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Bio Glasses And Glass-Ceramics: Properties, Preparation, And Clinical Application

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Abstract – Ceramics and glasses are not the same as metals, despite being near relatives. Both have excellent strength, hardness, elastic modulus, and chemical inertness and are electrical and thermal insulators. Glasses are amorphous, whereas ceramics are crystalline. These glasses are being utilized as implants in the human body to mend and replace damaged or diseased bones due to their biocompatibility and bioactivity. Because they encourage new bone formation both along with the bone-implant contact and within the implant distant from the bone-implant interface, bioactive glasses are osteoconductive and osteoinductive materials.

Keywords – ***Biomaterials, Therapeutic Ion, Intraorally, Antibiotics***

I. Introduction

Ceramics and glasses are not the same as metals, although they are close cousins. Both have excellent strength, hardness, elastic modulus, and chemical inertness and are electrical and thermal insulators. Ceramics are crystalline, whereas glasses are amorphous. Ceramics, inorganic glasses, and glass-ceramics are together referred to as "ceramic materials." "Ceramics are crystalline and are typically harder, stronger (particularly in compression), stiffer, and have a more excellent melting point than metals, but they are electrically and thermally insulating and considerably less ductile and tough; they are generally brittle"[1]. In general, most are considerably more resistant to chemical attack. Inorganic glasses made from or related to ceramics usually have comparable properties but substantially different optical properties, being transparent to light in most cases. "Glass-ceramics, which are crystalline materials formed from amorphous inorganic glasses by thermal treatments known as devitrification, are more similar to ceramics than glasses"[2, 3]. Many characteristics that make ceramics and glasses appealing for certain functional features and severe operating conditions also make them challenging to manufacture into big and complicated forms[4]. Furthermore, while ceramics and glasses are attractive because they have distinct physical, electrical, thermal, optical, and chemical properties than metals, they usually need coupling with metals in devices or structures where structural integrity is important. As a result, it is important to join different ceramics or glasses with metals.

A broad variety of materials are utilized in the manufacture of medical devices, and each chemical will interact with the biological environment in some way. These compounds are commonly referred to as biomaterials. A biomaterial is a man-made material that is intended to come into touch with live tissue[5]. Despite major breakthroughs in disciplines such as tissue engineering, most biomaterials are still synthetic and used as implants to replace sick or injured tissues. Biomaterials are a diverse group of materials that might be natural or synthetic, inorganic or organic, metals, polymers, or ceramics.

In response to the requirement to limit interfacial mobility in implanted bioinert ceramics, bioactive glasses and glass-ceramics have been created. Thus, Hench proposed to the US Army Medical Research and Development Command in 1967 that research be done to change the chemical composition of glasses in order to allow contact with the physiological system and create a chemical link between live tissue and the implant surface[6]. The most prevalent application of biomaterials is in the replacement of hard tissues in the body, such as knee and hip joint prostheses, and the alleviation of dental hard tissues, especially enamel and dentine, is perhaps the most ubiquitous application of biomaterials[7]. Although bioceramics are commonly utilized in bone restoration, patients are more likely to be introduced to them when they require dental treatment. [8]Teeth are comprised of enamel and dentine, and unlike bone, these tissues do not have the ability to heal themselves if they are damaged by dental illnesses such as caries and periodontal disease[9]. Every year, millions of individuals seek dental care, and the need for attractive tooth-like restorations is growing. Ceramics are ideally equipped to satisfy this need, and dental materials are one of bio ceramics' fastest expanding applications[10].

The goal of this research is to evaluate and decide on Glasses and Glass Ceramics Preparation, Properties, and Medical Applications. Furthermore, the author would look into how AW GC might be tested more successfully in a laboratory to see how the mechanical properties alter for medicinal purposes.

II. Bioactive Glasses And Glass-Ceramics

Bioactive glasses are a type of surface reactive glass-ceramic biomaterial that includes the first bioactive Glass, Bioglass®. Because of their biocompatibility and bioactivity, these glasses are being used as implant devices in the human body to repair and replace broken or diseased bones. “Bioactive glasses are osteoconductive and osteoinductive materials because they promote new bone development both along with the bone-implant contact and within the implant away from the bone-implant interface”[11]. Glass, rather than being a particular component, “is a state of matter, a subset of the solid state”. Glass is a network of atoms kept together by covalent interactions with oxygen atoms. Silica tetrahedra are randomly joined together to form a silica-based glass, as illustrated in **Fig.1**. Glass-ceramic materials are polycrystalline solids with a remnant glassy phase that results from the controlled crystallization of glasses. Crystallinity ranges from 0.5 to 99.5 percent, with the most common value being 30-70 percent. Any glass-forming process may be used to mass manufacture it. It is possible to design the material's nano or microstructure. The majority have zero or extremely low porosity. It is possible to mix and match desired attributes.

