Carbon-Fiber Framework for Full-Arch Implant-Supported Fixed Dental Prostheses Supporting Resin-Based Composite and Lithium Disilicate Ceramic Crowns: Case Report and Description of Features

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This case report presents a new approach for shock-absorbing carbon-fiber composite frameworks for full-arch implant-supported fixed dental prostheses supporting resin-based and lithium disilicate ceramic crowns. It describes the characteristics of the materials used, the procedures for implementing the framework, and the requirements to achieve the best mechanical and clinical properties. The result is a full-arch prosthesis with masticatory load shock-absorption capacities, chemical bonding between materials, good esthetics, and wear similar to natural enamel. A 24-month follow-up full-arch bimaxillary implant-supported rehabilitation, performed with computer-guided surgery, is described. Int J Periodontics Restorative Dent 2019;39:175–184. doi: 10.11607/prd.2964

The international literature has shown that a critical factor for maintaining osseointegration is the occlusal load transmitted to the implant by the prosthesis. Unlike natural teeth, implants have no periodontal ligament. A relationship of ankylosis is thus formed with the bone structure, preventing the absorption of masticatory load (shock absorption). Moreover, the lack of proprioception decreases the likelihood of occlusal adjustment by the neuromuscular system. In such conditions, load is transferred directly to the bone without any intermediate shock-absorbing element. It is therefore crucial to avoid overloading so as to prevent microfractures in the peri-implant bone. This applies particularly in full-arch rehabilitations, especially bimaxillary ones. Even in the case of immediate loading, the control of overloading is a favorable factor. For this reason, since the 1980s, use of an occlusal material with shock absorption properties (low modulus of elasticity) to absorb the masticatory load while protecting the bone from the risk of overloading, has been recommended.

There are divergent views that reject a relationship between the prosthetic material used and the transmission of stress at the peri-implant level. However, research carried out in this field with a mastication robot indicates that...
Table 1 Comparison of the Compressive Strength of Carbon-Fiber, Gold Alloys, and Reinforced Polyether Ether Ketone (PEEK)

<table>
<thead>
<tr>
<th>Material</th>
<th>Carbon-fiber</th>
<th>Au 51%</th>
<th>Au 40%</th>
<th>Reinforced PEEK (carbon-fiber, glass fiber)</th>
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</thead>
<tbody>
<tr>
<td>Compressive strength (MPa)</td>
<td>500</td>
<td>440</td>
<td>520</td>
<td>12</td>
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<tr>
<td>E-module</td>
<td>66,000</td>
<td>69,000</td>
<td>81,000</td>
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</table>

Materials and Methods

Carbon-Fiber Composite

Carbon-fiber is a fine, filiform structure that can be used to make materials known as composites. The fibers are united with a matrix that is generally made from a resinous material; its function is to hold the resistant fibers together, to protect them and maintain the shape of the product. The properties of the composite are strongly influenced not only by the quantity of carbon but by the orientation of the fibers.

In dentistry, a new composite material was recently introduced (Dream Frame [DF], DEI Italia) consisting of a network of multidirectional carbon fibers embedded in a matrix of epoxy resin of plant origin with high biocompatibility and high resistance properties (Bio Resin, DEI Italia). The fibers used in DF are high modulus, with a tensile modulus of 437 GPa and tensile strength of 3,932 MPa. They are arranged multidirectionally in 48 × 15-cm fabric sheets (Standard Method UNI EN 12127, UNI EN 1049-2), so that the material can discharge compression and bending force irrespective of the vector directions of the masticatory loads. To make structures, the sheets of fabric are arranged in position and embedded in the matrix. Tests to evaluate the mechanical properties of the material after impregnation were carried out by the laboratory Tec Eurolab (Campogalliano, Italy): three-point bend test at ambient temperature (Reference Standard UNI EN ISO 14125:2011) on samples of DF in 3- and 4-mm-diameter bars showed an ultimate strength ranging between 408 and 500 MPa and an elastic modulus of between 57,758 and 66,000 MPa. These values are similar to those of gold alloys (Table 1). The best mechanical performance was obtained by following the protocol provided by the manufacturer. In fact, mechanical testing carried out by the Faculty of Engineering of Genoa University (Italy) on sample bars of DF 7 cm in length, 5 mm in width, and 3 mm in thickness, performed without any protocol, produced results with a wide range of variability compared with values from samples using the correct protocol (ie, made in a muffle using pressure and heat treatment). The following tests were performed: (1) dynamic elastic modulus tests and Internal friction (IF) measurements with pulse excitation on a free-free bar apparatus with initial stress with an IF of approximately 0.5 MPa; (2) instantaneous load to measure the static modulus of elasticity with direct instantaneous load of 24.1 N in a three-point bending flexural test on a bar at a maximum tension of about 55 MPa;
and (3) Compressive strength, measured using three-point bending at a shear rate of 850 microstrains per second for 20 seconds (Table 2).

