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REVIEW ARTICLE

Bioactive Glass: A Material for the Future

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ABSTRACT

Bioactive glasses are novel dental materials that are different from conventional glasses and are used in dentistry. Bioactive glasses are composed of calcium and phosphate which are present in a proportion that is similar to the bone hydroxyapatite. These glasses bond to the tissue and are biocompatible. They have a wide range of medical and dental applications and are currently used as bone grafts, scaffolds and coating material for dental implants. This article reviews various properties of bioactive glasses and their applications and also reviews the changes that can be made in their composition according to a desired application.

Keywords: Bioactive glasses, Apatite formation, Glass transition temperature, Network connectivity, Air abrasion.

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INTRODUCTION

A material is said to be bioactive, if it gives an appropriate biological response and results in the formation of a bond between material and the tissue. Bioactive glasses are silicate based, containing calcium and phosphate.[1]

Hench was the first to develop bioactive glasses (1969) and these glasses were able to bond to tissues.[2] Safety of these bioactive glasses was a concern, so various studies were performed to ensure that bioactive glasses are safe for clinical applications. Wilson et al (1981) reviewed these studies and proposed that bioactive glasses are safe for clinical use.[3]

COMPOSITION

Bioactive glasses have different families and each family has a different composition.

Some classes of bioactive glasses, like Bioglass™ (45S5), are now being used intraorally as bone grafting material after gaining FDA approval.[4]

45S5 bioactive glass is composed of SiO_2 (46.1 mol%), CaO (26.9 mol%), Na_2O (24.4 mol%) and P_2O_5 (2.6 mol%).[5] 45S5 is able to form HCAP (hydroxycarbonated apatite) in less than 2 hours and binds to tissues.[1]

Process of Formation

Bioacitve glasses were initially obtained via melting at higher temperatures. Two common processes for the formation of bioactive glasses are melting and sol-gel process. Rounan Li et al (1991) demonstrated that the formation of bioactive glasses with a composition of SiO_2-CaO-P_2O_5 by sol-gel processing and it was observed that glasses made from the sol-gel process required lower temperatures as compared to conventional melting method.[6] It has also been suggested by Peltola T et al (1999) that glasses made from sol-gel processing have increased bioactivity.[7]

Mechanism of Action of Bioactive Glasses and Apatite Formation

When a bioactive glass is present in an aqueous solution, it reacts with it. As a result of this reaction, a change in the structure and chemical composition of bioactive glass occurs[8] which causes its dissolution and HCAP is formed.[9]

Different glass compositions were used by Kokubo et al (1990) to study the growth of apatite in simulated body fluid (SBF). It was observed that calcium ions of the glass dissolve and apatite's ion activity product is greater than before. The silica network which acts as a place for apatite nucleation, gets disrupted. The growth of the apatite is therefore based on utilization of calcium and phosphate ions from SBF.[10]

Glass Transition Temperature of a Bioactive Glass

Glass transition temperature (Tg) is a range of transformation when an amorphous solid is changed into a super cooled liquid on heating.[11] Properties like dissolution rate and strength of different glasses can be compared with the help of Tg.[12]

Tg and peak crystallization temperature are two very important properties of a glass. A big processing window between these two makes sure that the glass sinters without crystallization.[13] If a bioactive glass crystallizes, it becomes less bioactive because the ion exchange between the glass and aqueous solution is resisted by the crystalline phases.[14]

Network Connectivity of a Bioactive Glass

The number of bridging oxygen atoms are responsible for the network connectivity (NC) because these bridging oxygen atoms join the two neighboring polyhedra.[15]

NC can be utilized to assess the bioactivity, surface reactivity and solubility of a glass. A decreased NC shows that the glass has low Tg but higher solubility and higher reactivity and vice versa.[16] Therefore, NC is an important

tool for designing new glasses with different compositions for different applications.

