Applications Of Bioactive Glass In Dentistry : A literature review

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ABSTRACT

Bioactive glass (BG) is an innovative biomaterial with significant potential in various fields of dentistry, including orthodontics, periodontology, endodontics, and implantology. Its unique properties, such as bioactivity, antimicrobial effects, and ability to form strong bonds with hard and soft tissues, make it highly effective for enhancing dental treatments. In orthodontics, bioactive glass is incorporated into adhesives, brackets, wires, and retainers to promote enamel remineralization, reduce demineralization, and improve overall oral hygiene during treatment. Beyond orthodontics, BG is utilized in restorative dentistry to improve bonding and remineralization, periodontology for bone regeneration, and endodontics for promoting healing in root canals. It also plays a critical role in implantology by enhancing osseointegration and preventing bacterial infections. Future advancements in bioactive glass, including the development of smart orthodontic devices, advanced composites, and nano-sized particles, hold promise for improving treatment outcomes and expanding its application in dental care.

Background

Bioactive glass (BAG) represents a revolutionary class of biomaterials that actively interacts with biological systems to promote tissue repair and regeneration[1]. Initially introduced by Larry L. Hench in the 1970s, the first formulation, Bioglass 45S5, marked a paradigm shift in biomedical materials by demonstrating the ability to bond seamlessly with both hard and soft tissues without eliciting inflammatory or toxic responses.[2] This discovery opened new avenues for bioactive glass in healthcare, particularly in the fields of orthopedics and dentistry.

Bioactive glass is a silicate-based material with a distinctive three-dimensional network structure of silica. Its composition is specifically engineered to promote ion exchange and the formation of hydroxyapatite layers when in contact with body fluids, enabling strong chemical bonding with bone and other tissues.[3,4] The classical composition of Bioglass 45S5 includes 45% silicon dioxide (SiO2), 24.5% calcium oxide (CaO), 24.5% sodium oxide (Na2O), and 6% phosphorus pentoxide (P2O5). Modifications to this composition have led to enhanced properties, including sodium-free variants and formulations containing additional bioactive compounds like calcium fluoride, tricalcium phosphate, fluorapatite, and diopside[5,6,7].

Over the years, the methods for producing bioactive glass have evolved. The melt-quenching method, traditionally used, involves heating raw materials to over 1300°C. However, the high energy consumption and lack of precise control over porosity have led researchers to adopt the sol-gel technique, a versatile and energy-efficient alternative that facilitates better customization of the glass's properties, including its pore size and bioactivity.[8]

Recent advancements have also explored natural templates, such as marine sponges, for bioactive glass synthesis. These organisms, abundant in oceans worldwide, produce bioactive compounds with potential applications in regenerative medicine[9]. Marine sponge-derived bioactive glasses, with their unique microstructural properties, have gained interest for their sustainable production and promising biological performance.

In dentistry, bioactive glass has gained prominence due to its multifaceted applications across various specialties[10]. It is utilized in periodontics for regenerating periodontal tissues, in endodontics for root canal disinfection and sealing, and in implantology for enhancing osseointegration. Furthermore, its incorporation into oral care products, such as toothpaste, highlights its role in remineralizing enamel and reducing dentin hypersensitivity.

The remarkable versatility of bioactive glass stems not only from its ability to bond with tissues but also from its biocompatibility and bioactivity, ensuring minimal risk of adverse reactions. With ongoing advancements in material science and the integration of novel manufacturing techniques, bioactive glass continues to hold immense promise for transforming dental and medical treatments.[11]