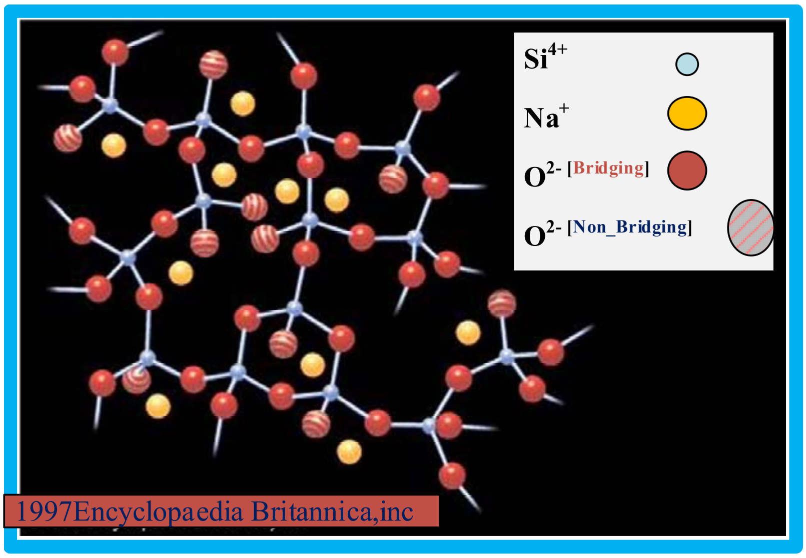

Fig.1.A glass network of atoms held together by covalent bonds

Window glass is frequently made from the soda-lime-silica (Na2O-CaO-SiO2) combination. These components are also present in bioactive glasses but in fewer amounts than in inert glasses. The vast majority of bioactive glasses are silicate-based glasses that dissolve in physiological fluids and can operate as a therapeutic ion transfer channel. The anti-infective and angiogenic characteristics of “Bioactive Glass set it apart from other synthetic bone grafting biomaterials (such as hydroxyapatite, biphasic calcium phosphate, and calcium sulfate)”[12]. Because these bridging oxygen atoms as shown from **Fig.2.** below, connect two nearby polyhedra, the quantity of bridging oxygen atoms is responsible for network connection.

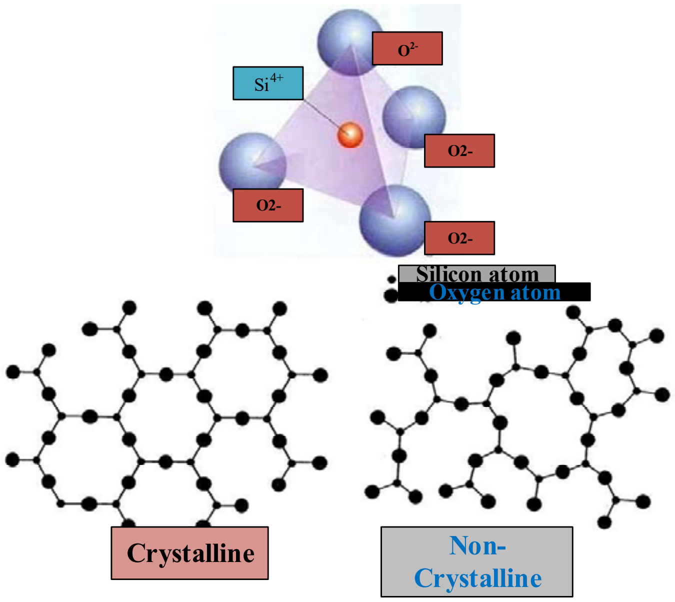

Fig.2.Quantity of bridging oxygen atoms for network connection

2.1 Apatite formation and the mechanism of action of bioactive glasses and glass ceramics

When bioactive Glass is inserted into the bone cavity, it interacts with bodily fluids, activating the Glass. During this activation phase, the bioactive Glass undergoes a series of chemical processes that provide the optimal circumstances for bone regeneration via osteoconduction[13]. Ions such as Na, Si, Ca, and P are liberated. On the bioactive glass surface, a silica gel layer develops. CaP crystallizes, creating a coating of hydroxyapatite on the bioactive Glass's surface. Following the formation of the hydroxyapatite layer, the bioactive Glass interacts with biological entities such as blood proteins, growth factors, and collagen. New bone develops onto and between the bioactive glass structures as a result of this interactive, osteoconductive, and osteostimulative process[14]. Bioactive Glass binds to bone, promoting the creation of new bone. Osteostimulation begins by activating osteogenic cells, which increases the pace of bone remodeling. The radio-dense nature of bioactive Glass enables post-operative assessment. In the last transformative phase, the process of bone regeneration and remodeling proceeds[15]. Over time, the bone regenerates fully, restoring the patient's original structure. Bone consolidation takes place. Over time, bioactive Glass continues to repair into bone.