Relationship between Tg and Hardness

A linear relationship exists between Tg and hardness of a bioactive glass. A decreased Tg of a bioactive glass predicts that the glass has reduced hardness.[12] A similar relation between hardness and Tg of a bioactive glass was explained by Baesso et al (1999), where hardness was found to be decreasing with a decreasing Tg.[17]

Effects of Various ions on Bioactivity

It was proposed by Hench and West (1996) that Na_2O content in bioactive glass determines the rate of formation of HCAP[18] but Li et al (1991) demonstrated that the sol-gel derived bioactive glasses which contained no Na_2O were more bioactive than melt derived bioactive glasses with same composition. Increased bioactivity is actually dependant on size and volume of the pores in the gel. Therefore, Na_2O content is not a determinant of bioactivity.[19]

Phosphate content was also considered important for bioactivity but it was proved that P_2O_5 free bioactive glasses also showed bioactivity.[20]

Effect of Fluoride on the Bioactivity of the Glass

Fluoride prevents demineralization and increases remineralization.[21] For the prevention of caries, the role of fluoride is very important as it forms FAP (fluorapatite) by replacing hydroxyl ions in apatite structure. This substitution has a profound effect on solubility of enamel.[22] Keeping the importance of fluoride in mind, its incorporation in bioactive glasses is of immense interest.

Brauer D et al (2009) performed a study to understand the effect of addition of fluoride in the properties of bioactive glasses. CaF_2 concentration was increased in SiO_2-CaO-P_2O_5-Na_2O system while network connectivity was kept constant. It was observed that incorporation of fluorine in bioactive glass, decreased its Tg which means that the glass has reduced hardness and is more bioacitve. Also, the onset of crystallization and peak temperatures were decreased when CaF_2 was increased.[23]

Effect of Sodium on the Bioactivity of the Glass

The content of sodium oxide can affect the properties of a glass.[24] Wallace KE et al (1999) explained the relationship between sodium oxide content and different properties of bioactive glasses, like hardness and bioactivity. SiO_2-CaO-P_2O_5-Na_2O glass system was used to study. Network connectivity was kept constant by removing one mole percent of CaO and adding one mole percent of Na_2O. It was observed that by increasing Na_2O content, the Tg and peak crystallization temperature declined linearly. NC of a glass is not affected when Na_2O is replaced with CaO in a glass. However, this replacement has an influence on the packing of atoms. Glass network expands when Na_2O is increased and this results in a decrease in density of the glass. Because of this property, Na_2O is referred as network disrupter. The addition of Na_2O has an effect on Tg because Tg is an expression of network disruption of a glass; therefore, Tg is reduced when Na_2O content is increased.[9]

Indications of Bioactive Glasses

Bioactive glasses have a wide range of applications. Bioglass™ also known as 45S5 is most commonly used for bone grafts.[25] Bioactive glasses help in the repair of hard tissues[26] and various compositions are being used nowadays for preparation of scaffolds[27] and as coating material for implants.[28]

LitKowski et al (1997) conducted an *in vitro* study and used Bioglass™ (45S5) on dentinal surfaces of teeth and demonstrated increased occlusion of dentinal tubules by 45S5 as compared to non-45S5 compounds thereby proposed that it should also decrease dentine hypersensitivity *in vivo*.[29]

In addition to remineralization, bioactive glasses have antibacterial effects[30] as they can raise the pH of aqueous solution.[31] Bioactive glasses when used for air polishing, yielded better results in terms of stain removal and patient comfort as compared to traditional sodium bicarbonate powder.[32] Bioactive glass can also be utilized for cutting cavities in teeth by air abrasion.[33]

Replacement of Alumina with a Bioactive Glass in Air Abrasion System

Bioactive glasses can replace alumina in air abrasion system.[34] Toxicology studies have shown that bioactive glasses cause negligible pulmonary tissue reactions and glass components are also safely excreted.[35] The hardness of bioactive glasses is less than alumina but they can cause remineralization of the surface unlike alumina.

Therefore, bioactive glasses of different composition and hardness should be produced to test their cutting efficiency.[4]

CONCLUSION

Bioactive glasses with various compositions are now used for wide range of applications. Bioactive glasses have become an area of interest for researchers and research is

still continuing on various aspects of these glasses. With their current applications, a bright future of these glasses in the field of medicine and dentistry can be easily predicted.

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