An experimental study using a polariscope sought to evaluate the extent and speed of transmission of occlusal loads to the supporting tissues when crowns of various materials were used on titanium implants (QSMD FabLab). The implants were embedded in a photoelastic plate. The crowns were screw retained and were made of zirconia (ZS Blank KaVo), metal-ceramic (Keramit NP, Nobil-Metal), metal-composite resin, (Keramit NP, Nobil-Metal), polymethyl methacrylate (PMMA) (Sinergia Block, Nobil-Metal), polyether ether ketone (PEEK)—composite resin (BioHPP, Bredent), carbon-fiber composite—composite resin (DF, DEI Italia), self-curing acrylic resin (PMMA Proviso, DEWA), interpenetrated composite resin (Enamic, VITA), and lithium disilicate (IPS e.max, Ivoclar Vivadent). Using a universal material testing machine (model 3366, Instron), the crown was subjected to a gradually increasing occlusal load, at a velocity of 1 mm/min, using a small sphere placed in the central pit of the occlusal surface, and the test chart was drawn automatically. The stress distribution in the photoelastic resin was tested with a polariscope mounted in the universal machine. Photographs of

<table>
<thead>
<tr>
<th>Samples</th>
<th>Average length (mm)</th>
<th>Average thickness (mm)</th>
<th>Length (mm)</th>
<th>Density (g/cm³)</th>
<th>Static E (MPa)</th>
<th>Dynamic E (MPa)</th>
<th>Rupture (MPa)</th>
<th>Q-1 (10⁻³)</th>
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<td>CP</td>
<td>WP</td>
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<td>Averages</td>
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<td>2.88</td>
<td>1.33</td>
<td>1.33</td>
<td>26,141</td>
<td>42,762.5</td>
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</table>

WP = samples made without correct protocol; CP = samples made with correct protocol.

**Figure 1** Types of crowns, photoelastic spectra, and load transmitted after 3 seconds.
The photoelastic spectra were taken at 1 frame per second (Nikon D 90 with a Micro Nikkor 55-mm lens). Figure 1 shows a series of photographs that illustrate the phenomenon. The preliminary data showed that the crown made with a substructure of composite resin reinforced with carbon-fiber (DF) and an occlusal coating of composite resin presented a load transmission speed about half that of crowns made of metal-ceramic and zirconia (Fig 2). Further research is required to assess the behavior of crowns and larger prosthetic structures made up of DF alone or DF with various types of veneering, to understand the role played in load transmission by each material and the best combination of materials. A cytotoxicity test performed at the Nobil Bio Ricerche laboratories (Portacomaro, Italy) on L929 fibroblasts (mouse connective tissue) grown in the presence of DF indicates a total absence of adverse phenomena. The samples were sterilized in accordance with ISO 10993, and the tests followed the EN ISO 10993-5:2009 standard. The direct contact method between cells and material was used, and after 48 hours of growth the cells were observed under an optical microscope (Leica DMI4000 B) and the results compared with negative samples (Fig 3).

Technical Procedures

To construct the framework, the dental technician makes a wax model of the beam that incorporates abutments blasted with 90/180 micron aluminium oxide and inserts it into a metal muffle (DF Muffola) containing silicone with a hardness of 70 ShA (Addition Mask 70, DEI Italia) that makes a negative duplicate of the shape. At this point, the carbon fabric sheets are superimposed and impregnated with the epoxy resin inside the muffle (which acts as a mold and counter mold for the definitive shape). The muffle is pressurized by tightening the screw and placed in a small dedicated furnace (DF Black Oven, DEI Italia) for 2 hours and 15 minutes at 80°C. The black framework is finished with burs while the black background is masked with a silicon dioxide–based white opaquing agent (White Mask, DEI Italia).
Passivation is obtained by incorporating the abutments directly during the molding of the carbon fibers.

