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Osseointegration of fiber-reinforced composite implants: Histological and ultrastructural observations

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ABSTRACT

Objectives. The aim of this study was to evaluate the bone tissue response to fiber-reinforced composite (FRC) in comparison with titanium (Ti) implants after 12 weeks of implantation in cancellous bone using histomorphometric and ultrastructural analysis.

Materials and methods. Thirty grit-blasted cylindrical FRC implants with BisGMA–TEGDMA polymer matrix were fabricated and divided into three groups: (1) 60 s light-cured FRC (FRC-L group), (2) 24 h polymerized FRC (FRC group), and (3) bioactive glass FRC (FRC–BAG group). Titanium implants were used as a control group. The surface analyses were performed with scanning electron microscopy and 3D SEM. The bone–implant contact (BIC) and bone area (BA) were determined using histomorphometry and SEM. Transmission electron microscopy (TEM) was performed on Focused Ion Beam prepared samples of the intact bone–implant interface.

Results. The FRC, FRC–BAG and Ti implants were integrated into host bone. In contrast, FRC-L implants had a consistent fibrous capsule around the circumference of the entire implant separating the implant from direct bone contact. The highest values of BIC were obtained with FRC–BAG (58 ± 11%) and Ti implants (54 ± 13%), followed by FRC implants (48 ± 10%), but no significant differences in BIC or BA were observed ($p = 0.07$, $p = 0.06$, respectively). TEM images showed a direct contact between nanocrystalline hydroxyapatite of bone and both FRC and FRC–BAG surfaces.

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Conclusion. Fiber-reinforced composite implants are capable of establishing a close bone contact comparable with the osseointegration of titanium implants having similar surface roughness.

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1. Introduction

The long-term clinical success of oral implants is based on the presence and maintenance of a proper bone response. Implant materials have been classified into three categories [1] based on the biological response: (1) biotolerant type, characterized by distance osteogenesis [2] where the implant is surrounded by a fibrous connective tissue capsule; (2) bioinert type, characterized by contact osteogenesis [3,4] and formation of direct bone-to-implant contact without an intervening connective tissue layer; and (3) bioreactive type, where the implant allows new bone formation around itself, thereby exchanging ions to create a chemical bond with the bone [5].

Sufficient strength and stiffness, biocompatibility and long-term stability are important criteria that ceramic and polymeric composites have to fulfill for their successful use as non-metallic implants. In 1969, Hodosh placed custom-made polymer implants directly into the fresh extraction sockets of teeth for the first time [6–9]. Since then most studies have been performed in experimental animals but some work has been published with selected human patients [6]. It has been reported that the attachment of polymer implants can be achieved using connective tissue capsule resembling the periodontal ligament [7]. However, due to the high failure rate of 60% after the seven years follow-up of 10 patients, this acrylic resin implant was not recommended for clinical use [10]. At the same time, Brånemark et al. demonstrated good results with osseointegrated titanium implants [11], and defined the osseointegration as a "direct structural and functional connection between ordered living bone and the surface of a load-carrying implant" [11]. Although osseointegration was meant originally to describe a biologic fixation of the titanium dental implants, it is now used to describe the attachment of other materials used for dental and orthopedic applications as well [12].

Currently, a majority of implants are made of high modulus metals and their alloys [13]. The problem of stress-shielding, which results from an elastic modulus mismatch between these metallic materials and natural bone [14], has stimulated new research for the development of polymer composite materials that can more closely match the modulus of bone. Furthermore, bone can be considered as an anisotropic natural fiber-reinforced composite (FRC) material composed of collagen fibers and inorganic hydroxyapatite matrix. Therefore, non-metallic FRC implants have been developed for head-and-neck, maxillofacial and orthopedic applications [15–18], which also make them an interesting material for oral implants. Several surface modification or coating methods can be used in order to improve implant bioactivity and enhance the osseointegration process. Acid etching, grit blasting and various CaP coatings are frequently applied on titanium implants. FRC materials allow modifications by embedding bioactive ceramics such as bioactive glass (BAG) directly on the implant surface.

The bulk and surface properties of FRC implant materials have been characterized [19–23] and evaluated in biological environments [16,24–27]. FRCs have been found to be durable materials, whose strength and elasticity are well adapted to the physiological requirements of bone [21–23]. FRC implants have also shown good mechanical performance in the laboratory environment [19,20]. Furthermore, FRC materials have been found to be cytocompatible in cell cultures and have demonstrated a similar cellular response to titanium [24].

Only a few in vivo studies about the tissue response to FRC implants have been reported [16,28,29]. These studies have shown that highly polymerized FRC is biocompatible and induces neither toxic nor inflammatory reactions. FRC surfaces induce a bone response similar to titanium after 4 and 12 weeks of healing in the cortical bone of pig tibia [25]. Neither grit-blasted FRC implants nor FRC–BAG implants revealed toxicity in the pig bone tissue during the 12-week healing period. The establishment of strong bone contact with the FRC implant surface indicates that the material is biocompatible in the bone environment [25,26]. However, the quality and quantity of new bone formation on the FRC implant compared to titanium is not known.

The present study set out to compare the quantity and quality of bone formation between surface modified FRC and titanium implants.

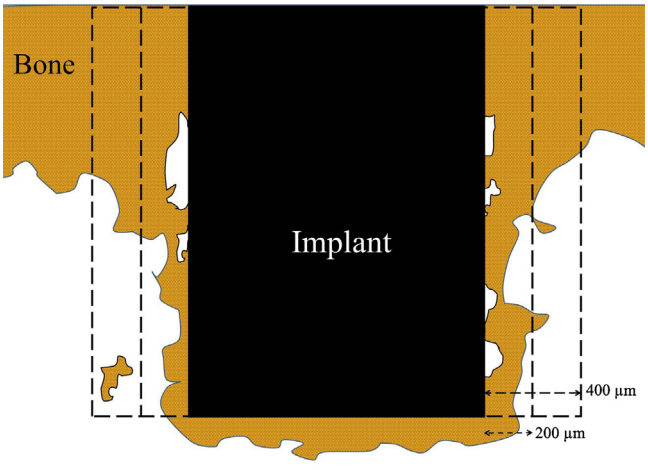

Fig. 1 – Schematic diagram showing the measurement of the area of bone around the implants by calculating the percentage of the surface area occupied by bone (BA) inside a region of interest (ROI) area extending 200 µm, and 400 µm from the implant surface into bone.

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