Hench and West (1996) asserted that the “Na_2O content of bioactive glasses affects the rate of HCAP synthesis, but Li et al. (1991) discovered that sol-gel produced bioactive glasses with no Na_2O were more bioactive than melt formed bioactive glasses with the same composition”[16]. The size and volume of the pores in the gel influence increased bioactivity. As a result, the presence of Na_2O is not a predictor of bioactivity. Tg and peak crystallization temperature was observed to decrease linearly with increasing Na_2O content. In a glass, replacing Na_2O with CaO has no effect on the NC. However, this change has an influence on atomic packing. When the Na2O concentration is increased, the glass network expands, resulting in a decrease in glass density. Because of this property, Na_2O is referred to as a network disrupter.

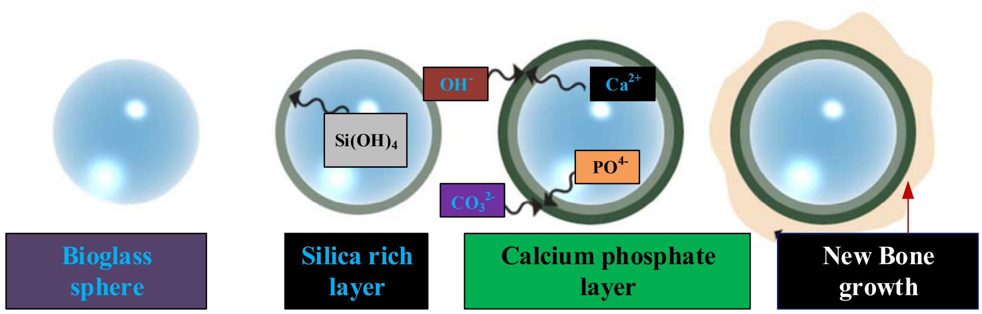

Fig.3.The chemical bond between the bioactive glass particles and the surrounding bone[17]

The bioactive properties of bioglass are derived from the material's ability to form a bone-like mineral layer as shown above **Fig.3**.on its surface (hydroxyl-carbon-apatite - HCA)[18]. The ions produced by the bioactive glass particles combine with local ions to form an HCA coating on the surface as they disintegrate in vivo. Because the HCA layer is similar to bone minerals, it creates a chemical link between the bioactive glass particles and the surrounding bone. Bioactive glasses are classified into several groups, each with its own makeup. Following FDA permission, certain types of bioactive glasses, such as BioglassTM (45S5), are currently being utilized intraorally as bone grafting material. 45S5 bioactive Glass is made up of SiO2 (46.1 mol%), CaO (26.9 mol%), Na2O (24.4 mol%), and P2O5 (2.6-mole percent). 45S5 attaches to tissues and can produce HCAP (hydroxyl carbonated apatite) in less than 2 hours.

2.2 A bioactive glass's and glass ceramics network connectivity

The quantity of bridging oxygen atoms influences network connection since they connect two neighboring polyhedra (NC). NC may be used to assess the bioactivity, surface reactivity, and solubility of a glass[14]. A lower NC value implies that the Glass has a low Tg but higher solubility and reactivity, and vice versa. "As a result, NC is an important tool for producing new glasses with diverse compositions for a variety of applications. Phosphate exists in BG as a separate orthophosphate phase and is required for apatite precipitation in physiological solutions." Aside from phosphate content, as shown from **Fig.4**.[19] below network polymerization (Qn structure) has a major impact on glass dissolving and apatite formation, and NC or split network models are useful and successful in predicting bioactivity[20].