Resin-Based Composite Crowns

A microfilled hybrid composite was used (Experience, DEI Italia). This light-curing composite resin is made from dimethacrylate and filler (barium glass filler, fumed silica) in accordance with ISO:4049:2000–Type 1, Class 2a, Group 1. It was stratified, in various masses, in a single block by means of a molding technique with a transparent muffle of silicone material (THP Transparent Hard Putty, DEI Italia) directly on the framework. The polymerization, conducted in an anaerobic environment and under pressure, provides a material with adequate compactness and uniformity able to resist masticatory forces and wear. The elasticity, hardness, and abrasion are close to those of the natural tooth: 22 µm every 200,000 mastication cycles at 15 N; compressive strength ≥ 350 MPa; flexural strength 130 MPa. The tests performed demonstrated its biocompatibility and its ability to absorb the shocks of occlusal forces.

Lithium Disilicate Crowns

Disilicate is a metal-free glass-ceramic with a flexural strength that can reach 380 to 450 MPa. It is available in two forms. Lithium metasilicate (Li2SiO3) is more malleable and therefore can be worked by drilling and then heat-treated to be transformed into disilicate (Li2Si2O5) or, alternatively, as a mass for hot-pressing. It can be adhesively luted after etching with 4% to 5% hydrofluoric acid for 20 minutes and silanization, and it presents wear values similar to those of enamel. In the clinical case presented, a monolithic lithium disilicate glass-ceramic was used (e.max CAD Monolithic Solutions, Ivoclar Vivadent). This is a Type II/Class 3 dental ceramic with flexural strength ≥ 360 MPa, compliant with ISO 6872:2015. The framework and the diagnostic wax-up were scanned with a 3D scanner (Arctica AutoScan, KaVo). The data processed by the computer software (multiCad, KaVo, Germany) are sent to the CAM milling machine (Arctica Engine, KaVo), which extrudes every single crown from solid material. They are then colored and crystallized. Cementing was performed with a Panavia V5 adhesive resin cement system (Kuraray Noritake), after cleaning with ethyl alcohol.

Clinical Case

A 67-year-old woman consulted a private dental office, asking for a full-arch rehabilitation of the maxilla and mandible. The patient presented with a complete rehabilitation with a fixed partial denture of the maxillary and mandibular arch, permanence of the maxillary incisors, canines, right second premolar, and...
left first and second molars and the mandibular right incisors, canine, and first premolar and left canine, second premolar, and second molar, affected by advanced chronic periodontitis and caries, generalized increased pocket probing depths ranging from 10 to 15 mm, and generalized tooth mobility ranging from grade 2 to 3. The amount of attached gingiva was adequate. Cone beam computed tomography showed a sufficient quantity of bone for implant treatment in the anterior and lateroposterior region as far as the second premolars (Fig 4). Bone quality, measured with implant planning software, was D4 in the maxilla and D3 in the mandible. After removal of the existing fixed partial dentures, the residual abutments showed caries that prevented the teeth from being reused as prosthetic pillars. Therefore, a bimaxillary full-arch implant screw-retained dental prosthesis was chosen, using computer-assisted flapless surgery with delayed loading in the maxilla and immediate loading in the mandible. The treatment plan involved extraction and immediate insertion of six implants with a diameter of 4 mm and a length of 15 mm in the maxilla and four implants with a diameter of 4 mm and a length of 13 mm in the mandible (Fig 5). A full provisional removable prosthesis was applied in the maxilla, while a provisional fixed prosthesis was applied in the mandible, 24 hours after implant insertion (Fig 6). At 4 months after surgery, two definitive prostheses made with a carbon-fiber framework and veneered with resin-based composite and lithium disilicate ceramic crowns were fitted (Figs 7 and 8). The patient signed an informed consent outlining the purpose of the study, the procedures, the risks involved, the benefits, the alternatives, withdrawal of consent, the costs, the form of privacy, and authorization for use of images and for publication. In the event of complications, free treatment was to be provided with a 3-year follow-up.
Discussion