Mechanism of Action and Properties: Bioactive glasses (BAGs) are highly regarded for their ability to form direct bonds with hard and soft tissues, a property rooted in their unique surface chemistry and structural composition.[12,13] When implanted into the body and exposed to biological fluids, BAGs undergo a sequence of surface reactions that facilitate tissue regeneration and antimicrobial activity. The process begins with the release of ions such as sodium, silica, calcium, and phosphate, which increases the local pH and osmotic pressure[14]. This triggers the formation of a silica gel layer on the glass surface, which subsequently attracts and facilitates the deposition of amorphous calcium phosphate. Over time, this layer crystallizes into hydroxyapatite, a mineral phase closely resembling bone. Hydroxyapatite stimulates osteoblast activity, thereby promoting bone regeneration and establishing strong graft-to-bone bonding. As BAGs degrade, they release therapeutic ions that enhance their bioactivity by promoting angiogenesis and exhibiting antimicrobial effects.[15,16,17]

The broad-spectrum antimicrobial properties of BAGs, particularly formulations like S53P4, arise from their ability to increase pH and osmolarity locally, creating an environment that inhibits bacterial survival and biofilm formation.[18,19] These glasses have demonstrated efficacy against various pathogens, including Staphylococcus aureus, Escherichia coli, and Klebsiella pneumoniae, making them promising for managing bone infections such as osteomyelitis and peri-implantitis. Moreover, novel advancements in bioactive glass technology, such as copper-doped mesoporous SiO_2-CaO glass (Cu-MBG), have introduced materials with enhanced antibacterial properties against resistant strains like Staphylococcus epidermidis. The antimicrobial effectiveness of BAGs is further influenced by factors like particle size, with smaller particles providing larger surface areas for ionic interactions.[2021,22,23]

The bioactivity of BAGs is significantly influenced by their silicate concentration, with optimal bonding observed at silicate levels between 45% and 52%. Mechanical biocompatibility is another defining feature, as BAGs exhibit no signs of toxicity or inflammatory response when interacting with tissues[24]. This, combined with their ability to biodegrade at controlled rates, makes them highly versatile in various applications. Traditionally produced using melt-quenching techniques, newer methods like the sol-gel process have resulted in BAGs with higher surface areas, faster apatite formation, and improved mechanical strength. Additionally, sodium-free BAG formulations have been developed, retaining the bioactivity and solubility of traditional compositions while offering alternative properties.[25]

Overall, the unique combination of surface chemistry, antimicrobial efficacy, and mechanical compatibility underlines the versatility of BAGs. These materials not only support bone and tissue regeneration but also hold significant promise for addressing infections and improving outcomes in diverse dental and orthopedic applications.[26]

Table-1 summarizing the properties of bioactive glasses (BAGs) based on the provided information:

Property	Description
Bioactivity	Forms a strong bond with hard and soft tissues by facilitating the deposition of hydroxyapatite.
Biocompatibility	Non-toxic, non-inflammatory, and exhibits no foreign body response when interacting with tissues.
Antimicrobial Properties	Increases pH and osmotic pressure locally, inhibiting bacterial survival and biofilm formation.
Ion Release	Releases sodium, silica, calcium, and phosphate ions, enhancing bioactivity and promoting healing.
Angiogenesis Support	Stimulates new blood vessel formation, aiding in tissue regeneration.
Surface Area	High surface area enhances dissolution rate and apatite formation.
Customization	Composition can be altered to include elements like copper, zinc, and strontium for specific uses.
Particle Size	Smaller particles increase surface area, enhancing bioactivity and antimicrobial effectiveness.
Degradability	Gradual biodegradation aligns with tissue regeneration timelines.
Mechanical Properties	Enhances strength when incorporated into composites; mimics natural bone structures.
Therapeutic Ions	Copper-doped and alkali-free variants provide additional antibacterial effects.
Manufacturing Methods	Produced using melt-quenching or sol-gel processes for tailored properties.

Applications of Bioactive Glass in Restorative Dentistry

The introduction of bioactive materials in restorative dentistry marks a significant evolution from the earlier use of inert and biocompatible materials to regenerative materials. Among these, bioactive glass (BAG) stands out for its unique ability to interact with biological tissues, elicit cellular responses, and form strong chemical bonds with hard and soft tissues. This bioactivity offers new opportunities in managing dental caries, hypersensitivity, and enamel remineralization, paving the way for innovative restorative techniques[27].

