Bioactive glasses as group of biomaterials used in dentistry

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Abstract: Bioactive glasses are able to bond to both soft and hard tissue and promote the bone growth. The bioactivity behavior of these glasses is related to the formation of a biologically active hydroxyapatite layer on the surface of the glasses. The mechanism of bonding of bioactive glasses to tissues includes a series of surface reactions that occur when the glass is exposed to an aqueous environment. Bioactive glasses have a wide range of applications, such as bone grafts, scaffolds, coating materials, and are used for hypersensitivity treatment. One of the most important properties of bioactive glasses is their ability to exhibit antibacterial activity, which creates a bacteria-free environment while healing and regenerating the defect area. These potentials of bioactive glass make it a unique material to be widely used in dentistry. Such materials can stimulate bioactive behavior around the fixed restorations margins and provide a bioactive surface. Therefore, they can develop periodontal tissue attachment and create complete sealing of the marginal gap. This sealing can prevent the failure of fixed ceramic restorations by eliminating the secondary caries, micropenetration of oral bacteria and their adhesion on the cement surface.

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1. Introduction

BAGs were introduced in dentistry: As substitutes for reconstruction of voids and defects of facial bones (Schepers, et al., 1991; Schepers, et al., 1993; Suominen and Kinnunen 1996), in rehabilitation of the dentoalveolar complex, including BAG implants (Wilson, et al., 1994) and regeneration of periodontal bone support (Larmas, et al., 1995; Shapoff, et al., 1997; Lovelace, et al., 1998). BAGs may have therapeutic value as mineralizing agents in caries prophylactics, and also as a desensitizing agent in clinical situations where opened dentinal tubules lead to hypersensitive teeth (Orchardson, et al., 1994).

Furthermore, in implantology, a coating of technically adequate BAG on the fixture surface may serve as a means to attach mucosal or dermal soft tissues to the osseointegrated construction by an HCA bridge (Linde and Berglundh 1998). In addition, BAGs may also have an application in root canal therapy providing a biological seal in the form of mineral deposition inducing materials in the root canal and at the apex (Sarin and Rekhi 2016). The base components are usually SiO_2, Na_2O, CaO, and P_2O_5 and given below are percentages in weight of the most common BAGs.

Bioglass composition in wt %:

SiO_2-45 wt% Na_2O - 24.5 wt% CaO - 24.5 wt% P_2O_5-**6 wt**%.

The most studied is the Bioglass ® 45S5. The abbreviation indicates that it contains 45% in weight of SiO_2 (oxide creator) and the molar rate between Ca/P is of 5:1. Glasses with significantly lower molar rate (in the form of CaO and P_2O_5) do not generate connections with the bone (Sarin and Rekhi 2016).

The ability of BAG to support osteogenesis:

When the glass composition exceeds 52% by weight of SiO_2, the glass will bond to the bone but not to soft tissues. This finding provided the basis for clinical use of Bioglass for implants to maintain the alveolar ridge of edentulous patients. BAG is used extensively in dentistry in the treatment of bone defects, ridge preservation, and periodontal bone defects (Subbaiah and Thomas 2011).

Mengel et al., (2006) conducted a clinical and a radiological study to compare the long-term effectiveness of a bioabsorbable membrane and a BAG in the treatment of intrabony defects in patients with generalized aggressive periodontitis, results showing significant improvement in probing depth and clinical attachment loss. Radio graphically, the defects were found to be filled significantly more in BAG group (Subbaiah and Thomas 2011). The material has also been used for repair of alveolar bone defects in humans (Mengel, et al., 2006) and recently it has been used for sinus floor augmentation in humans, showing bone regenerative activity (Furusawa and Mizunuma 1997).

BAGs of the SiO2-Na2O-CaO-P2O5 type have recently been suggested as topical root canal disinfectants (Zehnder, et al., 2004). The ability of BAG to support osteogenesis is well known but recent work has also shown its proangiogenic potential, which should provide benefits for the application of BAG to soft tissue repair which are being seen in recent works regarding the tissue-engineered regeneration of structures such as the synovial joint condyle, bone tendon complex, bone ligament junction, and the periodontium.

The potential of these materials for remineralization of both enamel and dentin has been studied in vitro and in situ and holds promise (Mukai and ten Cate 2002; Madan, et al., 2011). In addition, the unique ionic reactions and potential antimicrobial and anti-inflammatory properties might prove useful in treating gingivitis.

