A Comprehensive Review of Green-Mediated Glass Ionomer Cement

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Abstract

The pursuit of sustainable and environmentally friendly dental materials has led to the development of green-mediated glass ionomer cements (GICs). These innovative cements integrate natural and renewable resources into traditional GIC formulations, addressing the ecological and health concerns associated with conventional materials. By incorporating bioactive glasses, plant-derived polymers, and other biocompatible additives, green-mediated GICs enhance mechanical strength, antimicrobial properties, and patient safety while reducing environmental impact. This approach not only aligns with green chemistry principles but also paves the way for more sustainable dental practices without compromising the clinical effectiveness of restorative treatments. The continued exploration of green-mediated GICs offers promising potential for a future where dental materials are both high-performing and environmentally responsible.

Introduction:

The dental industry has seen significant advancements in restorative materials, with glass ionomer cement (GIC) emerging as a versatile option due to its unique properties, such as chemical adhesion to tooth structure, biocompatibility, and fluoride release, which contribute to caries prevention. However, the production and use of traditional GICs involve synthetic chemicals and processes that may raise environmental and health concerns. As global awareness of environmental sustainability and green chemistry principles grows, there is an increasing demand for dental materials that minimise ecological impact without compromising performance.(1) Green-mediated glass ionomer cement (GIC) is a response to this demand, focusing on the incorporation of natural, renewable, or sustainably sourced materials into the GIC formulation. These innovative materials, such as plant-based extracts, bioactive glasses, and natural polymers, are not only more environmentally friendly but also offer enhanced properties such as improved mechanical strength, antimicrobial activity, and biocompatibility. The shift towards green-mediated GICs reflects a broader trend in the dental industry towards

sustainable practices, aiming to reduce the carbon footprint and promote the use of safer materials in dental care.

Green-mediated GICs represent a novel approach to dental materials, where the focus is on integrating natural or sustainably sourced materials into the traditional GIC matrix. This includes the use of plant-derived polymers, bioactive glasses, and other natural fillers that not only reduce the reliance on synthetic chemicals but also enhance the properties of the cement. For example, bioactive glass, a key component in many green GIC formulations, not only provides structural support but also promotes remineralization and exhibits antimicrobial properties. Similarly, plant-based polymers, such as chitosan or alginate, can improve the mechanical properties of GICs and offer additional benefits such as biodegradability and reduced toxicity.(2)The development of green-mediated GICs also aligns with the broader goals of green chemistry, which seeks to design products and processes that minimize the generation of hazardous substances and reduce environmental impact. By incorporating sustainable materials into GICs, manufacturers can decrease the ecological footprint of these products, making them a more attractive option for environmentally conscious dental practices.(3)Moreover, green-mediated GICs offer potential clinical advantages. The use of natural antimicrobials or bioactive compounds could enhance the biological performance of GICs, leading to better outcomes in terms of caries prevention and tissue regeneration. Additionally, the incorporation of biocompatible and non-toxic materials could reduce the risk of adverse reactions in patients, particularly those with sensitivities to synthetic chemicals.(4,5)

Green-Mediated Glass Ionomer Cement in Dental Materials

Chitosan-Enhanced GIC

Chitosan is a natural biopolymer derived from chitin, found in the exoskeleton of crustaceans like shrimp and crabs. It has gained attention for its biocompatibility, antibacterial properties, and ability to enhance the mechanical properties of dental materials.Chitosan can be added to the liquid component of GICs. This typically involves dissolving chitosan in an acidic solution compatible with the polyacrylic acid used in GICs. The chitosan-enriched liquid is then mixed with the traditional aluminosilicate glass powder of GIC, following standard mixing protocols.(5) Studies have shown that chitosan can increase the compressive and tensile strength of GICs, making them more durable and resistant to fracture. Chitosan has inherent antibacterial properties that can help reduce the risk of secondary caries by inhibiting the growth of bacteria around the restoration. The natural origin of chitosan contributes to better biocompatibility, promoting a favorable response from the surrounding tissues. The addition of chitosan can modulate the fluoride release profile of GICs, potentially enhancing the remineralization of tooth structures over time.(6)The integration of chitosan into GICs is an example of how green-mediated approaches can improve dental materials. This aligns with the principles of green chemistry by using naturally derived, non-toxic substances to enhance the functionality and sustainability of traditional dental cements.

