Photoelastic stress analysis in mandibular bone surrounding bar-clip overdenture implants

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Abstract: The aim of this *in vitro* study was to evaluate, using the photoelastic analysis method, the stress distribution in mandibular bone surrounding a bar-clip overdenture when 2 implant angulations were simulated. Two mandibular photoelastic models were manufactured, with 2 implants embedded in the interforaminal region: model 1 - PAPI, a photoelastic analysis model with parallel implants; and model 2 - PAAI, a photoelastic analysis model with angled implants. A bar-clip retention system and an overdenture were positioned over the implants, and loads of 1.0, 2.0 and 3.0 bars were applied. The resultant stresses that developed in the supporting structure were photoelastically monitored and were recorded photographically. The results showed that there were no similarities in the areas of stress among the photoelastic resin models when the angulation of the implants was evaluated. Model 1 - PAPI presented a higher stress concentration at the implant apex, while in model 2 - PAAI, there were higher stress concentrations on the mesial and distal implant faces. Within the limitations of this study, it was concluded that the PAPI photoelastic model demonstrated better stress transfer compared to the PAAI model, since the forces oriented along the axis were better absorbed by the bone.

Descriptors: Dental Prosthesis; Dental Implants; Dentures; Biomechanics.

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Introduction

When conventional complete dentures are converted into implant-retained overdentures, clear increases in the patient's masticatory function, denture retention and stability,[1] phonetics[2-4] and oral hygiene can be observed.[5] These advantages are important for explaining the popularity of overdentures as an alternative to conventional complete dentures.[6-8]

Bar-clip and O-ring overdenture abutments are the most common types, and they are classified as resilient systems.[9,10] These retentive mechanisms attached to implants transmit stress to the bone differently than natural teeth supported by periodontal ligaments.[5,11,12] If the incident force on the implant exceeds the physiological limit, it can result in overload, with consequent bone microfractures that can heal with non-mineralized connective tissue or lost tissue, because the implants are not prepared to support excessive force.[5,13,14] Therefore, it is essential that questions be addressed regarding the biomechanical behavior of implants and how they react to the surrounding tissues when submitted to loads, because they are directly related to the preservation of supporting tissues. Moreover, the mandibular nerve and the foramen represent limitations in edentulous patients. An alternative to avoid injury to these structures is to angle the implants. Another advantage is a reduction in the prosthesis cantilever. However, the effects of nonaxial load, caused by implant angulation, on the integrity of osseointegration have rarely been reported in the literature on overdentures. Thus, this study included a photoelastic model with 10° angulated implants, divergent from the midline, because it has been suggested that this divergence can usually be tolerated.[15]

The purpose of this study was to compare the load transfer characteristics of a bar-clip attachment system for 2 implant-retained mandibular overdenture designs, vertically and 10° inclined implants, using photoelastic analysis.

Methodology

Two photoelastic models of an edentulous mandible were fabricated with PL-2 photoelastic resin (Vishay Intertechnology, Malvern, USA). These mandibles were obtained from a photoelastic cranium (Figure 1).

Figure 1 - Photoelastic cranium.

The photoelastic cranium's superior teeth and the mandible were reproduced with Flexitime silicone impression material (Heraus Kulzer GmbH, Hanau, Germany), resulting in stone casts (Zhermack SpA, Rovigo, Italy) that were positioned, using a bite record, in a semi-adjustable articulator (Bio-art, São Carlos, Brazil), allowing for artificial anatomic tooth arrangement (Ivoclar Vivadent, Barueri, Brazil). A silicone mold (Flexitime) facilitated the duplication of this inferior wax denture to obtain a surgical guide. This guide was placed on a stone mandible to allow the perforations, made with a maxicut drill (KG Sorensen, Cotia, Brazil), to obtain positions with the implant analogs (Conexão Sistemas de Prótese, Arujá, Brazil). A delineator (Bio-art) was used to enable parallelism between them. These 2 implants analogs, with diameters of 4.1 mm, were embedded in the interforaminal region at a distance of 22 mm.[16]

Perforations in the stone mandible were created to allow for the fabrication of 2 photoelastic mandible models:

- In model I, the implants were vertically oriented, perpendicular to the occlusal plane and parallel to each other;
- in model II, the implants were 10 degrees divergent from the midline.[12]

Flexitime silicone transfer impressions were obtained from the stone mandible. After polymerization, the stone mandible was removed with the implant replicas from the impression.

