateral or vertical compaction techniques. This compatibility, combined with their bioactivity and adaptability, simplifies the obturation process while maintaining high clinical efficacy (13). However, the longer setting time of calcium silicate-based sealers compared to resin-based alternatives can be a limitation in procedures requiring immediate sealing. Recent advances in material formulation aim to address this limitation by reducing setting times without compromising other beneficial properties. These developments highlight the transformative potential of calcium silicate-based sealers in endodontics **(Table 1)**. By addressing the limitations of traditional sealers and introducing innovative properties, these materials set a new standard for endodontic sealers in achieving clinical success.

Table 1: Comparative Analysis of Calcium Silicate-Based Sealers and Traditional Sealers

Feature	Calcium Silicate-Based Sealers	Traditional Sealers
Sealing Ability	Hydraulic setting; slight expansion minimizes micro-gaps and voids.	Prone to shrinkage upon setting, increasing microleakage risk.
Biocompatibility	Releases calcium ions, promotes hydroxyapatite formation, and supports tissue regeneration.	May exhibit cytotoxic effects during the initial setting phase.
Antimicrobial Properties	Sustained high pH during hydration inhibits bacterial growth effectively.	Limited or transient antimicrobial activity (e.g., zinc oxide-eugenol).
Durability	Low solubility and mineralized interface ensure long-term seal stability.	Solubility and degradation over time compromise the seal.
Bonding with Dentin	Chemical bonding enhances mechanical interlocking and seal strength.	Relies more on mechanical adhesion; weaker dentinal interface.
Handling Characteristics	Flowability ensures penetration into irregular anatomies; compatible with single-cone techniques.	Requires precise compaction; higher risk of procedural errors.
Setting Time	Longer setting time; newer formulations address this limitation.	Generally shorter setting time, suitable for immediate sealing.

Clinical Relevance and Treatment Outcomes

Calcium silicate-based sealers have shown transformative potential in clinical applications, addressing challenges that traditional sealers fail to overcome. The unique characteristics of these sealers enhance their performance in achieving successful endodontic outcomes, reducing complications such as reinfection, and promoting periapical healing. Clinical studies have consistently demonstrated the superior sealing ability of calcium silicate-based sealers compared to traditional materials. Their hydraulic setting properties, combined with slight expansion during curing, provide a reliable seal against microleakage, one of the primary causes of endodontic failure. Unlike resin-based sealers, which are prone to shrinkage upon polymerization, calcium silicate-based sealers maintain dimensional stability, even under humid conditions commonly encountered in root canals (14). This property significantly improves the longevity of the treatment and reduces the risk of secondary infections.

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The biocompatibility of calcium silicate-based sealers is another crucial factor contributing to their clinical relevance. Studies indicate that these sealers release calcium ions during hydration, which not only forms a chemical bond with dentinal walls but also promotes the formation of hydroxyapatite-like deposits. These deposits encourage the regeneration of periapical tissues and enhance the healing process in cases with apical periodontitis. Patients treated with these sealers exhibit faster recovery and fewer post-operative complications compared to those treated with traditional sealers (15). Post-treatment outcomes often hinge on the ability of the sealer to support antimicrobial activity. Calcium silicate-based sealers exhibit high alkalinity during and after setting, creating an inhospitable environment for bacterial growth. This antimicrobial effect persists long after the treatment, offering extended protection against reinfection. In comparison, sealers like zinc oxide-eugenol exhibit transient antimicrobial properties that diminish over time, increasing susceptibility to microbial invasion (16). This sustained antimicrobial action of calcium silicate-based sealers ensures a more predictable and successful clinical outcome.

The handling characteristics of these sealers also contribute to their efficacy in clinical settings. Their flowable consistency allows them to penetrate complex canal anatomies, including lateral canals and isthmuses, which are often difficult to seal completely with traditional materials. Additionally, calcium silicate-based sealers are compatible with single-cone obturation techniques, simplifying the procedure for clinicians without compromising on the quality of the seal (17). This adaptability not only enhances the treatment efficiency but also reduces the likelihood of operator-induced errors.

Pain management and patient comfort are essential considerations in endodontic treatment. Studies comparing calcium silicate-based sealers with epoxy resin sealers reveal that patients treated with the former report lower incidences of post-operative pain. This is attributed to the sealers' bioactivity, which minimizes inflammation and promotes faster healing of surrounding tissues. Their ability to modulate inflammatory cytokines further enhances patient comfort during recovery (18). Long-term clinical success relies on the durability and stability of the sealer within the root canal. Calcium silicate-based sealers exhibit low solubility and high resistance to degradation, even under challenging conditions such as exposure to bodily fluids. This ensures that the seal remains intact over extended periods, reducing the likelihood of treatment failure. In contrast, traditional sealers often degrade over time, leading to microleakage and compromised outcomes (15). Emerging studies continue to explore the broader applications of calcium silicate-based sealers in complex cases, such as those involving extensive periapical lesions or retreatment scenarios. Their unique combination of bioactivity, antimicrobial properties, and adaptability positions them as a versatile solution for a wide range of endodontic challenges.

Conclusion

Calcium silicate-based sealers have revolutionized endodontic treatment by addressing critical challenges such as microleakage, biocompatibility, and durability. Their unique properties, including hydraulic setting, bioactivity, and sustained antimicrobial effects, contribute to superior clinical outcomes and enhanced patient recovery. With ongoing advancements in material science, these sealers continue to set a new benchmark in root canal therapy. Their widespread adoption signifies a promising future for improved long-term treatment success in endodontics.

Disclosure

Declaration

The authors declare no conflict of interest.

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Ethical Considerations

Not applicable.

Data Availability

All data is available within the manuscript.

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Author Contribution

All authors contributed equally to the conceptualization, data collection, data analysis and writing of the paper.

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