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Mechanical characteristic and biological behaviour of implanted and restorative bioglasses used in medicine and dentistry: A systematic review

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ABSTRACT

Objective. Nowadays bioactive glasses are finding increasing applications in medical practice due to their ability to stimulate re-mineralisation. However, they are intrinsically brittle materials and the study of new compositions will open up new scenarios enhancing their mechanical properties and maintaining the high bioactivity for a broader range of applications. This systematic review aims to identify the relationship between the composition of bioactive glasses used in medical applications and their influence on the mechanical and biological properties.

Methods. Various electronic databases (PubMed, Science Direct) were used for collecting articles on this subject. This research includes papers from January 2011 to March 2016. PRISMA guidelines for systematic review and meta-analysis have been used. 109 abstracts were collected and screened, 68 articles were read as relevant articles and a total of 22 papers were finally selected for this study.

Results. Most of the studies obtained enhanced mechanical properties and the conservation of bioactivity behaviours; although a lack of homogeneity in the characterization methods makes it difficult to compare data.

Significance. New compositions of bioactive glasses incorporating specific ions and the addition in polymers will be the most important direction for future researches in developing new materials for medical applications and especially for dentistry.

Contents

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1. Introduction

In 1969, Hench et al.[1] developed a new material for medical applications; creating a solid base for the following 40 years of research in the bone/tissue regeneration field. 45S5 was the first bioactive glass generated, with a composition showing an excellent biocompatibility. Its composition by weight is: 45% SiO_2, 24.5% Na_2O, 24.5% CaO and 6% P_2O_5. This material is able to bond with bone and stimulates bone growth due to hydroxy-carbonate apatite (HCA) formation. This type of apatite is chemically and structurally very similar to the mineral phase of hard tissues.

Bonding to bone and tissues has been well documented and investigated by a large series of bioactive glass compositions [2,3]. The mechanism of bone bonding enables the bioglass (BG) to develop an adherent interface with tissues that resists mechanical forces. In many cases, the interfacial strength of adhesion is equivalent to or greater than the cohesive strength of the implanted material or the tissue bonded to the bioactive implant. Five steps have been described for bone-bounding mechanism in bioactive glass [4]:

- Step 1: fast release of Na^+ and Ca^{2+} ions which are exchanged with the H_3O^+ ions present in the solution. A rapid increase of solution pH develops.
- Step 2: network silica is attacked by hydroxyl groups causing the formation of $Si(OH)_4$ in the solution.
- Step 3: Silanols (–Si–OH groups) form a silica rich layer on the surface thanks to re-polymerization reactions.
- Step 4: Ca^{2+} and $PO_4{}^{3-}$ migrate to the newly formed silica surface forming a CaO–P_2O_5 film on top.
- Step 5: CaO–P_2O_5 film crystallize and incorporate other ions from the solution (such as OH^- and $CO_3{}^-$) will form a HCA layer.

For the treatment of bone defects or dental trauma as well as diseases such as osteoporosis, cancer and infectious diseases, it is essential to develop new active materials that are able to interact with host surroundings, enhancing and directing complete tissue healing, repair and regeneration. Synthetic biocompatible materials are used to replace damaged tissues but the weakness of some chemical, biological and/or physical properties results in implant failure that requires retreatment.

The original 45S5 bioglass has been already used in different materials for repairing bone defects in the jaw and orthopaedics. Bioactive glass grafts were originally developed for replacing ear bones and alveolar bone defects around teeth; the products used were based on particles rather than monolithic shape, *i.e.* PerioGlas® and NovaBone®. Micro and nano-particles have superior bioactive behaviours due to a larger specific surface area that allows a faster ion release. Bioactive coatings are likewise very important for metallic implants because they have the potential to improve their performance by providing strong bonding to the host bone and to the resin cement [5]. Nevertheless, 45S5 bioglasses are applied also to non-permanent materials especially used in dentistry. BG-pastes are favourable for the treatment of dentin hypersensitivity [6], enamel demineralization [7] and for tooth bleaching [8]. Finally, bioactive glasses have satisfying characteristics as a scaffold material for bone tissue engineering, but the application of glass scaffolds for the load-bearing bone defects reparation is often limited by their low mechanical strength and fracture toughness.

Despite the excellent biological properties, mainly osteoblast proliferation and differentiation induced by the released ions by the material, bioglasses are brittle materials that are easily cracked. This low strength and fracture toughness prevents their use for load-bearing implants [9]. The development of new glass compositions with improved mechanical properties is a challenging objective and the trend is to incorporate different elements to obtain better biological and physical characteristics. Crystallinity significantly changes the fracture characteristics of glasses. This opens the way for glass-ceramics as offerings with improved mechanical properties. On the other hand, the introduction of crystalline phases could decrease the bioactivity. Several attempts have been made to preserve the amorphous structure of the glass with the addition of silver, magnesium, strontium, boron, zinc, aluminium, fluoride, potassium, gallium, barium and zirconia. Addition of silver [10] and boron [11] have been investigated in order to improve the strength and develop antibacterial and antimicrobial materials; magnesium has stimulatory effects on the growth of new bony tissues [12]; calcium is shown to be responsible for osteoblast proliferation [13], while elements like zirconia improve the mechanical properties but decrease the bioactivity behaviour [14].

In recent years, bioactive glass particles have been introduced as fillers in conventional composites for tissue