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Structural and Morphological Properties of Borate Bioactive Glasses for Bone Tissue Regeneration

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As a promising biomaterial with tremendous potential in several biological applications, borate bioactive glass has just come to light. It is a desirable option for bone regeneration, dental implants, wound healing, tissue engineering, drug delivery systems, and other applications due to its distinctive mix of bioactivity, biocompatibility, and controlled degradation. By ensuring biocompatibility, unpleasant responses and consequences are kept to a minimum during its safe contact with biological tissues. A benefit in preventing infections at the implant site is provided by some borate bioactive glasses, which also have innate antibacterial capabilities. Borate bioactive glass can offer healing tissues with temporary mechanical support while progressively being replaced by new bone thanks to its regulated breakdown behaviour. Its adaptability to varied forms expands the range of medical situations in which it can be used. A thorough understanding of borate bioactive glass is made possible through the combination of XRD, Raman Spectroscopy, and FE-SEM investigation, which eventually leads to the design of superior biomaterials with increased performance and biocompatibility. Although melt-quenching is the most frequent method for producing BBGs, sol-gel processing of BBGs is becoming more popular and seems to be a potential alternative. The applications of BBGs are explored, the importance of borate bioactive glass as a potential substance in developing medical and dental technology, assisting in bettering patient care and treatment outcomes in the area of regenerative medicine and future research possibilities are recommended, in this review paper.

Keywords: bioactive glass, biocompatibility, support, technology, medicine.

1. Introduction

In 1969, bioactive glasses were made, opening the door to a second generation interfacial bonding of an implant with host tissues. A third generation of biomaterials is made possible by tissue regeneration and repair employing Bio glass gene activation capabilities(Ege et al. 2022). Devices that replace a body component or function can be made from biomaterial in a way that is secure, dependable, affordable, and medically acceptable(Rahaman et al. 2011). The term "biomaterial" has come to mean a synthetic material that is utilized to replace a portion of a living system or to perform a function in close proximity to living tissue.The principal classes of biomaterials that are widely used in biomedical applications include metals, polymers, ceramics, and composites(Fu et al. 2010).Metals are inorganic substances with exceptional atomic configurations and bonding properties that result in improved mechanical, thermal, and electrical properties. They are perfect for a number of medical applications due to their conductivity and mechanical strength, notably the load-bearing capabilities, including hard tissue replacement prostheses, fixation devices, dental implants, and active devices including stents, guide wires, and electrodes(Yao et al. 2007).The most inclusive category for biomaterials is polymers. These organic, long-chain compounds are used in medicines, implanted devices, device coatings, catheters, vascular grafts, and surgical tools due to their versatility in composition and properties(Wang et al. 2014).Biological inertness and excellent compressive strength in ceramics, an inorganic, nonmetallic material, make them suitable for use in medical applications(Zhao et al. 2015). Ceramics comprise substances made of silicates, metallic oxides, carbides, sulphites, refractory hydrides, selenite, and carbon-based compounds like diamond and graphite. Despite their reputation as being incredibly durable, ceramics are constrained by their relative brittleness and subpar mechanical qualities. Covering for load-bearing implants, dental sensors, and medical and orthopedic implants are some other advantageous features of these(Yamaguchi 2022).On a macroscopic level, composite materials are mixtures of two or more different biomaterials, allowing for the optimal physical and mechanical characteristics of each to be utilized(Deliormanlı 2015). They typically consist of a continuous phase (the matrix) and at least one discontinuous phase that has been immobilized or embedded in it. The fact that each component keeps its unique qualities sets this apart from homogenous mixes like metallic alloys.Biocompatible indicates that when it comes into contact with live tissue, bioactive glass won't have any negative effects. It is perfect for medical applications because of this.Bioactive glass is helpful for bone regeneration and repair since it has been demonstrated to encourage the formation of new bone tissue.The capacity of bioactive glass to chemically bind with living tissues promotes the growth of new bone.Because bioactive glass is biodegradable, it can eventually disintegrate and be absorbed by the body.It has been demonstrated that bioactive glass possesses antibacterial characteristics, making it effective for treating infected bone tissue.Chemical composition is the primary distinction between borate and silicate in bioactive glass. While silicon dioxide (SiO_2) is the primary glass-forming oxide in SBG, boron oxide (B_2O_3) is the primary glass-forming oxide in BBG(Deliormanlı and Konyalı 2019).In comparison to silicate bioactive glass (SBG), it has been discovered that borate bioactive glass (BBG) has better bioactivity and faster dissolution rates. This is due to the fact that borate ions are more soluble and may be discharged into the environment more easily, encouraging cell growth and regeneration. On the other hand, silicate bioactive glass (SBG), which has superior mechanical strength and stability, is more frequently used in tissue engineering applications(Ensoylu et al. 2022). SBG is also easier to process and mold into the shapes you want because it has a lower melting point. For their potential in tissue engineering and regenerative medicine, silicate and borate bioactive glasses have undergone substantial research. For usage in in vitro tissue regeneration, either borate or silicate bioactive glass may be preferred depending on the particular application and specifications.

