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Bioglass-A Miracle Material

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Abstract: *Material sciences have experienced immense progress in the evolvement of new materials, especially in the past 30 years. Some of the materials like Glass Ionomer, Composite, Mineral trioxide aggregate have proved their excellence but hunt for a material which could fulfill all the requirements in dentistry is still going on. Materials used in the replacement of tissues have come a long way from being inert to compatible, and now regenerative. Larry Hench developed a material using silica (glass) as the host material, incorporated with calcium and phosphorous to fuse broken bones. This material mimics bone material and stimulates the re-growth of new bone material. Thus, due to its biocompatibility and osteogenic capacity it came to be known as "bioactive glass-bioglass." It is now encompassed, along with synthetic hydroxyapatite, in the field of biomaterials science known as "bioactive ceramics." This article aims at the various uses in dentistry, of this novel, miracle material which can bond, induce osteogenesis, and also regenerate bone.*

Keywords: *Bioactive, Bioceramic, Biocompatible, Bioglass, Regeneration.*

I. 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] They are a subset of inorganic bioactive materials, which are capable of reacting with physiological fluids to form tenacious bonds with bone through the formation of bone-like hydroxyapatite layers and the biological interaction of collagen with the material surface [2]. It has been found that reactions on bioactive glass surfaces lead to the release of critical concentrations of soluble Si, Ca, P and Na ions, which induce favourable intracellular and extracellular responses leading to rapid bone formation [3].

In the history of development of materials used in dentistry, specifically replacement materials, shows that the aim has been to create materials that were as chemically inert as possible. In mid 60s, the biocompatibility and long-term survival of the material was achieved by minimizing the material-host interaction. The materials used at that time were mostly metallic, which caused corrosion and eventual failure by the aggressive nature of body fluids. This led to the search of materials that could withstand the chemical attack of the body.In the late 1960s and early 1970s, the search for better biocompatibility of implant materials resulted in the new concept of bioceramic materials that would mimic natural bone tissue.

II. Compositions

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 graftingmaterial after gaining FDA approval.[4]

The original bioglass (45S5) composition is: 45% silica (SiO_2), 24.5% calcium oxide (CaO), 24.5%sodium oxide (Na_2O), and 6% phosphorous pentoxide (P_2O_5) in weight percentage. Minerals that occur naturally in the body (SiO_2, Ca, Na_2O, H, and P) are the constituents of bioglass, and the molecular proportions of the calcium and phosphorous oxides are similar to those in the bones. The surface of a bioglass implant, when subjected to an aqueous solution, or body fluids, converts to a silica-CaO/P_2O_5 -rich gel layer which then mineralizes into hydroxycarbonate in few hours.[5][6][7].More the dissolution, better the bone tissue growth.[8] This gel layer resembles hydroxyapatite matrix so much that osteoblasts were differentiated and new bone was deposited.[9] $Ca_5(PO_4)_3(OH)$ is the chemical formula for hydroxyapatite, a natural mineral form of calcium apatite and usually written as $Ca_{10}(PO)_6(OH)_2$. 45S5 is able to form HCAP (hydroxycarbonated apatite) in less than 2 hours and binds to tissues.[1]

Certain compositional range of bioactive glass containing SiO2, Na2O, CaO, and P2O5 like ordinary soda-lime-silica glasses in specific proportions shows bonding to bone. Three important compositional features of these glasses differ from traditional Na2OCaO- SiO2 glasses: (1) less than 60 mol. % SiO2, (2) high-Na2O and high-CaO content, and (3) high-CaO/P2O5 ratio. As known, SiO2/Al2O3 act as glass network former, CaO/MgO/P2O5 is the network modifier and Na2O/K2O is the fluxing agent. These compositional features make the surface highly reactive when exposed to aqueous medium. 45S5 bioactive silica glasses are based upon 45 wt. % SiO2, S as the network former, and a 5 to 1 molar ratio of Ca to P. Glasses with very lower molar ratios of Ca to P (in the form of CaO and P2O5) do not bond to bone (Hench and Paschall, 1973). Different substitutions in the 45S5 compositions of 5-15 wt. % B2O3 for SiO2, or 12.5 wt. % CaF2 for CaO or crystallizing the various bioactive glass compositions to form glass-ceramics were found to have no measurable effect on the ability of the material to form a bone bond (Hench & Paschall, 1973). But, addition of small 3 wt. % Al2O3 to the 45S5 formula prevents bonding.