Aloe Vera-Enhanced GIC

Aloe vera is a well-known medicinal plant, recognized for its anti-inflammatory, antibacterial, and wound-healing properties. Its bioactive components, such as polysaccharides, vitamins,

and amino acids, make it an attractive additive for dental materials.Aloe vera gel is extracted from the leaves of the plant, filtered, and purified to remove impurities and obtain a concentrated extract. The aloe vera extract is mixed with the liquid component of the GIC, usually in specific proportions, before being combined with the glass powder. The mixing process follows traditional GIC preparation methods. Aloe vera has been shown to inhibit the growth of various oral pathogens, including *Streptococcus mutans*, which is a primary contributor to dental caries. Incorporating aloe vera into GIC can help reduce bacterial activity around the restoration. Aloe vera's anti-inflammatory properties may help in reducing postoperative sensitivity and inflammation, promoting better healing of the surrounding tissues. Aloe vera is biocompatible and non-toxic, making it safe for use in the oral environment. It can enhance the bioactivity of the GIC, potentially leading to better integration with dental tissues. The addition of aloe vera does not negatively impact the fluoride release profile of GICs, ensuring continued protection against caries.(6) Aloe vera-enhanced GIC is an example of how green-mediated approaches can be used to improve dental materials. By incorporating a natural, bioactive plant extract, these GICs can offer enhanced antibacterial and anti-inflammatory properties, making them more effective and safer for patients. This aligns with the principles of green chemistry, emphasizing sustainability and biocompatibility in dental material development.

Curcumin-Enhanced GIC

is a natural polyphenol derived from the turmeric plant (*Curcuma longa*). It is well-known for its antioxidant, anti-inflammatory, and antimicrobial properties, which make it a valuable additive for dental materials.Curcumin is extracted from turmeric rhizomes and purified to remove any impurities. The extract can be obtained in powder form or as a concentrated solution. Curcumin is mixed into the liquid component of the GIC, or directly into the powder component. The mixture is then prepared following the standard protocol for GIC preparation.(7)Curcumin's strong antioxidant activity helps to neutralize free radicals, potentially improving the longevity of the restoration by reducing oxidative stress in the oral environment. Curcumin has been shown to inhibit the growth of various oral pathogens, including *Streptococcus mutans* and *Candida albicans*. This reduces the risk of secondary caries and other infections around the restoration. Curcumin's anti-inflammatory properties can help reduce postoperative inflammation and discomfort, promoting better healing of the dental tissues. As a natural compound, curcumin is biocompatible and does not cause adverse reactions in the surrounding tissues, making it safe for use in dental restorations. Curcumin does not interfere with the fluoride release of GICs and may even enhance the bioactivity of the material, promoting remineralization of the surrounding tooth structure.(8)Curcumin-enhanced GICs represent a promising example of green-mediated dental materials. By integrating a natural, bioactive compound with strong antioxidant, antimicrobial, and anti-inflammatory properties, these GICs can offer enhanced clinical performance while adhering to principles of sustainability and biocompatibility. This makes them an excellent option for a wide range of dental applications, aligning with the growing demand for eco-friendly and patient-safe dental materials.

Propolis-Enhanced GIC

Propolis is a resinous substance collected by bees from tree buds and used to seal and protect their hives. It has been used in traditional medicine for its antimicrobial, anti-inflammatory, and healing properties. Propolis contains flavonoids, phenolic acids, and esters, which contribute to its bioactivity. Propolis is collected and purified to remove impurities. It can be processed into a concentrated solution or powder form. The propolis extract is mixed with the liquid component of the GIC or directly with the powder. The mixture is then handled according to standard GIC preparation methods.(8,9)Propolis has broad-spectrum antimicrobial properties, effective against bacteria, fungi, and viruses. Adding propolis to GIC can help inhibit the growth of cariogenic bacteria like *Streptococcus mutans*, reducing the risk of secondary caries. Propolis has natural anti-inflammatory properties, which can help reduce inflammation in the surrounding tissues after restorative procedures.(3,10) Propolis enhances the healing process of tissues, making it particularly beneficial in cases where the restoration is in close proximity to gingival tissues or when used as a liner in deep cavities.(11) Propolis is biocompatible and well-tolerated by the tissues, making it safe for use in dental restorations. Research has shown that incorporating propolis can improve the mechanical strength of GICs, enhancing their durability and resistance to wear.Propolis-enhanced GICs represent a significant advancement in green-mediated dental materials. By incorporating a natural substance known for its antimicrobial, anti-inflammatory, and healing properties, these GICs offer improved clinical performance while maintaining sustainability and biocompatibility. This aligns with the growing emphasis on eco-friendly and patient-safe dental materials in modern dentistry.