1. **Bioactive Glass in Resin Composites**
   The incorporation of BAG into resin composites introduces antibacterial and remineralizing properties, making it a promising solution for preventing secondary caries. Studies have demonstrated that composites containing up to 15% BAG exhibit reduced bacterial penetration at restoration margins, thus enhancing clinical longevity. However, challenges persist, such as balancing the hydrophilic nature of BAG with the hydrophobic requirements of resin matrices, which can affect ion release, bioactivity, and mechanical properties. Silanization of filler particles, while improving mechanical strength, may compromise bioactive ion release, highlighting the need for optimized formulations[28,29].
2. **Bioactive Glass in Glass Ionomer Cement (GIC)**
   The incorporation of BAG into GIC formulations has shown potential in enhancing remineralization and bioactivity while maintaining the desirable properties of GIC, such as fluoride release and chemical bonding with dental tissues. Resin-modified GIC (rmGIC) with BAG has demonstrated improved water absorption, which facilitates the

formation of a bioactive matrix capable of remineralization. This combination enhances clinical outcomes by providing sustained bioactivity and reducing the risk of demineralization[30].

3. **Enamel Remineralization**
   BAG has emerged as an alternative to traditional remineralization agents like fluoride and casein phosphopeptide-amorphous calcium phosphate (CPP-ACP). It promotes hydroxyapatite (HAP) and fluorapatite (FAP) formation, effectively repairing early caries lesions. Bioglass® 45S5 and BiominF® are examples of BAG-based products that have shown superior remineralization of white spot lesions (WSLs) compared to conventional treatments. These materials offer a minimally invasive approach to manage enamel demineralization and early caries[31].
4. **Management of Dentin Hypersensitivity (DH)**
   BAG-based formulations, such as NovaMin® and BioMinF®, provide effective solutions for dentin hypersensitivity by occluding exposed dentinal tubules and forming a protective HAP layer. These formulations are incorporated into toothpaste and have demonstrated sustained efficacy in reducing pain associated with DH. The release of ions from BAG, combined with its ability to bind collagen fibers, makes it a reliable choice for non-invasive management of DH.[32]
5. **Bioactive Glass in Dental Adhesives**
   The acid-etching process in restorative dentistry often activates matrix metalloproteinases (MMPs), leading to collagen degradation and compromised adhesive interfaces. Incorporating BAG into dental adhesives offers a dual benefit: it prevents MMP activity through pH modulation and enhances the mechanical properties of the adhesive. Experimental adhesives containing Bioglass® 45S5 and niobophosphate BAG fillers have demonstrated improved bond strength, microhardness, and radiopacity without compromising mechanical integrity, offering a promising future for adhesive restorations.[33]

The versatility of BAG in restorative dentistry highlights its potential to address critical challenges, from managing secondary caries and dentin hypersensitivity to improving adhesive interfaces and enamel remineralization. Despite mechanical limitations, ongoing research into BAG formulations aims to optimize bioactivity and durability, ensuring its broader clinical application in modern dentistry.

