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Photoelastic analysis of stresses transmitted by complete dentures lined with hard or soft liners

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A B S T R A C T

Stresses transmitted on the alveolar bone ridge by lined conventional complete mandibular dentures can decrease the bone absorption level. The aim of this in vitro study was to evaluate the stresses induced on the alveolar bone ridge of lined conventional complete mandibular dentures by using photoelastic analysis. One maxillary and three mandibular conventional dentures were developed for the following treatments: 1 — Unlined denture (control), 2 — Denture lined with resin-based material, and 3 — Denture lined with silicone-based material. The photoelastic analysis took place with the dentures in the position of maximum intercuspation, and the mandibular photoelastic models were axially loaded with 10 kgf (98 N). Unlined denture (control) presented stresses along the model, especially on the anterior and left lateral sides with less stresses on the right side. On the left lateral side, the denture base lined with resin-based material demonstrated similar stresses to that of the control; however, lower stresses occurred in the premolar and retromolar regions. Denture bases lined with silicone-based material showed decreased fringe orders and homogeneous distribution of induced stresses. Both lined dentures exhibited lower stresses when compared to unlined dentures. Silicone-based material provided a more homogeneous distribution of stresses.

1. Introduction

Conventional complete dentures have long been the only option for rehabilitation of edentulous patients. Although dentures are not an ideal substitute for natural teeth, they remain as usual treatment for the great majority of these patients. However, while some patients are satisfied with their dentures, others are unable to adapt to conventional complete dentures displaying significant problems in adapting of the mandibular denture [1].

Over the years, there were significant advances in the evolution of the biomaterials and biological researches, resulting in improvements in the technical procedures for complete dentures. Unfortunately, many patients with financial constraints do not receive the benefits of an oral rehabilitation with complete dentures supported by implants. Thus, costs and dentist's ability for this type of oral rehabilitation with implants are factors commonly responsible in the clinical decisions of treatment [2]. Acrylic resin is the material widely used for manufacturing of denture bases. However, the acrylic resin is a rigid material and can cause discomfort and injury to oral soft tissue due to friction caused by the denture base during the chewing efforts. Consequently, the oral mucosa can become less resilient over years, reducing the ability to absorb the stress caused by the denture, overloading the alveolar bone. The patient's difficulty to exercise the masticatory function is due to atrophic and thin mucosa supporting the stress caused by the occlusal force. Unfortunately, edentulous patients are unable to change these inherent characteristics of the mucosa [3].

For many years, the concept is that the lining of the denture base compensates the loss of thickness of the soft tissue and improves mucosal function. Several types of liners exist for patients displaying soft tissue chronic discomfort in contact with the rigid denture base. There are opinions that a soft lining material associated with rigid acrylic resin base may compensate the atrophy and thickness of the mucosa, contributing to oral health, comfort and improvement of the patient's masticatory function and satisfaction [4–6].

Previous studies evaluated the liner materials with regard to clinical questions, such as tensile strength and tear resistance [7], color change [8], setting and stress relaxation [4], effect of viscoelastic properties under pressure of dentures [9], hardness and roughness [10], and bond strength to the denture base polymer [11]. However, there have no reports comparing different types of liner materials with respect to stresses induced by the dentures on the mandibular alveolar bone ridge when submitted to masticatory simulated loadings.

Different methods such as photoelasticity, finite element and extensiometry are available to analyze the tensions associated with mucus-supported oral prostheses. The photoelastic analysis allows observing the distribution and behavior visual of tensions in the model structure. The method is based on the principle of the internal mechanical stress change produced in complex geometrical structures; for this

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is used as visible light patterns that indicate the location and magnitude of the stresses. Two types of stresses (fringes) are revealed by the linear polariscope. The colorful patterns (clear) are the isochromatic fringes representing the stress intensity, and the isoclines (dark) overlapping the colored fringes are related to stress direction (location and intensity). In this technique, the stresses are easily photographed or measured, while for other methods are necessary graphics and distribution schemes of forces based on data and/or numerical models.

Due to these satisfactory characteristics, the photoelastic analysis was employed by many years in various areas of dentistry field [12–15]. Currently, the method has been also applied to analyze the stresses induced in implant-supported prostheses [16–18]. The reason for the success of these studies was the direct and immediate information given by the images without the need of complex calculation or hypothetical data to build the model of study, as occurs in the element finite analyses. Another fact considered important for the development of this study was the absence of reports showing the stresses induced by the dentures when submitted to masticatory simulated loadings.

Based on these considerations, the purpose of this in vitro study was to investigate the distribution of stresses induced by the lined mandibular complete denture on the alveolar bone ridge using photoelastic analysis. The work hypothesis was that mandibular dentures relined with different materials would promote different stress levels on the mandibular alveolar bone ridge.

2. Materials and methods

Three conventional mandibular complete dentures with modified bases served as model for this experiment. Shortened marginal fringes of each denture base only covered the crest of the alveolar ridge. This procedure was necessary so that the marginal fringes of the mandibular denture base did not prevent the reading of the induced stresses on the photoelastic model. As the aim of the study is not to verify the level of retention of the prosthesis, the concept stating that the alveolar bone ridge as a whole (crest and marginal fringes) supports the mandibular denture was irrelevant in the study. No change occurred on the marginal fringes of the conventional maxillary denture.