2. Materials and Methods

2.1 Materials

Borate Precursors: Borate salts (SRL), such as B_2O_3, are generally used to make borate bioactive glass. Tetra ethyl ortho silicate (Sigma Aldridge), sodium and calcium nitrate procured from Merck. Similarly, ortho phosphoric acid obtained from spectrum reagents and chemicals.

2.2 Methods

Sodium, calcium precursors included on the silica and phosphate gel, then the samples dried and sintered to prepare the final material. Similarly, on the borate matrix all the precursors added and formulated the material.

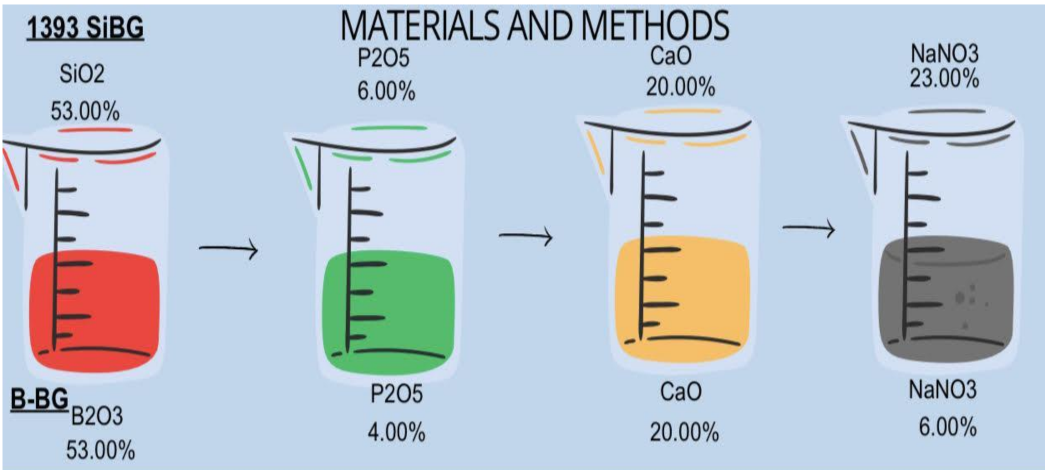

Figure 1:Preparation of bioactive glass.

2.3 Characterization Techniques:

Synthesized Bioactive materials were characterized to further analyse the properties of the prepared materials. X-ray diffraction patterns used to study the crystalline phases with the wavelength of Cu Kα (Bruker D8 advance). Functional group properties were analyzed through Raman spectroscopy (WITEC ALPHA300 RA – Confocal Raman Microscope with AFM). To investigate the morphological and elemental analysis by FE-SEM and EDS [JEOL (JSM -IT 800) { FE-SEM }] and Oxford Instrumentations [EDS].

3. Results:

3.1 X-Ray Diffraction (XRD):

Peaks may be sharp and well-defined for crystalline borates, indicating a highly ordered atomic arrangement, or broad and diffuse for amorphous or semi-crystalline borates, indicating a partially crystalline structure. The borate bioactive glass contains crystalline phases, which may be determined through the XRD examination. A broad, featureless hump in the XRD pattern, which denotes the absence of long-range order, will be visible if the glass is completely amorphous (non-crystalline).The results may provide crucial details regarding the structure of the glass, which can affect its characteristics and behavior, including its bioactivity, if crystalline phases are found.