2. Clinical Applications

Bioactive-glass (B-G) is a material known for its favorable biological response when in contact with surrounding fibro-osseous tissues, due not only to an osteoconductive property, but also to an osteostimulatory capacity, and superior biocompatibility for use in human body, the possibility of employing these biomaterials to fill and repair dentoalveolar defects in a rapid and controllable way has been thoroughly investigated by oral and maxillofacial surgeons as well as dentists (Gosain 2004). Since its introduction, the original B-G has been released as PerioGlas® (now sold by NovaBone Products LLC, Alachua, FL, USA) for periodontal regeneration, and NovaBon (NovaBone Products LLC) or Biogran® (BIOMET 3i, Palm Beach Gardens, FL, USA) used in oral and maxillofacial surgery. Other commercial products based on melt-derived calcium sodium phosphosilicates, BonAlive® (BonAlive Biomaterials, Turku, Finland) and StronBoneTM (RepRegen Ltd, UK), are also available for bone reconstructive surgery (Gosain 2004).

One of the first commercial applications of B-Gs in dentistry was to prevent the resorption of alveolar bone after tooth removal and to maintain or enhance bony ridge form for subsequent restorative treatments with implant supported prostheses (Margonar, et al., 2012). Root cones of B-G, placed in fresh residual extraction cavities as well as into artificial sockets produced by bone splitting of previous extraction sites, were able to recreate original alveolar ridge dimensions prior to dental implant surgery (Margonar, et al., 2012). In the re-entry procedure 12 months after insertion, bone formation was clearly visible providing evidence of the superiority of this material compared to other bone graft substitutes (Profeta and Prucher 2015).

There has been a number of clinical studies that have demonstrated consistent results in a variety of alternative treatments including the surgical modification/reduction (elevation) of the maxillary sinus (Stavropoulos, et al., 2012), the regeneration of inter proximal bone defects in periodontal therapies (Lovelace, et al., 1998), periapical application during endodontic microsurgery (Pantchev, et al., 2009), management of cystic defects (El-Ghannam, et al., 2004), as well as reconstructive procedures for treating peri-implantitis (Talreja, et al., 2013). All these clinical applications have one thing in common —the proven efficacy and effectiveness to bond with hard tissue and enhance its growth due to the osteoconductive and osteostimulatory properties of the glass. Osteoconduction refers to the ability to support the migration of bone starting from the walls of the defect toward the central portion of the graft (Schepers and Ducheyne 1997).

New bone formation has been demonstrated histologically in human oral bone defects treated with B-G (Margonar, et al., 2012). There is also evidence that the replacement and infiltration of osseous tissue start at 4 months, and all B-G particles completely disappear at 16 months following the grafting procedure (Tadjoedin, et al., 2000). Consequently bone formation occurred in multiple growth sites, rapidly filling the bone defect. This new bone had the histologic and biomechanical properties of the surrounding bone as soon as 6–7 months after grafting (Merkx, et al., 2003). Furthermore, histology revealed rare inflammatory cells and absence of giant cells even around the remaining particles, which confirmed the biocompatibility of B-G (Margonar, et al., 2012). Antimicrobial activity of B-G (Peltola, et al., 2008). might contribute to the resolution of inflammatory responses and provide extraordinarily favorable conditions for an uneventful healing process (Tadjoedin, et al., 2000; Stavropoulos, et al., 2012). Wilson et al., (1981) was the first to document the safety of use of B-G and long-term studies confirmed that it is well tolerated in children (Lindfors 2009) and adults (Lindfors, et al., 2010).

NovaMin®

NovaMin® is technically described as an inorganic amorphous calcium sodium phosphosilicate (CSPS) material that was designed based on a class of materials known as bioactive glasses. It comprises