Maxillary and mandibular dentures were made with QC-20 acrylic resin (Dentsply, Petropolis, RJ, Brazil) by using the traditional method to fabricate dentures in metallic flasks (DCL; Campinas Dental Products, Campinas, SP, Brazil). The basic structure of this polymer is the following: Pre-polymerized spheres of poly(methylmethacrylate) and small amount of initiator (benzoyl peroxide) are the components of the powder. The liquid consists predominantly of methyl methacrylate with small amounts of inhibitor (hydroquinone). Glycol dimethacrylate is added into the liquid as a cross-linking agent. The poly (methylmethacrylate) for artificial teeth is similar to those for denture base; however, the cross-linking agent amount into artificial teeth is greater than for denture base acrylic resin. This polymer is a rigid material and has no photoelastic behavior.

The mounting of the teeth (SR Vivodent PE and Orthosit PE; Ivoclar Vivadent, Barueri, SP, Brazil) was in compliance with the line force concentration situated above the alveolar ridge, so that the axial loading be similarly distributed. The mounting of teeth was performed with a Mondial 4000 semi adjustable articulator (Bio-Art Dental Products, Sao Carlos, SP, Brazil) with standardized guides: Condylar guide of 30°, Bennett's angle of 15° and incisal pin in zero degree.

The photoelastic models were made with Araldite GY 279 BR and photoelastic resin hardener HY 2963 (Araltec Chemical Products, Guarulhos, SP, Brazil) by using an Elite Double silicone mold (Zhermack, Rovigo, Italy) obtained from a mandibular stone cast. The solution obtained with the proportion of 100 mL photoelastic resin to 48 mL hardener was injected into the silicone mold with a syringe. Photoelastic resin setting was at room temperature for 24 h, according to the manufacturer's recommendations.

To perform the stress analysis, the mandibular denture placed on the photoelastic model was related in occlusion with the maxillary denture by using an articulator (Mondial 4000). Three groups were performed for the mandibular dentures: 1 — Denture base without lining material (control); 2 — Denture base lined with hard acrylic resin-based material (New Truliner; The Harry J. Bosworth Co, Skokie, Illinois, USA), and 3 — Denture base lined with resilient silicone-based material (Ufi Gel SC Voco; GMBH, Cuxhaven, Germany).

Although the Ufi Gel SC reliner (Voco) is for indirect use, the denture base lining procedure was following the direct clinical method for both materials. Thus, both maxillary denture and lined mandibular denture were placed in a hydraulic press under light loading to simulate a clinical occlusal contact in habitual position. Each liner material was proportioned and mixed as recommended by the manufacturers. All procedures were performed at room temperature, and both liner materials were used in 1 mm-thick layer [9,19,20].

A layer of liquid petroleum jelly brushed on the photoelastic models improved the view of the fringes. Observation, analysis and photographs of the fringes occurred in the lingual side of the photoelastic models (anterior, left and right). In general, the vision by the lingual side showed less interference of overlapped structures. This is an important detail in the methodology considering that other areas can interfere in the definition of the photoelastic fringes causing an inaccurate analysis of the stresses.

The axial loading exercised on the mandibular denture was always in the same position on the maxillary stone cast. Under these conditions, all mandibular dentures were axially loaded with 10 kgf (98 N). Maximum bite force for denture wearers ranges between 7.03 kgf (69 N) and 14.57 kgf (142.9 N) according to previous studies [21–23].

A brief description of photoelasticity would be important to understand the reason of the study. The photoelasticity shows any state of tension in models made with transparent, homogeneous and isotropic materials. Under effect of a white light source, optical effects show colored bands (chromatics) covering the range of the visual spectrum. These optical effects are series of alternating black and white bands with order number at a point, depending on the load intensity applied to the model. At points within the bi-dimensional model only readings for maximum shear stress and individual values of principal stresses are obtained by numerical methods.

When the photoelastic model is loaded in a linear polariscope, the luminous intensity is a function of the relative retardation, i.e., in the model it is an isochromatic fringe. This configuration evaluates the gradient of stresses in the model without overlapping the isoclinic fringes. Thus, the photoelastic model works as wave retarder with the characteristic that the optical axes of the model are coincident with the directions of the principal stresses due to the birefringence effect.

In a linear polariscope with white light, the fringes observed are colored; however, the zero-order fringes are black, facilitating observation and determining the gradient of stresses in the model. The isochromatic fringes represent the set of points with the same value for the difference among the principal stresses. Thus, light bands of different colors that depend on the fringe order form isochromatic fringes. Fringe orders at a model point are analyzed by photographing the model, and the observed spectrum shows typical colors for each fringe order. As an example, the colors of the orders of entire fringes (Nf) and their transitions are shown in Fig. 1.

In the current study, a circular polariscope of flat transmission (PTH-A-01 model; Federal University of Uberlandia, MG, Brazil) analyzed the photoelastic stresses and a digital camera (Canon EOS XSI; New York, NY, USA) takes the photographs. The color pattern versus fringe order analysis was according to the schematic demonstration of isochromatic fringe order.

It is possible to assign numeric values to the fringes in order to establish statistical comparison [24,25]. However, visual analysis of the stresses has been enough to establish the desired comparison, as observed in previous works [26–28]. Thus, the following methodological