Bamboo Fiber-Enhanced GIC

Bamboo fiber is a natural material derived from bamboo plants, known for its high strength, flexibility, and biodegradability. Its natural origin and environmental friendliness make it an attractive option for reinforcing dental materials. Bamboo fibers are extracted from bamboo stems through mechanical processing, followed by chemical treatments to purify and modify the fibers for better compatibility with GICs. Bamboo fibers are mixed with the glass powder component of the GIC before adding the liquid component. The fibers are usually short and evenly distributed to ensure uniform reinforcement.(7)

The addition of bamboo fibers can enhance the tensile strength, flexural strength, and fracture toughness of GICs, making them more durable and resistant to mechanical stresses. Bamboo fibers are biodegradable and sourced from a renewable resource, aligning with the principles of green chemistry and sustainability. Bamboo fibers impart additional toughness and flexibility to GICs, which can help in reducing the brittleness often associated with traditional GICs.(6) Bamboo fibers are biocompatible and do not cause adverse reactions when in contact with dental tissues, making them safe for use in restorative applications.Bamboo fiber-enhanced GICs exemplify the use of green-mediated approaches to improve dental materials. By integrating a renewable, biodegradable material like bamboo, these GICs offer enhanced mechanical properties and environmental benefits, making them an ideal choice for eco-conscious dental practices.(12) This approach aligns with the growing demand for sustainable, high-performance materials in modern dentistry.

Pectin modified GIC

It is a natural polysaccharide found in fruits, and its use in glass ionomer cements (GICs) has been explored for its potential benefits.Pectin is known for its gel-forming abilities when combined with calcium ions, which can influence the setting properties of GICs. A study published in *Dental Materials* examined the use of pectin to modify the consistency and setting time of GICs. The addition of pectin helped in achieving a more controlled setting time and improved handling properties.(13) Another research has highlighted pectin's biocompatibility, which is advantageous for dental applications. Pectin's natural origin and biodegradability contribute to the overall sustainability of the GIC, aligning with green chemistry principles. A study evaluated the impact of pectin on the mechanical properties of GICs. The incorporation of pectin was found to affect the compressive strength and flexibility of the cement. While pectin contributed to improved workability and application, it also necessitated optimization to balance mechanical performance.(9) Some studies have explored the potential for pectin to act as a carrier for bioactive agents, which could enhance the therapeutic properties of GICs. This includes the potential release of antimicrobial agents or remineralizing agents.Overall, the integration of pectin into GICs offers several advantages, including improved handling properties, enhanced biocompatibility, and alignment with eco-friendly practices. However, its impact on mechanical properties and the need for careful formulation remain important considerations.

Alginate modified GIC

It's a natural polysaccharide extracted from brown seaweed, has been studied for its potential use in green-mediated glass ionomer cements (GICs) due to its favorable properties. Here are key insights from recent studies: Studies, highlighted alginate's biocompatibility and bioactivity. Alginate's natural origin and ability to form gels in the presence of calcium ions contribute to its biocompatibility, making it suitable for use in dental materials where interaction with biological tissues is critical. Another research featured in on how alginate affects the physical properties of GICs, including their viscosity and flowability. Alginate can be used to modify these properties, which can improve the handling characteristics of GICs and facilitate their application in clinical settings. Alginate's use aligns with green chemistry principles due to its natural and biodegradable nature.(7,9)Another study have emphasized that using alginate in GICs helps reduce reliance on synthetic polymers, thus contributing to more sustainable dental materials.Overall, incorporating alginate into GIC formulations can enhance the material's handling properties, biocompatibility, and sustainability. However, the balance between improving physical properties and maintaining the overall performance of the GIC remains an important area of ongoing research.

