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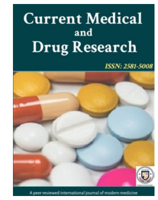

Development of Self-healing Bioactive Endodontic Sealers Containing Microcapsules that Release Calcium Silicate after Microcrack Formation

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ABSTRACT

The development of self-healing bioactive endodontic sealers represents an innovative approach to improving the long-term success of root canal treatment. Conventional sealers are susceptible to degradation, shrinkage, and microcrack formation over time, which may compromise the apical seal and permit bacterial reinfection. Incorporating microcapsules containing calcium silicate into bioactive sealer formulations offers a promising strategy for autonomous repair of these defects. When microcracks develop within the sealer matrix, the embedded microcapsules rupture and release calcium silicate, initiating a mineralization process that fills the cracks and restores sealing integrity. In addition to self-repair, calcium silicate contributes to bioactivity by promoting hydroxyapatite formation, stimulating periapical tissue healing, and enhancing the biological compatibility of the material. The integration of antibacterial nanoparticles and advanced encapsulation technologies may further improve resistance to microbial colonization while maintaining favorable mechanical properties. This emerging biomaterial concept combines regenerative potential with intelligent material design to enhance the durability and clinical performance of endodontic sealers. Although current findings indicate considerable promise, further optimization of microcapsule characteristics, healing efficiency, and long-term mechanical stability, together with comprehensive laboratory investigations and well-designed clinical studies, is required before these self-healing bioactive sealers can be widely adopted in routine endodontic practice.

INTRODUCTION

Successful root canal treatment depends on the complete elimination of microorganisms and the establishment of a durable three-dimensional seal that prevents bacterial reinfection. Endodontic sealers play a critical role by filling the microscopic irregularities between the core filling material and dentinal walls, thereby enhancing the integrity of the obturation system. However, conventional sealers may undergo polymerization shrinkage, dissolution, fatigue, and microcrack formation during function, leading to compromised sealing ability and eventual treatment failure. These limitations have stimulated the search for advanced bioactive materials capable of maintaining long-term structural and biological performance (Walsh et al., 2018).

Bioactive calcium silicate-based materials have emerged as promising alternatives because of their ability to release calcium ions, promote hydroxyapatite formation, and stimulate mineralized tissue repair. Their excellent sealing ability, biocompatibility, and regenerative potential have expanded their applications in vital pulp therapy and endodontic procedures, providing a foundation for the development of next-generation root canal sealers (Singh, 2019; Walsh et al., 2018). Studies evaluating calcium-containing sealers have also demonstrated favorable tissue compatibility and reduced

Table 1: Components and Functional Roles of Self-Healing Bioactive Endodontic Sealers

Component	*Function*	*Clinical significance*
Bioactive sealer matrix	Provides structural framework	Stable root canal obturation
Microcapsules	Store healing agent	Activated upon microcrack formation
Calcium silicate	Promotes biomineralization	Restores sealing and supports healing
Capsule shell	Protects healing agent	Enables controlled release
Antibacterial nanoparticles	Reduce bacterial colonization	Minimizes reinfection risk
Radiopacifiers	Improve radiographic visualization	Facilitates postoperative assessment

cytotoxicity, supporting their clinical application in preserving periapical health (Cintra et al., 2017; Santos et al., 2019).

An emerging strategy for further improving sealer longevity involves incorporating self-healing microcapsules within the sealer matrix. Inspired by self-repair mechanisms in engineering materials, these microcapsules remain dormant until microcracks develop, at which point they rupture and release calcium silicate to restore structural continuity and sealing effectiveness. Similar encapsulation technologies have shown promising crack-healing performance in composite and cementitious materials, highlighting their potential for dental biomaterials (Ullah et al., 2016; Giannaros et al., 2016; Lvov et al., 2014; Goudarzi, 2013). Furthermore, integrating antibacterial nanoparticles with self-healing systems may provide additional protection against residual microorganisms while preserving bioactivity (Shrestha & Kishen, 2016). Consequently, the development of self-healing bioactive endodontic sealers represents a promising direction for enhancing the durability, biological performance, and long-term success of root canal therapy while supporting regenerative endodontic outcomes (Almokhatieb, 2019).

Development of Self-Healing Bioactive Endodontic Sealers

The development of self-healing bioactive endodontic sealers represents a novel strategy to improve the durability and biological performance of root canal obturation materials. Conventional sealers may undergo polymerization shrinkage, degradation, and microcrack formation during functional loading or aging, creating pathways for bacterial penetration and treatment failure. Self-healing technology addresses this limitation by incorporating microscopic capsules filled with calcium silicate into the sealer matrix. When microcracks propagate, the capsules rupture and release the bioactive agent, which reacts with surrounding fluids to promote mineral deposition and restore the integrity of the damaged region (Ullah et al., 2016; Giannaros et al., 2016). Calcium silicate also contributes to hydroxyapatite formation, tissue regeneration, and long-term sealing ability, making it an attractive healing component for endodontic applications (Singh, 2019; Walsh et al., 2018).