Since the 1980s, attempts have been made to use carbon fiber to construct prosthetic frameworks. Carbon/graphite-fiber–reinforced PMMA (CGFP) has been suggested as an alternative framework material for implant-supported fixed prostheses. However, a clinical multicenter study on a CGFP beam wrapped in acrylic resin and with
acrylic teeth on top showed that 19% of the prostheses were fractured. All the fractures were located at the distal abutments, and the fracture lines propagated through the acrylic material. These results were due to the fact that the technical procedure and the handling of the material, the fibers, and the acrylic resin could not be sufficiently standardized.27,28

These problems seem to have been overcome by using advanced technologies and materials (multidirectional high-modulus fibers woven into sheets; epoxy resin matrix instead of PMMA), applied with a standardized protocol (pressure molding and controlled thermal cycle in the furnace), which makes the mechanical characteristics of the framework excellent and consistent. The main characteristics required of the framework are rigidity, passivity, adhesion or retentivity for the veneer materials, and low cost.29 DF is indicated for making prosthetic mesostructures, since it has proven able to satisfy these requirements. The composite nature of DF provides mechanical stability, microelasticity, and chemical adhesion to composite materials and etchable metal-free materials. As the structures can be built using anatomical modeling, all the prerequisites are met for achieving good esthetic results. The framework can be constructed reasonably quickly in any dental laboratory without particular equipment.

Other characteristics are corrosion resistance, high resistance, and lightness. Its high precision avoids post-cementing to passivate the structure. The weight of a full-arch prosthesis made with today’s most widely used materials is quite different from the values of natural teeth, which are between approximately 10 and 20 g. Fixed partial dentures made with DF have a weight similar to natural teeth and improve patient comfort, integrating biologic and proprioceptive properties30 (Table 3).

Diagnostic investigations (computed tomography and nuclear magnetic resonance) can be performed without removing the prosthesis, as there are no radiation reflection phenomena. However, no literature currently available gives any indications as to the medium- and long-term clinical results. Further studies are needed to observe the behavior of materials over the course of time and the potential onset of complications. Furthermore, performance is affected by the need to use adequate thicknesses and technical procedures. Carbon-fiber structures must be at least 4 mm thick in the area of the connectors and pontics to ensure their mechanical strength. It is important to comply with firing and cooling requirements to achieve excellent results in the Sheffield test (one screw test). The dental technician must be trained to apply the stratification, molding, and baking protocol. Particular care must be taken during luting of the disilicate crowns to avoid incorrect positions or stress in the materials. The prostheses made in the above case were optimally

![Fig 9 Radiographic check-up at delivery of the final prostheses.](image)

| Table 3 Comparison of Weight in Full Arches Made with Different Prosthetic Materials |
|--------------------------------------|--------------------------------------|--------------------------------------|--------------------------------------|
| Prosthetic materials | Composite on carbon-fiber structure | Prettau zirconia with single luted crowns | Ceramic on CAD/CAM metal structure |
| Weight (g) | 13 | 95 | 125 |

CAD/CAM = computer-aided design/computer-assisted manufacture.
integrated from an esthetic point of view. The patient was fully satisfied with the esthetic and functional results achieved (Figs 9 to 11). The superstructures were continuously controlled; no implant or prosthetic complications were observed at the 2-year follow-up.

Conclusions

The materials and technologies available today allow creation of prostheses with frameworks and veneers the performance of which are difficult to achieve with traditional materials. The full-arch implant-supported fixed dental prosthesis described provides a simple prosthesis with a high esthetic yield, a weight and resistance to wear similar to natural teeth, lower costs than when using many other materials, good shock-absorption characteristics, and no need for post-passivation. For this reason, the present author believes that the framework of carbon-fiber composite material is promising for the creation of implant-supported full-arch prosthetic rehabilitations, and it can be a valid alternative to metal or metal-free products. New research and a longer clinical observation period will be needed to gain further information on the stability and durability of the materials studied.

Acknowledgments

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References