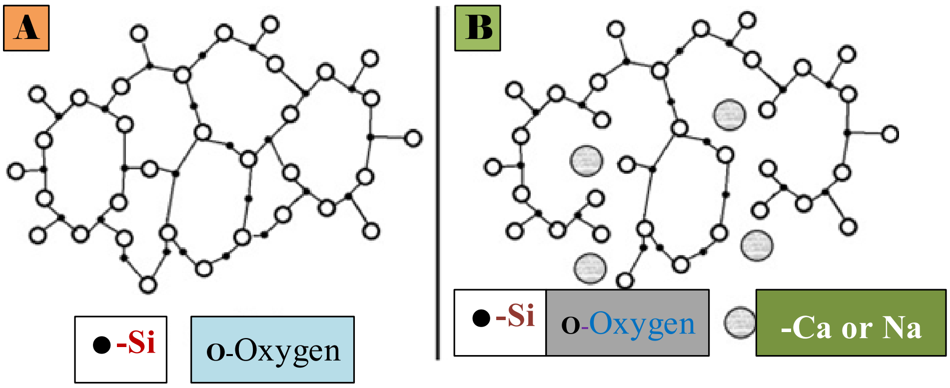

Fig.4.Schematic representation of a Si-based glass (a) and a bioglass (b).

Glass-ceramics are polycrystalline materials created by controlled crystallization of Glass, with crystalline content as high as 90% by volume embedded in the glass phase. According to the Nc model, "the bridging oxygen atoms are randomly distributed in the glass, and the likelihood of one atomic unit connecting covalently through bridging oxygen with another is determined by their relative concentrations"[15, 16]. The distribution of bridging and non-bridging species has a direct impact on glass characteristics, including hydrolytic stability, bioactivity, and mechanical properties (fracture toughness, hardness)[19]. Structural units in silicate glasses with limited network connection are likely to have low molecular mass and can migrate into solution[21]. When a result, as network connection declines, glass solubility increases. As a result, glass systems with limited network connections may be bioactive. Glasses and glass-ceramics with Nc values greater than 2.6 are termed non-bioactive because of their considerable resistance to disintegration[13, 22].

III. Preparation Of Glass And Glass Ceramics

There are now about five macro-classes of manufacturing techniques, as stated in **Table.1**. below available for the manufacture of BGs and Glass-ceramics. Numerous factors are evaluated in order to choose the best manufacturing process since the final aim is to get a specific composition capable of providing regulated bioactive activity, which is essential in possible therapies.

Table.1. Preparation methods for bioglass and glass ceramics

No	Method	Advantage	Disadvantage	Reference
1	Melt-quenching technique	• The product can be easily optimized by the Taguchi method.	• Nonlinear characteristics of these glasses • Impure semiconductor composition and surface imperfection of the nanoparticles • It can be used to overcome the inability of this approach to generate thin films	[23-26]
2	Sol-Gel	• Suitable for deposition on various substrates such as silica/glass rushing rings, glass wool • Simple homogeneity, repeatability, cheap cost, dependability, and controllability • Films may be readily fixed on substrates with complex forms and a wide surface area.	▪ A lengthy deposition period ▪ A dense coating of Nanoparticles cannot be attached to the substrate. ▪ The high temperature required to form anatase nanocrystals ▪ High cost of fabrication	[27-37]
3	Spray pyrolysis	• Continuous process and • Has considerably shorter processing times • No need for a vacuum • Synthesize materials in the form of powders and films	• Scaling up is difficult. • Low yield • Difficulties determining the growing temperature	[38-45]
4	Spray Drying	• The operation is continuous and may be fully automated. • It is suitable for both heat-resistant and heat-sensitive goods. • It is possible to create almost spherical particles.	• Has not produced particles with various morphology. • The fast drug release rate and results burst.	[46-48]
5	Modified Stöber	▪ It can produce nearly monodisperse silica particles ▪ provides an excellent model for investigating colloidal phenomena ▪ enabling the manufacture of controlled-size spherical monodisperse silica particles	▪ The aerogel is fragile	[49-51]

IV. Clinical Application

Biomaterials, both natural and synthetic, are used in medical applications to preserve, enhance, or replace damaged tissue or biological processes. Biomaterials is a new field that combines medicine, biology, physics, and chemistry, as well as more recent impacts from tissue engineering and materials science. In 1987, the European Society of Biomaterials defined "biomaterial" as a non-biological material used in a medical device to interact with biological processes. Common orthopedic materials include metals and metal alloys, biostable plastics, bioabsorbable polymers, biocomposite polymers/ceramics, bioceramics, collagen, and extracellular matrices. They work adequately and improve the recipient's life, yet they nevertheless have frequent failures. As a result, while biomaterials are successful in terms of their characteristics and activities, they will never be as effective as the original material. Bioglass and glass ceramics are synthetic materials that come into contact with physiological fluids on a regular or irregular basis and are used to replace or restore function to biological tissues.