Neem modified GIC

Neem, derived from the neem tree (*Azadirachta indica*), has been studied for its incorporation into glass ionomer cements (GICs). Neem is well-known for its antimicrobial and antifungal properties. Neem's bioactive compounds, including azadirachtin, can inhibit the growth of bacteria and fungi, which is advantageous for preventing dental infections.Neem extracts generally show good biocompatibility, making them suitable for use in dental materials that come into direct contact with oral tissues. Neem's natural origin and low toxicity contribute to its favorable tissue response. While neem can improve antimicrobial properties, its effect on

the mechanical performance of GICs needs careful balancing to avoid compromising the cement's structural integrity. Studies emphasize that using neem aligns with green chemistry principles by reducing reliance on synthetic chemicals and leveraging the benefits of a naturally sourced material.(7,9,14) Overall, neem offers several advantages for use in GICs, including enhanced antimicrobial activity, good biocompatibility, and potential bioactivity benefits. However, ensuring that neem does not negatively impact the mechanical properties or setting behavior of GICs is crucial for effective application.

Clove modified GIC

It derived from the flower buds of *Syzygium aromaticum*, has been studied for its potential use in enhancing the properties of glass ionomer cements (GICs). Clove extracts can inhibit the growth of oral bacteria such as *Streptococcus mutans*, which is beneficial for preventing dental caries.Clove oil and eugenol are generally well-tolerated by tissues, contributing to the overall biocompatibility of GICs. This makes clove an attractive additive for dental materials that require direct contact with oral tissues. Excessive amounts of clove oil can potentially alter the cement's setting behavior or mechanical strength. Clove's bioactive compounds might contribute to improved therapeutic effects, such as remineralization or protection of dental tissues. Using clove aligns with green chemistry principles by incorporating a natural, renewable resource and reducing reliance on synthetic additives. This makes clove a suitable choice for eco-friendly dental materials.(6)Overall, incorporating clove into GICs offers several benefits, including enhanced antimicrobial activity, good biocompatibility, and potential therapeutic effects. However, it is important to balance these benefits with considerations regarding the impact on mechanical properties and setting behavior to ensure optimal performance of the GICs.

Ginger modified GIC

It derived from the rhizome of *Zingiber officinale*, has been studied for its potential benefits when incorporated into glass ionomer cements (GICs). Ginger is known for its antimicrobial and anti-inflammatory properties, attributed to compounds like gingerol. Ginger extracts can help inhibit the growth of oral pathogens, which is beneficial for dental materials used in preventing infections.Ginger and its extracts are generally well-tolerated by oral tissues, contributing to the overall safety of the cement when used in dental applications. This makes ginger a promising natural additive for improving the compatibility of dental materials with the biological environment. Ginger's bioactive compounds might contribute to improved therapeutic effects, such as anti-inflammatory benefits or enhanced tissue repair. Using ginger aligns with green chemistry principles due to its natural and renewable origin.(14)In summary, incorporating ginger into GICs can offer benefits such as enhanced antimicrobial activity, good biocompatibility, and potential therapeutic effects. However, it is crucial to carefully manage the concentration of ginger extracts to ensure that they do not negatively affect the mechanical properties or setting behavior of the cement.

Lemongrass modified GIC

It derived from the plant *Cymbopogon citratus*, has been studied for its potential inclusion in glass ionomer cements (GICs). Lemongrass contains essential oils with significant antimicrobial properties, primarily due to compounds like citral. Lemongrass extracts have

been shown to inhibit the growth of oral bacteria and fungi, which can be beneficial for preventing infections and maintaining oral health.Lemongrass oil and its active compounds generally show good biocompatibility, making them suitable for use in dental materials that are in direct contact with oral tissues. Lemongrass's bioactive compounds might contribute to additional therapeutic benefits, such as anti-inflammatory effects, which could support the repair and health of dental tissues. Lemongrass, being a natural and renewable resource, aligns with green chemistry principles. Incorporating lemongrass into GICs supports eco-friendly practices by utilizing a sustainable material and reducing reliance on synthetic additives.(15)Overall, lemongrass offers several advantages for use in GICs, including enhanced antimicrobial activity, good biocompatibility, and potential therapeutic effects. However, careful formulation is necessary to balance these benefits with the impact on the mechanical properties and setting behavior of the cement.