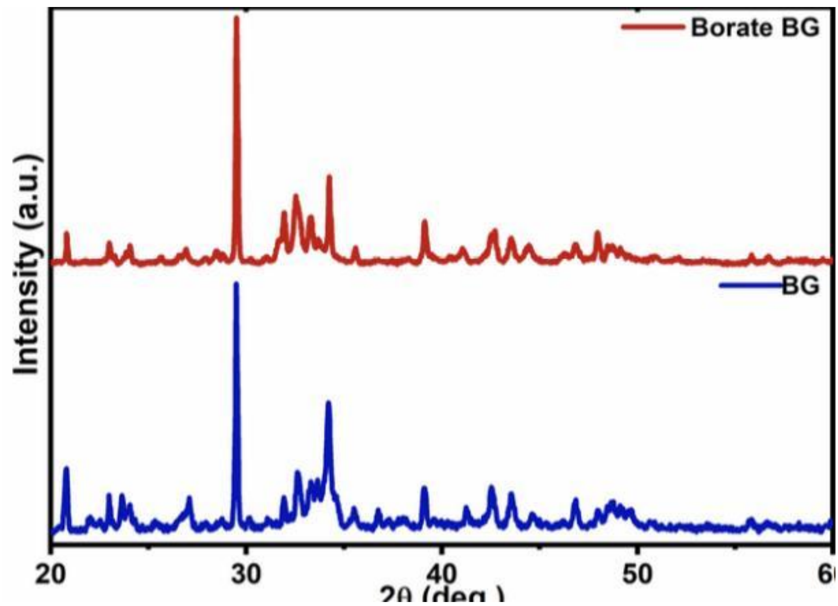

Figure 2: X-Ray Diffraction Patterns of pure bioglass and borate bioglass

3.2 Raman Spectroscopy:

One of the most prominent features in the Raman spectrum of borate bioactive glass is a broad and intense peak centered around 1000 cm-1, which corresponds to the symmetric stretching vibrations of the BO3 units in the glass network. This peak is often referred to as the borate band, and its position and shape can provide information about the local coordination and ordering of the B-O bonds in the glass network.The Raman spectrum's peaks are related to particular vibrational modes, including the stretching, bending, or twisting of chemical bonds in glass. Understanding the glass's properties and behavior, especially its bioactivity and interactions with bodily tissues, requires knowledge of its molecular structure and bonding(Kargozar et al. 2018).

