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Biological and mechanical characterization of carbon fiber frameworks for dental implant applications

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ABSTRACT

Objectives: The aim of the present study was to investigate the biocompatibility and mechanical characteristics of dental implant frameworks made of carbon fiber composite.
Methods: The biocompatibility of intact samples and fragments was evaluated by cell count and MTT test according to EN-ISO 10993-5:2009 directions.
Destructive and non-destructive mechanical tests were performed in order to evaluate: porosity, static and dynamic elastic modulus of carbon fiber samples. These tests were conducted on different batches of samples manufactured by different dental technicians. The samples were evaluated by optical microscope and by SEM.
A compression test was performed to compare complete implant-supported fixed dentures, provided with a metal or carbon fiber framework.
Results: Carbon fiber intact and fragmented samples showed optimal biocompatibility. Manufacture technique strongly influenced the mechanical characteristics of fiber-reinforced composite materials.
The implant-supported full-arch fixed denture provided with a carbon fiber framework, showed a yield strength comparable to the implant-supported full-arch fixed denture, provided with a metal framework.
Significance: Carbon fiber-reinforced composites demonstrated optimal biocompatibility and mechanical characteristics. They appear suitable for the fabrication of frameworks for implant-supported full-arch dentures. Great attention must be paid to manufacture technique as it strongly affects the material mechanical characteristics.

1. Introduction

In implant prosthodontics metal frameworks are used to improve the prosthesis rigidity and stiffness, reducing possible complications such as prosthesis fractures while rigidly splinting the implants together [1]. Stiff prosthesis materials are supposed to distribute the stress more evenly to the abutments and implants [2].

In particular, accuracy and rigidity of prosthodontic frameworks have been reported as fundamental prerequisites for the predictable osseointegration of dental implants that will be immediately loaded [2–3]. Splinting implants with rigid prostheses immediately after implant placement seems to protect them from overloads and micromotions [2,4–6].

Metal alloys allow fabrication of a sufficiently rigid and stiff prosthesis even if the prosthodontic space is limited. The clinical result is a thin prosthesis showing a more natural appearance without pink soft tissue reconstruction and avoiding aggressive bone remodeling. The latter is necessary in order to accommodate a sufficiently rigid and thick full-acrylic prosthesis.

However, metal frameworks supporting fixed prostheses are expensive and time-consuming to fabricate and for this reason possible alternatives are emerging. Recent improvements in composite materials have made it possible to fabricate metal-free fixed partial dentures by using fiber-reinforced frameworks [7–8]. Fiber-reinforced acrylic resin prostheses offer a cheaper alternative for the patient and additional advantages for the clinicians (avoidance of casting) [9–10]. Fiber reinforcements may carry the loads, providing stiffness, strength and thermal stability. The polymeric matrix binds the fibers together transferring the load among them in the direction perpendicular to the fiber axis and guarantees the fibers protection against chemical attack and mechanical damage [11].

In dental literature glass fibers have been mainly used as reinforcement of resinous prostheses, due to their esthetic characteristics [7–10]. However their mechanical behavior appeared unsatisfactory compared to metal alloys [9]. Carbon fibers may guarantee better mechanical properties when compared to glass fibers (greater stiffness and strength). Carbon fibers are filaments made of 99.9% chemically pure carbon with a 5–10 μm diameter. They provide high stiffness, light

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Fig. 1. Extraction flasks containing fragmented samples (on the left) and intact samples (on the right).

weight, low density, low coefficient of thermal expansion, low abrasion, good electrical conductivity and vibration damping, biological compatibility, chemical inertness (except in strongly oxidizing environments or when in contact with certain molten metals), elasticity to failure at normal temperature, high fracture strength, high fatigue and creep resistance [12–14].

These characteristics make Carbon Fiber Reinforced Composites (CFRC) appear excellent for fabrication of frameworks in fixed implant-supported prostheses. However, their application in this field has not been investigated yet.

The first aim of the present study was to investigate the biocompatibility and the mechanical characteristics of CFRC samples realized by different dental technicians.

The second aim was to compare implant-supported full-arch fixed dentures provided with a CFRC framework or a gold alloy framework via a compression test.

2. Materials and methods

2.1. Biocompatibility analysis

The biocompatibility of CFRC was evaluated in vitro following the EN ISO 10993-5:2009 directions. Both intact and fragmented (residues of manufacturing) samples were evaluated.

L929 mouse fibroblasts (BS CL 56) were exposed to extracts of the samples. 7 g of samples were put in 20 ml of culture medium Minimum Essential Medium + glutaMAX (MEM-glutaMAX) supplemented with 10% fetal bovine serum (FCS), penicillin and streptomycin into T25 sterile flasks (Falcon, Becton & Dickinson Labware, Lincoln Park, NJ) (Fig. 1).