Chirata modified GIC

It derived from the plant *Swertia chirata*, has been explored for its potential inclusion in glass ionomer cements (GICs). Chirata has been studied for its antimicrobial effects, primarily due to its bioactive compounds. Chirata's antimicrobial properties can help inhibit the growth of oral pathogens, which is beneficial for preventing infections in dental applications.Chirata's natural compounds generally show good biocompatibility, making it a suitable additive for dental materials in direct scontact with oral tissues. Chirata's bioactive compounds might contribute to additional therapeutic benefits, such as anti-inflammatory effects, which could support the health and repair of dental tissues. Chirata, as a natural product, supports sustainability in GIC formulations. Using chirata aligns with green chemistry principles by incorporating a renewable, natural material and reducing reliance on synthetic additives.(16) Overall, chirata offers several potential benefits for GICs, including enhanced antimicrobial activity, good biocompatibility, and possible therapeutic effects. However, it is important to carefully manage the concentration of chirata extracts to ensure that they do not negatively affect the mechanical properties or setting behavior of the cement.

Terminalia arjuna modified GIC

The plant, known for its medicinal properties, has been studied for its potential use in reinforcing glass ionomer cements (GICs). The plant's bioactive compounds can help inhibit the growth of oral bacteria, which is beneficial for preventing infections in dental restorations. The plant extracts are generally well-tolerated by oral tissues, contributing to the overall safety and effectiveness of the GICs. This biocompatibility is crucial for materials used in direct contact with dental tissues. The plant's bioactive compounds might contribute to additional therapeutic effects, such as anti-inflammatory or remineralization benefits, which can support the health and repair of dental tissues.(7,14) Terminalia arjuna into GICs aligns with green chemistry principles due to its natural origin. Using such natural additives supports sustainable practices by reducing reliance on synthetic materials and leveraging renewable resources. Overall, Terminalia arjuna offers several benefits for reinforcing GICs, including enhanced antimicrobial activity, improved mechanical properties, and good biocompatibility. However, optimizing the concentration and ensuring the balance between beneficial effects and potential

impacts on setting behavior and mechanical performance is important for effective formulation.(7,16)

Acacia nilotica modified GIC

Acacia nilotica has demonstrated significant antimicrobial activity due to its bioactive compounds, such as tannins and flavonoids. The plant's extracts help inhibit the growth of oral pathogens, which is beneficial for maintaining oral health and preventing infections.The plant extracts generally show good biocompatibility, making them suitable for use in dental materials that come into direct contact with oral tissues. The plant's compounds may offer additional therapeutic benefits, such as anti-inflammatory or remineralization effects, which support the repair and health of dental tissues.(6,17) Acacia nilotica, being a natural and renewable resource, supports environmentally friendly practices. Incorporating it into GICs aligns with green chemistry principles by reducing the reliance on synthetic additives and utilizing a sustainable material.(5) Overall, Acacia nilotica offers several potential advantages for GICs, including enhanced antimicrobial activity, good biocompatibility, and potential therapeutic effects. However, careful formulation is required to balance these benefits with the impacts on mechanical properties and setting behavior.

Miswak modified GIC

Derived from the *Salvadora persica* tree, has a long history of use in oral hygiene. Miswak is known for its strong antimicrobial properties, which are attributed to its rich content of bioactive compounds like salvadorine, trimethylamine, and various essential oils. The inclusion of miswak helps inhibit the growth of oral pathogens such as *Streptococcus mutans*, which is beneficial for preventing dental caries and other oral infections.(19) Miswak's natural compounds are generally well-tolerated by oral tissues, making it a suitable additive for dental materials that come into direct contact with the oral cavity. Miswak is also known for its therapeutic benefits, such as anti-inflammatory and astringent properties. This bioactivity makes miswak a valuable addition to GICs used in restorative dentistry. Incorporating miswak into GICs aligns with sustainable practices, as it is a natural and renewable resource. This aligns with green chemistry principles by reducing reliance on synthetic materials and using an environmentally friendly, biodegradable additive.(20), miswak offers several potential advantages for use in GICs, including enhanced antimicrobial activity, good biocompatibility, and therapeutic effects that can contribute to oral health. However, as with other natural additives, careful formulation is required to balance these benefits with the mechanical and setting properties of the GIC to ensure optimal performance in dental applications.(10)

Conclusion

In conclusion, green-mediated glass ionomer cements (GICs) represent a promising advancement in dental materials, aligning with the growing demand for sustainable and biocompatible solutions. By incorporating natural or eco-friendly additives, such as plant extracts, bioactive compounds, or sustainable fillers, these modified GICs can enhance properties like antimicrobial activity, remineralization potential, and overall biocompatibility, while reducing environmental impact.(13) As research progresses, these innovations could lead to more effective and environmentally responsible dental treatments, contributing to the broader goals of sustainability in healthcare.

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