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Photoelastic analysis of mandibular full-arch implant-supported fixed dentures made with different bar materials and manufacturing techniques

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ABSTRACT

Purpose: To compare the stress distribution of mandibular full dentures supported with implants according to the bar materials and manufacturing techniques using a qualitative photoelastic analysis.
Material and methods: An acrylic master model simulating the mandibular arch was fabricated with four Morse taper implant analogs of 4.5 × 6 mm. Four different bars were manufactured according to different material and techniques: fiber-reinforced resin (G1, Trinia, CAD/CAM), commercially pure titanium (G2, cpTi, CAD/CAM), cobalt-chromium (G3, Co-Cr, CAD/CAM) and cobalt-chromium (G4, Co-Cr, conventional cast). Standard clinical and laboratory procedures were used by an experienced dental technician to fabricate 4 mandibular implant-supported dentures. The photoelastic model was created based on the acrylic master model. A load simulation (150 N) was performed in total occlusion against the antagonist.
Results: Dentures with fiber-reinforced resin bar (G1) exhibited better stress distribution. Dentures with machined Co-Cr bar (G3) exhibited the worst standard of stress distribution, with an overload on the distal part of the posteriors implants, followed by dentures with cast Co-Cr bar (G4) and machined cpTi bar (G2).
Conclusion: The fiber-reinforced resin bar exhibited an adequate stress distribution and can serve as a viable alternative for oral rehabilitation with mandibular full dentures supported with implants. Moreover, the use of the G1 group offered advantages including reduced weight and less possible overload to the implants components, leading to the preservation of the support structure.

1. Introduction

The highest prevalence of tooth loss is associated with the aging population, and this condition varies in different parts of the world [1–3]. For a long time, the only treatment option for rehabilitating edentulous patients was the denture, but it was often associated with lack of stability and retention, especially in the case of mandibular dentures associated with the loss of chewing ability [4].

Older age groups exhibit increased mandibular bone loss, especially in bone height, which requires shorter length implants [5]. The use of dentures offers crucial functional improvements, so it is important to study the rehabilitation of full arches [6].

With the success of implantology, full dentures supported with implants using the bar substructures have demonstrated a high success rate [7]. Different bar materials and formats that exhibit different biomechanical behaviors can be used [8,9]. Currently, more metal bars have been used, and some studies have investigated the influence of different alloys on the stress distribution [8–11]. Some studies have demonstrated significantly increased stress values for cobalt-chromium (Co-Cr) compared with other alloys, such as commercially pure titanium (cpTi), nickel-chromium-titanium (Ni-Cr-Ti) and palladium–silver (Pd–Ag) [8,10]. On the other hand, other authors found no influence of the bar material on the stress distribution in bone tissue [9,11].

The success of resin materials in implantology has been empirically credited to their ability to act as a shock absorber with better stress distribution [12,13]. In addition, resin materials offer a reduced elasticity modulus, providing lower flexural strength and no overloading of the screws and other prosthesis components [8,14].

A fiber-reinforced resin (Trinia) developed by Bicon Dental Implants weighs less than zirconium or Co-Cr and has a tensile strength equivalent to that of zirconium; its flexural and compressive strength is comparable to that of Co-Cr [15]. This material has been tested as a substructure of three-unit implant-supported fixed dental prostheses, and the results revealed the probability of similar survival, thus

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establishing metal-ceramic prostheses as the gold standard [16]. In addition, a preliminary short-term clinical study with fiber-reinforced resin bridges on four implants revealed a survival and success rate of approximately 97% [15]. However, there are no results for this material when used for the substructures of full dentures supported with implants, which is a valuable treatment for patients who have lost all their teeth because stress is dissipated throughout the arch.

This study compared the weight and stress distribution of mandibular full dentures supported with implants based on the bar materials (fiber-reinforced resin [Trinia], cpTi, and Co-Cr) and manufacturing techniques (CAD/CAM and conventional casting) used.

2. Materials and methods

An acrylic master model, com 7,8 mm de espessura e 30 mm de altura, simulating the mandibular arch was fabricated with four interforaminal perforations for placement of 4.5 × 6 mm Morse taper implant analogs (Bicon Dental Implants, Boston, MA, USA). These implant analogs were fixed with a cyanoacrylate adhesive (Super Bonder®, Henkel Loctite Sticker Ltd., São Paulo, SP, Brazil). The master model was duplicated in type IV gypsum (Durone IV, Dentsply Indústria e Comércio, Petrópolis, RJ, Brazil) using molding silicone (Silicone Master, Talladium Inc., Curitiba, PR, Brazil).

Initially, a fiber-reinforced resin bar (G1) (Trinia, Bicon Dental Implants, Boston, MA, USA) was manufactured by the CAD/CAM system (Cerec CAD/CAM System, Sirona, 19 μm precision). Then, the fiber-reinforced resin bar was scanned and machined (Dental Wings 3F, 21 μm precision) in cpTi (G2) and Co-Cr (G3) (Conexão Sistema de Implantes, Arujá, SP, Brazil). The G3 bar had to be milled internally due to the difficulty of correctly copying the abutment design. Finally, the fiber-reinforced resin bar was duplicated in wax and cast by the conventional method (G4) using an oxygen-gas flame with subsequent injection of the Co—Cr dental alloy (Fitcast, Talmax, Curitiba, PR, Brazil) into the mold by centrifugation (Table 1). The G4 bar was TIG (Tungsten Inert Gas, a welding methd that uses a non- consumable tungsten electrode in a protective atmosphere of inert gas) welded over the master model after the conventional cast. Standard clinical and laboratory procedures were used to fabricate 4 mandibular implant-supported dentures by an experienced dental technician, as performed in Cunha et al. [17].