Microcapsule technology has been extensively investigated in self-healing composites because it provides autonomous repair without external intervention. Encapsulation techniques using polymeric shells or clay nanotubes preserve the healing agent until mechanical stress ruptures the capsule wall, releasing calcium silicate directly into damaged regions (Lvov et al., 2014; Ullah et al., 2016). Similar approaches have demonstrated effective crack sealing in cementitious biomaterials, supporting their adaptation for endodontic sealers (Giannaros et al., 2016; Goudarzi, 2013).

The biological performance of these materials depends on their ability to maintain biocompatibility while enhancing antimicrobial activity. Calcium silicate-based materials stimulate mineralized tissue formation and exhibit favorable interactions with periapical tissues (Singh, 2019; Walsh et al., 2018). Incorporating antibacterial nanoparticles may further inhibit persistent endodontic pathogens without compromising bioactivity (Shrestha & Kishen, 2016). Studies evaluating calcium-containing sealers and bioceramic formulations have also reported acceptable cytocompatibility and tissue responses, supporting their potential clinical application (Cintra et al., 2017; Santos et al., 2019; Almokhatieb, 2019).

Challenges and Future Perspectives

Despite the promising potential of self-healing bioactive endodontic sealers containing calcium silicate-releasing microcapsules, several scientific and technical challenges must be addressed before their widespread clinical application. One of the primary concerns is achieving an optimal balance between the concentration of microcapsules and the mechanical

Table 2: Comparison Between Conventional and Self-Healing Bioactive Endodontic Sealers

Property	*Conventional sealers*	*Self-healing bioactive sealers*
Response to microcracks	Permanent defects	Autonomous crack repair
Calcium ion release	Limited	Triggered and sustained
Bioactivity	Moderate	Enhanced biomineralization
Long-term sealing	May deteriorate	Improved sealing durability
Antibacterial potential	Variable	Enhanced with nanoparticles
Periapical tissue support	Passive	Active regenerative potential

integrity of the sealer. Excessive incorporation of microcapsules may weaken the material, reduce compressive strength, and compromise its ability to withstand functional stresses within the root canal system. Conversely, an insufficient microcapsule concentration may limit the effectiveness of autonomous crack repair and reduce the overall healing capacity of the material (Ullah et al., 2016; Almokhatieb, 2019).

Another important challenge involves the design and durability of the microcapsules themselves. The encapsulating shell must remain stable during storage, mixing, and placement while rupturing efficiently when microcracks develop. Achieving predictable release of calcium silicate without premature leakage or degradation remains a major material engineering objective. Advances in encapsulation technologies, including clay nanotube-based delivery systems and multifunctional composite carriers, offer promising strategies for improving controlled release and maintaining long-term material stability (Lvov et al., 2014; Giannaros et al., 2016).

Biological performance is equally important for the successful translation of these materials into clinical practice. The released calcium silicate should stimulate mineralization, maintain biocompatibility, and support periapical tissue healing without inducing adverse inflammatory reactions. Furthermore, the incorporation of antibacterial nanoparticles should enhance antimicrobial activity while preserving favorable cellular responses and minimizing cytotoxicity. Continuous evaluation of tissue compatibility, ion release behavior, and biological safety remains essential for future material development (Cintra et al., 2017; Santos et al., 2019; Shrestha & Kishen, 2016).

Future research should focus on optimizing microcapsule size, distribution, and activation thresholds to maximize self-healing efficiency while preserving the physical properties required for durable root canal obturation. Long-term laboratory investigations should evaluate repeated healing cycles, resistance to bacterial leakage, dimensional stability, and performance under simulated clinical conditions. Well-designed preclinical and clinical studies are also necessary to establish treatment effectiveness and long-term safety. The integration of advanced bioactive ceramics, intelligent encapsulation systems, and antimicrobial nanotechnology may lead to multifunctional endodontic sealers capable of autonomous repair, sustained bioactivity, and enhanced resistance to reinfection. Such developments have the potential to improve the longevity and predictability of endodontic treatment while advancing the next generation of regenerative dental biomaterials (Walsh et al., 2018; Singh, 2019; Goudarzi, 2013).