The flasks were then incubated at 37 °C in a humidified 5% carbon dioxide incubator (relative humidity at 98%) for 72 h. The following day (day 2), a suspension of $2.14 \pm 0.08 \times 10^5$ fibroblasts/ml in 2.0 ml of Minimum Essential Medium + glutaMAX (MEM-glutaMAX) supplemented with 10% fetal bovine serum (FCS), L-glutamine, penicillin and streptomycin was put into 12-well cell culture sterile polystyrene plates (Cellstar, Greiner Bio-One GmbH, Kremsmünster, Austria). On the third day, the growth medium of the multi-wells was removed and substituted with 2 ml of extraction medium for each well.

Control cells were cultured in parallel in fresh culture medium and in contact with polyethylene (negative controls) and in fresh culture medium supplemented with 1% dioctylphthalate (positive control) (Fig. 2).

The 12 multi-wells containing the extracts and the controls were incubated at 37 °C in a humidified 5% carbon dioxide incubator (relative humidity at 98%) for 48 h. After 72 h of growth, the cells were observed using an inverted light microscope (Leica, Wetzlar, Germany) and photographed.

4 wells were then used to evaluate cell mitochondrial activity by using the 3-[4,5-dimethylthiazol-2yl]-2,5 diphenyltetrazolium bromide (MTT test, Sigma-Aldrich Srl, Milan, Italy). MTT (1 mg/ml) added to each well. After 2 h of incubation at 37 °C, the MTT precipitate was solubilized. The optical density was read at 570 nm using a spectrophotometer (GEnios, Tecan srl, Männedorf, Swiss).

The cells of 4 other wells were used for cell count. The extraction medium was removed and cells rinsed with phosphate buffered saline DPBS (Life Technologies, San Giuliano Milanese (MI), Italy) and immersed with 500 μl of 0.5 trypsin/EDTA 10× (Life Technologies). After 5 min the trypsin action was stopped by adding 100 μl of FCS. Then 10 μl of the cell suspension were added at 10 μl of 0.4% trypan blue solution. After 5 min, 10 μl of suspension were put into TC10 counting slides (Biorad, Hercules, CA, USA) and cell counting was performed 8 times for each sample (intact and fragmented samples) using TC10 Automated Cell Counter (Biorad).

2.2. Mechanical characterization of CFRC samples

2.2.1. CFRC samples

CFRC are not isotropic materials. This means that the mechanical, electrical and thermal properties of this particular material are extremely variable when measured in different directions. This happens either on the microscale, i.e. at the fiber level, and on the macroscale, i.e. at the final produced device. As a consequence, the final characteristics of the object produced with CFRC will be extremely influenced by the total fiber percentage, the fiber orientation and the geometrical lay-up of the various layers adopted to create the sample.

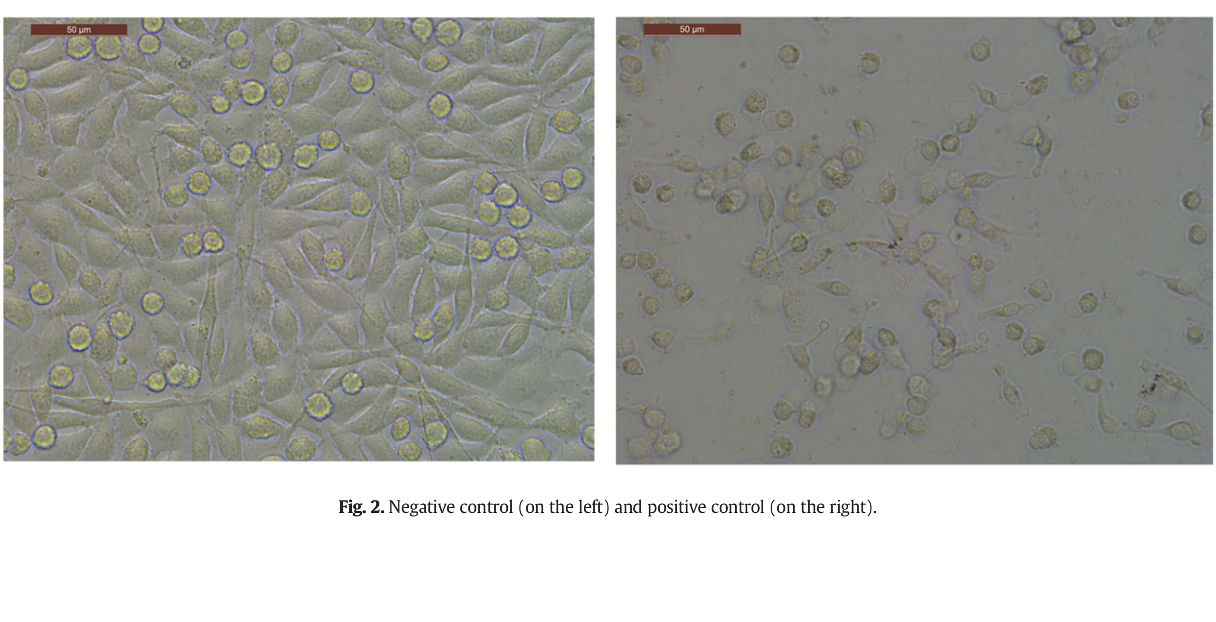

Fig. 2. Negative control (on the left) and positive control (on the right).