45% SiO_2, 24.5% Na_2O, 24.5% CaO and 6% P_2O_5 (Kobayashi, et al., 2010). The particular composition of NovaMin® is identical to that of the best known bioactive glass material, Bioglass®, and contains only calcium, sodium, phosphate and silica, all as an amorphous matrix. Its chemical formula is $CaNaO_6PSi$. NovaMin® delivers silica and ionic calcium, phosphorus and sodium, which are necessary for bone and tooth mineralization. It was developed and patented by NovaMin Technology, Inc., (Gjorgievska and Nicholson 2011) III. Uses Of Novamin At present, bioactive glasses have a wide range of clinical applications in both medicine and dentistry (Melek, et al., 2013). It has been proposed as the material of choice for bone regeneration (Debnath, et al., 2014), hypersensitivity (Burwell, et al., 2010), antigingivitis and antiplaque effect (Tai, et al., 2006). It is also used for implant coating, as air-abrasive particles to remove carious enamel and dentine (Farooq, et al., 2012), as a dental material to improve the bonding of the restorative material to dentin (Goudouri 2011), stain removing agent (Kakodkar, et al., 2013) and in endodontic treatments (Brannstrom 1986) IV. Bone And Tissue Regeneration NovaMin® has the property to promote osteogenesis by allowing rapid formation of bone. It also may act as a barrier retarding epithelial down growth and demonstrates antimicrobial property in vivo. Due to the merits of bioglass, it is one of the preferred alloplast (Ong, et al., 1998; Gerhardt and Boccaccini 2010). Mechanism of Action In bone regeneration, bioglass particles not only show osteoconductivity, but also an osteostimulatory effect. In the treatment for dentinal hypersensitivity the physical occlusion of Novamin® particles begins when the material is subjected to an aqueous environment (Kumar, et al., 2015).

Recent studies have also demonstrated a potential for Novamin® to prevent demineralization and/or aid in remineralization of white-spot lesions. NUPRO® NUSolution TM with NovaMin® is the newest Dentsply Professional prophy paste. It is currently the only product powered by NovaMin, delivering the triple benefit of tooth desensitization, tubule occlusion and stain removal (Milleman, et al., 2012). The potential of these materials for remineralization of both enamel and dentin has been studied in vitro and in situ and holds promise. In addition, the unique ionic reactions and potential antimicrobial and anti-inflammatory properties might prove useful in treating gingivitis (Kumar, et al., 2015).

Bioactive glasses/Bioglass scaffolds

Bioactive glasses/Bioglass are very attractive materials for producing scaffolds devoted to bone regeneration due to their versatile properties, which can be properly designed depending on their composition. An important feature of bioactive glasses, which enables them to work for applications in bone tissue engineering, is their ability to enhance revascularization, osteoblast adhesion, enzyme activity and differentiation of mesenchymal stem cells as well as osteoprogenitor cells.

Many trace elements have also been incorporated in the glass network to obtain the desired properties, which have beneficial effects on bone remodeling and/or associated angiogenesis (Kaur, et al., 2014).

Europium-Containing Mesoporous Bioactive Glass Scaffolds for Stimulating in Vitro and in Vivo Osteogenesis

Europium, as an important rare earth element, has been used as a solid-state lighting material. The prepared Eu-MBG scaffolds have highly interconnective large pores, a high specific surface area, and well-ordered mesopores, as well as uniformly distributed Eu. The incorporation of 2–5 mol % Eu into MBG scaffolds gives them a luminescent property. The in vitro degradation of Eu-MBG scaffolds has a functional effect on the change of the luminescence intensity. In addition, Eu-MBG can be used for labeling bone marrow stromal cells (BMSCs) in vitro and still presents a distinct luminescence signal in deep bone tissues in vivo to label new bone tissue via release of Eu ions. Wu et al., (2016) study for the first time reports that the incorporation of the rare earth element Eu into bioscaffolds has the ability to accelerate bone regeneration in vivo, and thus, the prepared Eu-MBG scaffolds possess bifunctional properties with biolabeling and bone regeneration (Wu, et al., 2016).

S53P4 Bioactive Glass in Bone Healing and Osteomyelitic Treatment

Treatment of osteomyelitis with S53P4 bioactive glass is safe and effective even in one-stage treatment options, without the addition of local antibiotics. Adequate debridement, proper defect filling, and adequate containment of the bioactive glass granules are essential (Wu, et al., 2016).

Bioactive glass fillers reduce bacterial penetration into marginal gaps for composite restorations:

Bioactive glass (BAG) has been shown to have both an antimicrobial effect on oral bacteria and the ability to remineralize adjacent mineralized tissues (Zehnder, et al., 2004; Vollenweider, et al., 2007; Waltimo, et al., 2007; Brown, et al., 2011). This suggests BAG containing composites may have the potential to slow the development and propagation of secondary tooth decay at restoration margins. It has been shown that composites containing up to 15% by weight non-silanated BAG filler can have mechanical properties comparable to, or superior to, commercial composites (Khvostenko, et al., 2013). Tauböck et al., (2014) showed that BAG particles embedded in a resin matrix can still induce bioactivity and increase the pH of a buffered saline solution. BAG containing resin dental composites reduce biofilm penetration into marginal gaps of simulated tooth restorations (Khvostenko, et al., 2016).

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