Biomaterials are used in a wide range of medical devices, including orthopedics, cardiovascular applications, wound healing, and many more. A body must satisfy the following requirements to implant biomaterials: biocompatible chemical composition to minimize adverse tissue reactions, sufficient resistance to degradation, enough strength to sustain the joint's cyclic stress, and excellent wear resistance.

Orthopedic implant devices are the most common application for biomaterials. Rheumatoid arthritis and osteoarthritis both damage the structure of freely mobile (synovial) joints, including the hip, knee, shoulder, ankle, and elbow. The discomfort in such joints, particularly weight-bearing joints like the hip and knee, can be excruciating, and the impact on ambulatory function can be disastrous. Since the introduction of anesthesia, antisepsis, and antibiotics, it has become feasible to replace these joints with prostheses, and the alleviation of pain and restoration of movement has been extensively documented in hundreds of thousands of patients. As a biomaterial for body implants, it must be biocompatible so that it does not cause an unfavorable reaction in the body or bodily fluid. It should also be non-toxic and non-carcinogenic. Many engineering materials are no longer accessible as a result of these restrictions. To function as an augmentation or substitute for organic tissues, the biomaterial must have strong physical and mechanical characteristics. As illustrated in Fig.5.below, biomaterials are utilized in medical applications because they are biocompatible and allow patients to recover faster.

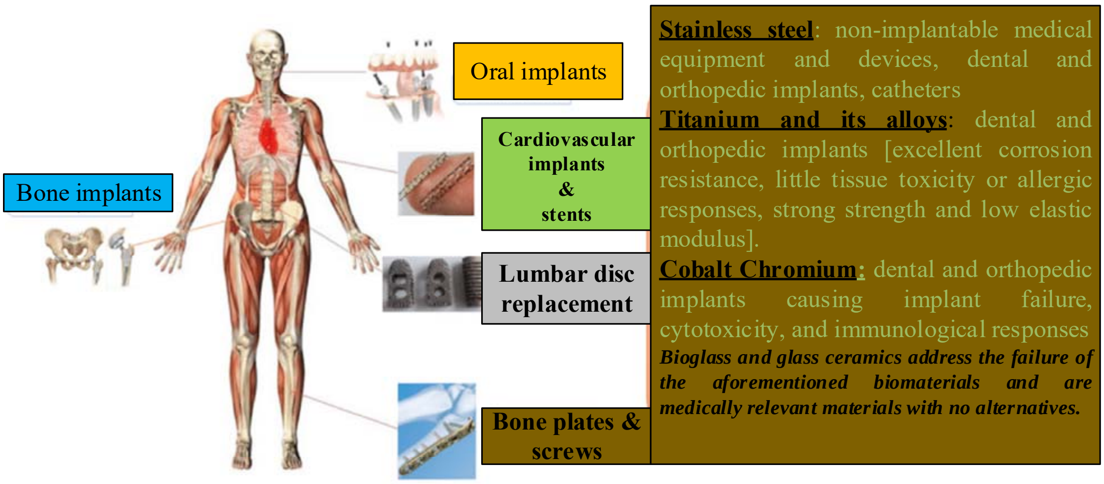

Fig.5. Biomaterials and Their Applications in Medical Devices[52]

The bending strengths of parent glass and glass-ceramic, which primarily precipitate apatite, are 72 and 88 MPa, respectively. Glass-ceramic has a high bending strength due to apatite precipitation. As demonstrated in the figure above, the extraordinary "bending strength of glass-ceramic is attributable to its high fracture toughness over or comparable to steel surgical implantation.

V. Conclusion And Future Endeavors

This review discusses the what and how of bioglass and glass-ceramics, as well as preparation methods and medicinal applications, as well as apatite production, and bone-bonding characteristics. The bioglass and glass-ceramic materials in this review have good Osseointegration and therapeutically acceptable mechanical features, including fracture toughness and flexural strength. However, the difficulty of this method to bulk nucleate and the lack of bioresorbable materials create new research and development problems. Although freshly produced chlorapatite GCs show the required resorb ability and Osseointegration, additional research is needed to investigate in vivo activity and the mechanism of action. The author wants to conclude that information gained from biomaterials research, including Glass and glass-ceramics, continues to amaze and transmit new notions in the structural solid-state addressed in this book, with unquestionably substantial future potential.

Conflicts of Interest: The author declares that there are no conflicts of interest.

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