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Review

Fiber glass–bioactive glass composite for bone replacing and bone anchoring implants

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ARTICLE INFO

Article history:
Received 8 September 2014
Received in revised form
30 November 2014
Accepted 7 January 2015

Keywords:
Fiber glass
Bioglass
Bioactivce glass
Fiber-reinforced composite
Implant
Cranial

ABSTRACT

Objective. Although metal implants have successfully been used for decades, devices made out of metals do not meet all clinical requirements, for example, metal objects may interfere with some new medical imaging systems, while their stiffness also differs from natural bone and may cause stress-shielding and over-loading of bone.

Methods. Peer-review articles and other scientific literature were reviewed for providing updated information how fiber-reinforced composites and bioactive glass can be utilized in implantology.

Results. There has been a lot of development in the field of composite material research, which has focused to a large extent on biodegradable composites. However, it has become evident that biostable composites may also have several clinical benefits. Fiber reinforced composites containing bioactive glasses are relatively new types of biomaterials in the field of implantology. Biostable glass fibers are responsible for the load-bearing capacity of the implant, while the dissolution of the bioactive glass particles supports bone bonding and provides antimicrobial properties for the implant. These kinds of combination materials have been used clinically in cranioplasty implants and they have been investigated also as oral and orthopedic implants.

Significance. The present knowledge suggests that by combining glass fiber-reinforced composite with particles of bioactive glass can be used in cranial implants and that the combination of materials may have potential use also as other types of bone replacing and repairing implants.

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http://dx.doi.org/10.1016/j.dental.2015.01.003
0109-5641/

Contents

1. Introduction

Biodegradable and biostable medical and dental composite materials have been developed considerably in recent decades. Currently, they can be used in many applications in reconstructive medicine. Although metal implants have been used successfully for many years, devices made out of metals do not meet all biomechanical requirements, such as isoelasticity of skeleton and bone and may lead to insufficient (stress-shielding) or over-loading situations around the implant [1]. This problem has been recognized specifically when used as metal implants in long bones. Metal implants may also induce cytotoxic reactions arising from the release of corrosion products of metal ions, and nanoparticles [2–5]. In addition, metallic objects interfere with medical diagnostics when using magnetic resonance imaging and do not allow postoperative radiation therapy to be performed [6–8]. In contrast, durable and tough non-metallic composites can be made from high-aspect ratio fillers, namely fibers embedded in a polymer matrix. The first studies using fiber-reinforced composites (FRCs) in medicine and dentistry occurred in the early 1960s, but more extensive research started in the early 1990s [9–11]. Introduction of FRCs as prosthodontic material in dentistry occurred in larger scale at the end of the 1990s. Applications of FRCs cover several fields of dentistry from restorative dentistry to prosthodontics, but fibers are also used in orthodontics and periodontology [12]. Besides the dental applications, FRCs have started to be used clinically as well in implant dentistry, with the first approved clinical applications in cranial surgery [13]. Research to develop oral and orthopedic implants based on FRC is ongoing. Implant applications utilize certain biomechanical properties of FRC, and benefit from the possibility of incorporating additional bioactive components to the implant structure. Particulates of bioactive glass have proved its suitability in this purpose [14,15]. FRC materials in implantology have been focused initially on cranial implants because nonmetallic implants enable the increasing utilization of magnetic resonance imaging in identifying a large number of infections related to autologous bone flaps and implants [16,17]. In implant dentistry, radiopaque materials like titanium and zirconia cause severe artifacts in cone beam computer tomography images [18].

Regardless of the location of the bone replacing or bone anchoring implant (maxillofacial, cranial or long bones), the material of the implant and implant device have to fulfill the requirements of permanently implantable medical devices of the European Directive classes 2B or 3. If the implant has an active role in tissues through its components, such as bioactive glass, the implant belongs to class 3 medical devices. Bioactive glass is considered an active component because of antimicrobial nature, which is a desired property for implants. This review describes the present status of the development and use of non-metallic glass FRC – bioactive glass implants.

2. Structure and material components of FRC

FRC is made of reinforcing fibers embedded in a polymer matrix. The glass fiber properties tensile strength and elongation at break partly control the reinforcing capacity of the fibers in polymers. However, several other factors such as fiber orientation and length, fiber adhesion to the polymer matrix, and volume fraction of fibers in the polymer matrix also contribute to the strength of the composite [19]. Correct material selection, through composite fabrication process, and especially correct design, enables the utilization of FRC in applications where high static and dynamic strength are required. In implant applications, fibers have been used as continuous unidirectional fibers or bidirectional fabric type arrangements according to the loading conditions. Anisotropicity of continuous unidirectional fibers limits their use in applications where direction of load is not known or cannot be predicted, but then continuous unidirectional fibers provide the highest possible reinforcing efficiency (Krenchel's factor) against the known direction of stress [20]. Oral and orthopedic implants, which are under development are manufactured using continuous unidirectional fibers whereas continuous bidirectional fibers are utilized in calvarial implants (Figs. 1 and 2).

2.1. *Resin matrix*

Thermoplastic and thermoset resins are used in FRC implants. Examples of thermoplastics with biomedical applications are polyethylene (PE), polyetheretherketone (PEEK), polyacetal (PA), and polyurethane (PU). Examples of thermosets which are utilized as biomaterials are epoxy polymer, bisglycidyl-A-dimethacylate (Bis-GMA), and triethyleneglycoldimethacryalate (TEGDMA) copolymer. Methacrylated dendritic polyesters have been tested also as resin matrix for biomedical