High amounts of Na2O and CaO as well as relatively high CaO/P2O5 ratio make the glass surface highly reactive in physiological environments (Hench, 1991). Other bioactive glass compositions developed over few years contain no sodium or have additional elements incorporated in the silicate network such as fluorine (Vitale-Brovarone et al., 2008), magnesium (Vitale-Brovarone et al., 2005; Vitale-Brovarone et al., 2007), strontium (Gentleman et al., 2010; O'Donnell & Hill, 2010; Pan et al., 2010), iron (Hsi et al., 2007), silver (Balamurugan et al., 2008; Bellantone et al., 2002; Blaker et al., 2004)

III. Applications

3.1 Bioglass as a graft material

To repair massive bone defects caused by disease and trauma, a bone grafting procedure is required. The limitations associated with the use of autografts and allografts have boosted the research and development of bone graft substitutes. The last three decades saw the trials of many glass and glass-ceramic compositions. Hench developed the glass-silicate which can bond to the bone. The bioactive glass bond with certain connective tissue through the formation of collagen meshwork. Bioactive glass with its interconnected porosity has added advantages in hard-tissue prosthesis. The porous structure supports tissue in/on growth and improves implant stability by biologic fixation. But its low fracture resistance makes it more useful in load-free areas.[10] Froum and Weinberg found significantly less gingival recession in sites where bioactive material was used, compared with control sites. Also bioactive glass sites showed significant improvement in clinical parameters compared with open flap debridement. [11]

3.2 Bioglass as endosseous implant

Although biocompatible metallic implants are strong, their bonding ability to bone tissue is very low (bioinert materials), so coatings have drawn attention as a method to improve their adherence. Stanley et al found that bioglass as the most promising implant material, in his in vivo study on Baboons. Bioglass caused ankylosis, usually by direct deposition of bone on the implant surface, with the added advantage of gradation of mineralization within the bioglass gel layer reducing from outward to inward providing mechanical compliance like the periodontal membrane in the natural tooth.[12] In another implant study, infectionless normal tissue healing with new bone formation as sighted in radiographs made bioglass a highly biocompatible innovation.[13][14]

3.3 Bioglass as remineralizing agent

Among the various clinical situations managed by dental professionals, the management of hypersensitive dentin still remains a challenge. The characteristic osteogenic activity of bioactive glass made it worth its trial in management of hypersensitivity by occluding dentinal tubules. A new dentifrice formulation containing a modified bioglass material, when used with a suitable vehicle, can be an excellent treatment for dentine sensitivity.[14] NovaMin® is the branded ingredient that is found in a number of professional use and over-the-counter dental products designed to give immediate and long-lasting relief from tooth sensitivity. Salonen et al. proved that S53P4 induced tissue mineralization at the glass-tissue interface and elsewhere. The study widened the use of bioglass in treatment of caries prophylaxis, in dentinal hypersensitivity, as root apex sealer, and as metal implant coating.[16] Dentine treated with melt-driven bioglass showed an apatite layer, which was continuous, adherent, and with particle formation. Bioerodible gel films have also been proved to be useful in the delivery of remineralizing agents.[17][18]

3.4 Bioglass as antibacterial agent

The reactions of bioglass in aqueous environment, leading to osseointegration prompted scientists to check its antibacterial activity. Recently, anti-microbial properties inherent in these materials have been described. One of these compositions has recently been formulated into a dentifrice and has demonstrated strong anti-microbial behavior in-vitro as well as in-vivo. Zhang D et al concluded that bioglass is an efficient antibacterial agent and its antibacterial effect was attributed to its alkaline nature.[19]

3.5 Bioglass in delivery of drugs and growth factors

In recent years wide spread research has been initiated with new advanced drug delivery systems with better drug control and prolonged action. The drug delivery process is of paramount importance in assuring that a certain molecule will reach without decomposition or secondary reactions at the right place to perform its task with efficiency. A drug delivery system should be inert, biologically compatible, good mechanical strength, good from the aspect of patient comfort. It should have ability to carry high doses of the drug, with no risk of accidental release; and easy in administering, removal, fabrication, and sterilization. Bioglass has been tried as a vehicle for drug delivery. Vancomycin on bioglass carrier has been tested for treating osteomyelitis with success[20].The fast-acting anti-inflammatory drug ibuprofen was released in the first 8 hours when immersed in simulated body fluid. [21]

3.6 Bioglass in bone tissue engineering

Tissue engineering and regenerative medicine aims to restore diseased or damaged tissue using combinations of functional cells and biodegradable scaffolds made from engineered biomaterials. One of the biggest hurdles in tissue engineering was to mimic the extracellular matrix. In bone tissue engineering, bioactive glasses and related bioactive composite materials represent promising scaffolding materials. Scaffolds built using biocomposite nanofibers and nanohydroxyapatite were naturally very porous, which in turn facilitated good cell occupancy, vascularity, movement of nutrients, and metabolic waste products. Studies comparing bioinert with bioactive glass ceramic templates, produced increased osteoblast proliferation and differentiation. This system helped the human fetal osteoblasts to adhere, migrate, proliferate, and mineralize into bone, which was a tremendous step ahead in the bone defect filling.[22][23]

IV. 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. A small limitation of low mechanical strength and low fracture resistance can be easily overcome by altering the composition and using in low load bearing areas.Very clearly the limitations of bioglass are minimal as compared to the versatile strength and huge forray of uses. Indeed Bioglass is a boon to the field of Medicine gifted by Larry Hench.

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