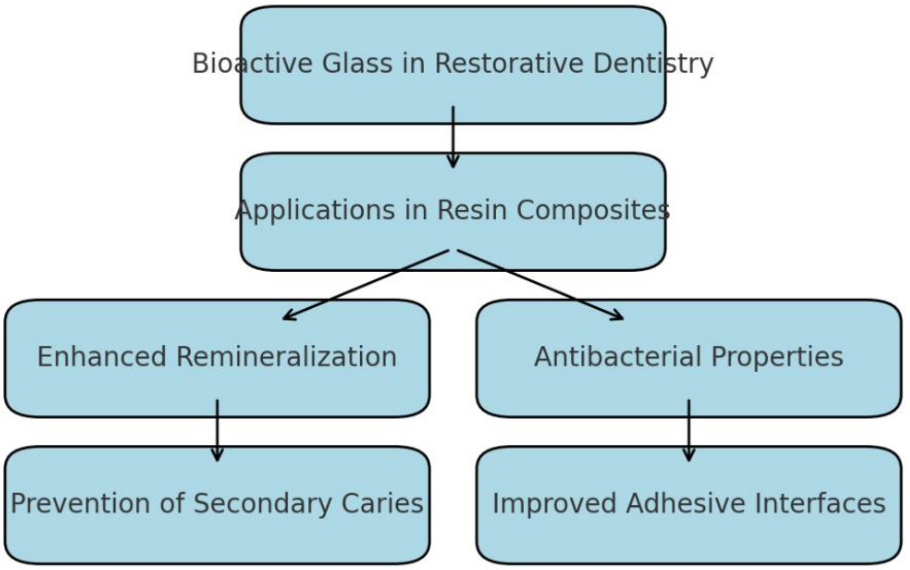

Figure 1- simple flowchart illustrating the role of bioactive glass in restorative dentistry. It starts with its central application and expands into specific properties and benefits

Application in Endodontics

Bioactive Glass as an Intracanal Medicament

Bioactive glass demonstrates considerable potential as an intracanal medicament due to its antimicrobial properties and capacity to enhance tissue repair. Its mechanism involves elevating the pH of the aqueous environment and increasing calcium ion concentrations, thereby creating an environment unsuitable for microbial survival. This material is particularly effective against persistent endodontic pathogens such as *Candida albicans* and *Enterococcus faecalis*, which are major contributors to treatment failure in root canal therapy[34].

The antimicrobial action of bioactive glass is complemented by its anti-inflammatory effects, which aid in the periapical repair process by reducing bacterial interference and promoting tissue healing. Furthermore, its osteoconductive properties support the regeneration of periapical bone defects, making it a valuable adjunct during the treatment of periradicular diseases.[35]

Using bioactive glass as an intracanal medicament ensures the disinfection of complex root canal anatomies, improves the longevity of treatment outcomes, and fosters hard tissue repair while maintaining compatibility with periapical tissues. This multifaceted functionality makes bioactive glass an exceptional choice for enhancing the success rate of root canal treatments[36].

Bioactive Glass in Periodontics

Bioactive glass has proven to be a valuable tool in periodontal therapy due to its multifaceted properties, including osteoconductivity, antimicrobial activity, and its ability to support tissue regeneration. The ability of bioactive glass to bond with both hard and soft tissues makes it highly effective in treating periodontal defects, especially in cases where traditional treatments may fall short. Its unique composition, which can be modified to release specific ions such as calcium, phosphorus, and silicon, enhances its bioactivity and promotes the formation of hydroxyapatite, the mineral component of bone.[37] This not only supports bone regeneration but also strengthens the tissue interface, making it particularly useful for periodontal bone grafting.

Additionally, the incorporation of antimicrobial elements like silver and copper into bioactive glass has expanded its application by preventing bacterial colonization and infection, which are common complications in periodontal therapy.[38] The development of mesoporous bioactive glasses, with their nanostructured features, further improves the material's ability to promote hemostasis, facilitate faster healing, and reduce the risk of infection through their antibacterial properties. As such, bioactive glass continues to be an indispensable material in periodontics, offering promising solutions for periodontal regeneration, implant stability, and the prevention of peri-implantitis, ultimately contributing to better long-term outcomes for patients.[39]

Applications of Bioactive Glass in Orthodontics

Bioactive glass is gaining significant attention in orthodontics due to its unique properties, including bioactivity, antimicrobial effects, and its ability to bond strongly with both hard and soft tissues. These features make it highly beneficial for various orthodontic applications.[40]

Orthodontic Adhesives:

Bioactive glass is incorporated into orthodontic adhesives to aid in enamel remineralization during orthodontic treatment. This reduces the risk of demineralization around brackets, which can otherwise lead to white spot lesions, a common issue during braces treatment. By enhancing remineralization, bioactive glass contributes to improved oral health during orthodontic procedures.[41]

Bracket Debonding:

Bioactive glass-coated adhesives are useful for bracket debonding as they help protect the enamel surface. This makes the process of removing brackets less invasive and less likely to cause damage to the enamel, preserving the tooth's integrity.[42]

Wire Coatings:

Bioactive glass is used as a coating for orthodontic wires, reducing friction between the wires and brackets. This minimizes irritation to the gingival tissues and contributes to smoother tooth movement. Additionally, these coatings have antimicrobial properties that help reduce bacterial colonization, promoting better oral hygiene during orthodontic treatment.[43]

Orthodontic Retainers:

Bioactive glass is incorporated into orthodontic retainers to maintain oral hygiene after active orthodontic treatment. The material slowly releases ions that inhibit bacterial growth, thus promoting a healthier oral environment and reducing the risk of infection or plaque buildup around retainers.[44]

Other Applications of Bioactive Glass in Dentistry

Bioactive glass is also utilized in several other areas of dentistry, benefiting restorative, periodontal, endodontic, implant, and prosthodontic treatments.

Restorative Dentistry:

In restorative procedures, bioactive glass is added to composite resins to enhance remineralization of carious lesions and improve the bonding strength between the resin and the tooth. This strengthens the tooth structure, preventing further decay.[45]

Periodontology:

Bioactive glass is an essential material for periodontal regeneration. It promotes osteogenesis, stimulating bone regeneration in periodontal defects. It is often used in graft materials for periodontal surgeries, helping to restore lost bone and improve healing[35].

Endodontics:

Bioactive glass is employed in root canal sealers and repair materials to promote periapical healing. The material provides an antimicrobial environment within the root canal, preventing infection and encouraging tissue repair.[10]

Implantology:

In dental implantology, bioactive glass enhances the osseointegration of dental implants. It improves the bond between the implant and bone, resulting in better stability and reduced risk of implant failure. Additionally, bioactive glass coatings on implants enhance resistance to bacterial infections, making implants safer and more durable[45].

Prosthodontics:

Bioactive glass is used in removable dentures to prevent fungal and bacterial infections. This ensures that the prosthesis remains hygienic, improves patient comfort, and reduces the risk of oral infections caused by the prosthetic device[46].

Future Recommendations

To maximize the potential of bioactive glass in orthodontics and dentistry, several future directions are recommended:[35]

Advanced Composites:

Further development of orthodontic adhesives with higher concentrations of bioactive glass could provide enhanced remineralization without compromising bond strength. This would lead to better long-term oral health outcomes during orthodontic treatment.[10,35]

Smart Orthodontic Devices:

Integrating bioactive glass into smart orthodontic appliances that can release ions based on changes in oral pH levels could revolutionize orthodontics. These "smart" devices could provide on-demand remineralization and antimicrobial effects, improving patient care and comfort.[10]

Customization of Bioactivity:

Future research could focus on tailoring the composition of bioactive glass to target specific orthodontic challenges, such as promoting faster bone remodeling to accelerate tooth movement. This could lead to more efficient and comfortable treatment for patients.

Research and Development:

Continued clinical trials are necessary to validate the long-term efficacy of bioactive glass in orthodontics. Research should also focus on its potential in preventing complications like decalcification and root resorption during treatment.

Nano-Bioactive Glass:

Exploring the use of nano-sized bioactive glass particles may improve both the mechanical properties and biological effects of the material. Nano-sized particles could enhance the material's ability to interact with tissues at a molecular level, leading to improved outcomes in orthodontic and other dental applications[47].

Conclusion

Bioactive glass has emerged as a highly versatile and beneficial material in orthodontics and dentistry at large. Its ability to remineralize enamel, reduce friction, promote bone regeneration, and prevent bacterial growth makes it an invaluable tool in various dental treatments. With ongoing research and advancements in material science, bioactive glass is poised to play an even more significant role in enhancing orthodontic care and overall oral health. Future innovations, including the development of smarter devices and advanced composites, will likely expand its applications, offering patients improved outcomes and more effective treatment options.

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