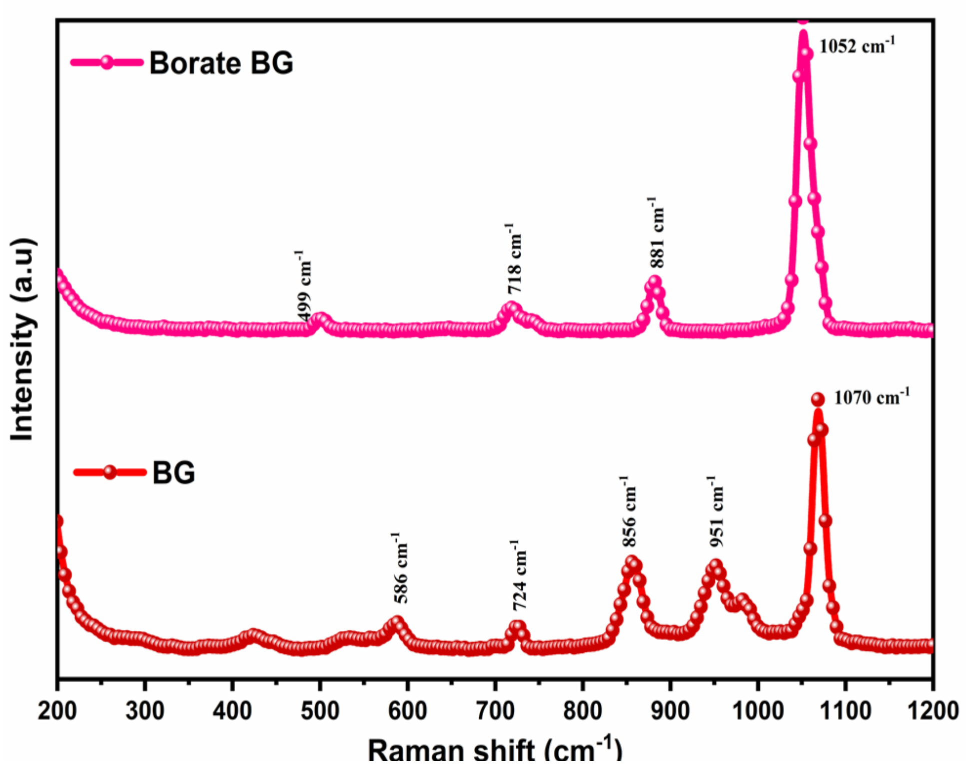

Figure 3: Raman Spectroscopy of pure bioglass and borate bioglass

3.3 Field Emission Scanning Electron Microscopy (FESEM) - Energy Dispersive Spectroscopy (EDS):

Small flake like morphology was observed in bioglass in the case if FE-SEM, alternatively bulk crystals was noted in borate introduced bioactive glasses. Similarly respected composition was analyzed through EDS.The borate bioactive glass's fine surface details and microstructural characteristics may be seen in FE-SEM pictures, which also disclose important details regarding its porosity, pore size distribution, and surface roughness.Insights regarding the material's surface properties and potential for cell adhesion and tissue integration in biomedical applications can be gained from the morphology and microstructure shown in FE-SEM images(Kolan et al. 2020).

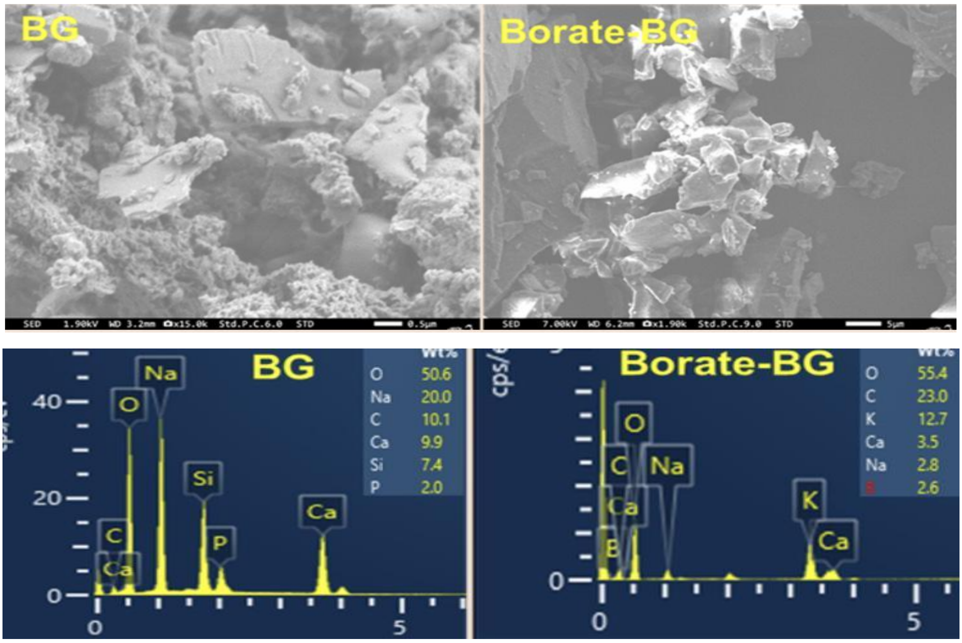

Figure 4: Morphological (FE-SEM) and Elemental (EDS) analysis of pure bioglass and borate bioglass

3.4 Antibacterial properties:

Both the material showed improved anti-bacterial activity. Overall with the study we found that crystallization was entirely different in silicate and borate and in case of anti-bacterial activity silica showed even better anti-bacterial zone than the borate and in morphology also silica induced bioactive glass shows smaller nano structures than borate bioactive glass.However, its local antibacterial actions might not be enough to treat infections that have spread throughout the body. They are particularly helpful in preventing infection near the implant site or inside a wound.

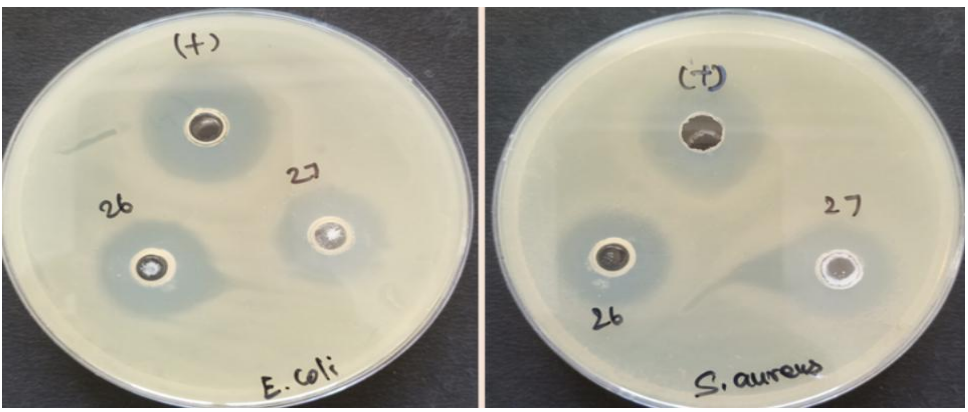

Figure 6: Antibacterial activity of pure bioglass and borate bioglass against E.coli and S. aureus. (26 borate bioglass , 27 pure bioglass)