A silicone impression (Silicone Master, Talladium do Brazil, Curitiba, PR, Brazil) of the master model with a screwed denture was performed to allow the correct transfer of the implants to the working models. Implants and prosthetic abutments (5.0 × 2.0 mm Stealth Abutment; 3.0 mm Post; Bicon Dental Implants, Boston, MA, USA) were then positioned in the silicone mold, and the photoelastic resin (Araldite GY 279 and Aradur 2963, Araltec, Guarulhos, SP, Brazil) was poured. Three similar photoelastic models were created for the remaining three groups.

A polariscope (PS-100 SF Standard Field Polarimeter, Strainoptics, Inc., North Wales, PA, USA) was used to monitor the isochromatic fringes, and a digital camera (EOS Rebel, Canon, Tokyo, Japan) was coupled to the polariscope to photograph each load sequence. For the qualitative analysis, the models were positioned in the polariscope adjusted to the circular polarization mode. A load simulation of 150 N [18] was performed in total occlusion against antagonist, with a full maxillary prosthesis as antagonist and using a 50 kgf load cell. For each loaded model, images of the right posterior, central and left posterior region were obtained. There was no birefringence on the models before the load. Fig. 1 shows the fringe orders for their corresponding stress in the photoelastic model.

Table 1
Groups and its properties.

Groups	Structure/ fabrication	Specific gravity	Elasticity modulus	Poisson ratio
G1	Trinia/CAD-CAM	1.68 g/cm^3	19.1 GPa	0.22
G2	cpTi/CAD-CAM	4.5 g/cm^3	110 GPa	0.33
G3	Co-Cr/CAD-CAM	8.3 g/cm^3	218 GPa	0.33
G4	Co-Cr/cast	8.3 g/cm^3	218 GPa	0.33

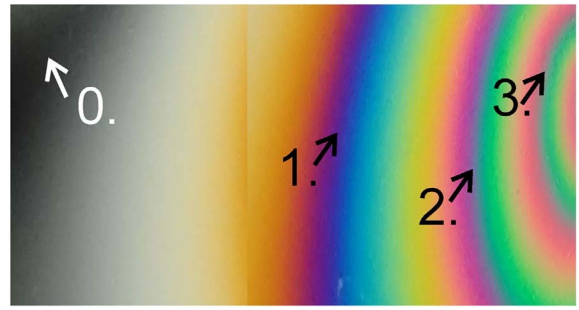

Fig. 1. Fringe Order and the corresponding stress value: 0 (black) = 0 kPa; 1 (violet/blue transition) = 232 kPa; 2 (purple/blue transition) = 464 kPa and 3 (red/green transition) = 696 kPa. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

3. Results

In the application of 150 N load in full occlusion against an antagonist (Fig. 2), fringes orders 1 and 2, equivalent to stress of 232 kPa and 464 kPa respectively, were visualized. An increased intensity of stress was noted in G3 (fringe order 2 in the right implant), with stress located in the cervical region of all implants. The other groups (G1, G2 and G4) exhibited reduced stress (fringe order 1). Of these groups, G1 had less stress in the cervical region of the implants. G1, G2, G3 and G4 exhibited stress in the cervical region of the two central implants. Specifically, G4 exhibited the highest concentration, whereas G1 exhibited the lowest concentration. As a general rule for all groups, the posterior implants (right and left) exhibited increased stress concentrations compared with the anterior implants, corresponding to a greater surface of natural occlusal contact in posterior teeth and horizontal cantilevers.

4. Discussion

Mandibular full dentures supported with implants are well-established as a treatment option for totally edentulous patients due to the high success rates reported by clinical studies. However, major complications occur when stresses exceed the physiological limit of bone, and the bone resorption process begins [19]. Thus, irreversible bone damage is expected when pathologic overloading occurs, causing micro-fractures at the bone–implant interface [20].

Morneburg and Proschel [21] analyzed the bite force of dentate adult patients with fixed prostheses, obtaining average values of 200 to 300 N with peak strengths of approximately 400 N. Similarly, Cosme et al. [22] analyzed bite force in patients with bruxism, with an average of up to 1000 N. In a more specific study, Muller et al. [23] analyzed bite force in patients with conventional denture, overdenture and implant-supported prosthesis, obtaining average values less than 100 N, approximately 100 N and between 200 and 300 N, respectively.

Despite the differences in values frequently encountered, a consensus exists regarding the correlation between overloading/parafunction and progressive marginal bone loss/implant loss in patients with complete fixed prostheses or overdentures [24,25].

As observed by Duyck et al. [26], in the present research the stress is highest in the implant closest to the cantilever in all situations. This finding suggests that increased marginal bone loss might be observed around the implant closest to a cantilever unit [27,28]. This observation