CONCLUSION

The development of self-healing bioactive endodontic sealers containing microcapsules that release calcium silicate following microcrack formation represents a promising advancement in restorative endodontic biomaterials. Conventional root canal sealers are prone to shrinkage, degradation, and crack formation over time, creating pathways for bacterial leakage and reducing the long-term success of endodontic treatment. By incorporating microcapsule technology into bioactive sealer formulations, these materials have the potential to autonomously repair structural defects as they occur, thereby maintaining the integrity of the root canal seal and extending the functional lifespan of the obturation system. The application of calcium silicate as the healing agent further enhances this concept because of its well-documented bioactivity, ability to stimulate mineralized tissue formation, and favorable biological response (Singh, 2019; Walsh et al., 2018).

Microencapsulation strategies provide a controlled mechanism for storing and releasing healing agents only when damage occurs, minimizing unnecessary material consumption while maximizing repair efficiency. Previous investigations in self-healing composite materials have demonstrated that microcapsules can effectively restore damaged structures through crack-triggered release mechanisms, providing a strong scientific foundation for adapting these technologies to dental biomaterials (Ullah et al., 2016; Giannaros et al., 2016). Likewise, advances in encapsulation technologies and calcium silicate composite engineering suggest that such intelligent materials could be successfully translated into endodontic applications (Lvov et al., 2014; Goudarzi, 2013).

Beyond self-repair, the incorporation of bioactive calcium silicate may improve the biological performance of endodontic sealers by promoting hydroxyapatite deposition, supporting periapical tissue healing, and maintaining excellent biocompatibility. The possible integration of antibacterial nanoparticles further strengthens the clinical potential of these materials by reducing microbial colonization and limiting reinfection within the root canal system (Shrestha & Kishen, 2016). Available evidence also indicates that modern bioactive sealers exhibit favorable cytocompatibility and tissue compatibility, supporting their suitability for clinical use (Cintra et al., 2017; Santos et al., 2019). Furthermore, optimization of ion-leachable material properties may contribute to improved mechanical stability and sustained bioactivity throughout the service life of the restoration (Almokhatieb, 2019).

Overall, self-healing calcium silicate-based endodontic sealers offer an innovative strategy for overcoming many limitations associated with conventional sealing materials. Although further laboratory investigations are required to optimize microcapsule design, healing efficiency, mechanical durability, and long-term clinical performance, the integration of autonomous healing technology with bioactive endodontic materials represents an important step toward more durable, biologically active, and clinically reliable root canal obturation systems capable of supporting improved treatment outcomes (Walsh et al., 2018; Singh, 2019).

REFERENCES

1. Singh, S. (2019). Vital pulp therapy: A Bio ceramic-Based Approach. *Indian Journal of Pharmaceutical and Biological Research*, *7*(04), 10-18.
2. Walsh, R. M., He, J., Schweitzer, J., Opperman, L. A., &

Woodmansey, K. F. (2018). Bioactive endodontic materials for everyday use: a review. *Gen Dent*, *66*(3), 48-51.

3. Shrestha, A., & Kishen, A. (2016). Antibacterial nanoparticles in endodontics: a review. *Journal of endodontics*, *42*(10), 1417-1426.
4. Lvov, Y., Aerov, A., & Fakhrullin, R. (2014). Clay nanotube encapsulation for functional biocomposites. *Advances in Colloid and Interface Science*, *207*, 189-198.
5. Ullah, H., M Azizli, K. A., Man, Z. B., Ismail, M. B. C., & Khan, M. I. (2016). The potential of microencapsulated self-healing materials for microcracks recovery in self-healing composite systems: A review. *Polymer reviews*, *56*(3), 429-485.
6. Giannaros, P., Kanellopoulos, A., & Al-Tabbaa, A. J. S. M. (2016). Sealing of cracks in cement using microencapsulated sodium silicate. *Smart Materials and Structures*, *25*(8), 084005.
7. Almokhatieb, A. A. (2019). *Structure, Properties and Performance Relationships of Different Ion-leachable Resin Composites*. The University of Manchester (United Kingdom).
8. Ravikumar, V. (2014). Fair and optimal resource allocation in wireless sensor networks.
9. Goudarzi, A. (2013). *Process Engineering, Characterization and Self-Healing Assessment of Toughened Calcium Phosphate Silicate Composite Bone Cements*. The University of British Columbia (Canada).
10. Cintra, L. T. A., Benetti, F., de Azevedo Queiroz, Í. O., Ferreira, L. L., Massunari, L., Bueno, C. R. E., ... & Gomes-Filho, J. E. (2017). Evaluation of the cytotoxicity and biocompatibility of new resin epoxy–based endodontic sealer containing calcium hydroxide. *Journal of endodontics*, *43*(12), 2088-2092.
11. Santos, J. M., Pereira, S., Sequeira, D. B., Messias, A. L., Martins, J. B., Cunha, H., ... & Santos, A. C. (2019). Biocompatibility of a bioceramic silicone-based sealer in subcutaneous tissue. *Journal of oral science*, *61*(1), 171-177.