4. Discussion:

Applications of borate bio active glass(Boccaccini et al. 2016), Borate bioactive glass' crystalline structure is crucial for adjusting its characteristics for particular biological applications. Our goal is to create the ideal balance between bioactivity, mechanical strength, degradation rate, and other crucial parameters by optimizing the glass composition and production conditions(Liang et al. 2008). Borate bioactive glass can be customized to offer superior performance and improved therapeutic outcomes in bone regeneration, dental implants, tissue engineering, and drug delivery applications by fine-tuning the crystalline structure.Due to its special qualities and adaptable traits, borate bioactive glass is extremely important in numerous biomedical applications. In the disciplines of medicine and dentistry, borate bioactive glass is prized for a number of reasons, including:Borate bioactive glass is extremely bioactive, which means that when implanted, it can chemically link with live tissues and promote bone regeneration(Balasubramanian et al. 2018). This characteristic is crucial for applications involving bone regeneration. The development of hydroxyapatite, a mineral component of natural bone, is triggered when borate bioactive glass is in touch with bone tissue. By encouraging the integration of the glass with the surrounding bone, this hydroxyapatite layer aids in bone regrowth and repair.Borate bioactive glass is biocompatible, which means that it is well tolerated by the body and does not cause any harmful side effects or toxicity. This characteristic is essential for biomedical materials since it guarantees that the glass can be implanted or used safely in close proximity to living tissues without injury(Dixit and Sinha 2021).Antibacterial capabilities: Due to the release of certain ions, some borate bioactive glasses have inherent antibacterial capabilities. This antibacterial action helps to improve patient outcomes by lowering the likelihood of postoperative problems and bacterial colonization and infection at the implant site(Jung 2010).Borate bioactive glass is versatile and may be made into a variety of shapes, including powders, particles, granules, and 3D porous structures(Boccaccini et al. 2016). Due to its adaptability, it can be used for a variety of biomedical procedures, such as bone grafting, dental implants, wound healing, tissue engineering scaffolds, and drug delivery systems.Dental Applications: Borate bioactive glass is also used in restorative and implant dentistry, as well as in dental implants. In dental implant, its capacity to encourage osseous integration—the bonding with bone—is valuable(Gönen et al. 2016).Borate bioactive glass may have a delayed breakdown rate, which enables it to support the healing tissue structurally while eventually being replaced by new bone, depending on the composition. Applications for tissue engineering benefit from this regulated breakdown.The bioactive properties of borate bioactive glass encourage osteoconductivity, supporting osteoblasts' development and adhesion. This characteristic makes it easier for the glass to blend in with the nearby bone tissue(Kaur et al. 2014).Borate bioactive glass can be utilized as a medication delivery system's carrier for controlled drug distribution. The glass structure can release medications or therapeutic substances in a regulated and sustained manner, improving the efficacy of treatment.

5. Conclusion:

The versatile and promising material known as "borate bioactive glass" has a lot of potential for use in different biomedical applications. Due to its special qualities, such as bioactivity, biocompatibility, antibacterial activity, and controlled degradation, it is a popular choice for bone regeneration, dental applications, wound healing, tissue engineering, and drug administration systems.Borate bioactive glass can integrate with living tissues and aid in bone regeneration thanks to its bioactivity, which is evidenced by the development of a hydroxyapatite layer on its surface. Due to the fact that it promotes osseointegration and increases the implant's long-term stability, this trait is essential for effective bone transplants and dental implants.Additionally, borate bioactive glass is adaptable to a variety of biological needs since it can be engineered into different forms, such as powders, particles, granules, and 3D porous structures.In conclusion, as a biomaterial that combines bioactivity, biocompatibility, and antibacterial qualities, borate bioactive glass holds enormous promise and will be a crucial part of developing medical and dental technology. In addition to improving patient care and treatment outcomes in the area of regenerative medicine and beyond, the continued research and development of borate bioactive glass are anticipated to further broaden its uses.

Conflicts of interest:

There are no conflicts to declare.

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