Two Master Screw implants, 3.75 × 13 mm with a 4.1 platform and a hexagonal external connection (Conexão), were screw-retained to the impression's open coping tray (Conexão), and photoelastic resin was poured into the silicone molds, according to the manufacturer's recommendations.[17] After polymerization, the impression copings' open trays were loosened, and the photoelastic models were obtained.

The bars were waxed on 2 UCLA abutments (Conexão) positioned on the stone mandible. Then, they were invested and cast with Verabond II Ni-Cr Alloy (Alba Dent Inc., Cordelia, USA).

The overdentures were waxed with the injection flask that was used to make the surgical guide, and they then were fabricated using conventional dental laboratory techniques. The clips (Conexão) were embedded, according to the manufacturer's recommendations.

Light-bodied silicone impression material (Aerojet Fiberglass, São Paulo, Brazil) was applied to the intaglio surface of the extension base of the overdentures to mimic the soft tissue.[5,12,13,16,18,19]

Each photoelastic model was fixed to the photoelastic cranium. This set was immersed in a tank of mineral oil (Campestre, São Bernardo, Brazil) to facilitate photoelastic observation.

Loads of 1, 2 and 3 bars were applied to the photoelastic mandible models from above to the top, as *in vivo*, during which the mandible moves up to the maxilla.[15] The teeth of the cranium were in contact with the artificial teeth from the overdenture. The occlusal contact determined the load application. The same overdenture was used in both groups, so in this manner, the points of load application were standardized.

In this study, stresses were observed and recorded photographically[17] using a Fuji S 9500 camera (Fujifilm Corporation, Tokyo, Japan) in the fields of a circular polariscope. The evaluation was undertaken using the following terminology:

- low stress: 1 fringe or less;
- moderate stress: between 1 and 3 fringes; and
- high stress: more than 3 fringes.[20,21]

The areas analyzed in both groups were the mesial, distal and apical regions from each implant and the right and left edentulous ridges from each group.

The photoelastic model images were named according to the implant angulations, followed by the amount of load applied:

- Model I - PAPI, for the photoelastic analysis model with parallel implants (PAPI0; PAPI1; PAPI2; PAPI3); and
- Model II - PAAI, for the photoelastic analysis model with angled implants (PAAI0; PAAI1; PAAI2; PAAI3).

Results

All the images obtained of model I, evincing the sequence of load applied and differences among the fringe patterns, are shown in Figure 2. PAPI0, without load, produced moderate stress (2 fringes) on the apical region of the right implant and less than 1 fringe order of stress on the body of the left implant; this stress was sparser in its mesial region and more delimited in its distal region. No fringes were observed on the right edentulous ridge, and low order stress (less than 1 fringe) was observed on the left.

PAPI1, seen in Figure 2, showed an increase in stress patterns in the previously analyzed areas, which was proportional to the load applied. A load of 1 bar produced a moderate stress (3 fringes) on the apical region of the right implant and 2 fringe orders of stress on the body of the left implant. No fringes were observed on the right edentulous ridge, and a moderate order of stress (2 fringes) was observed on the left. Little or no discernible stress appeared in the mandibular trigon, as indicated by the arrow.

Regarding PAPI2, Figure 2 shows an increase in the intensity of stress proportional to the load applied. High stress (more than 3 fringes) was observed on the apical region of the right implant, while moderate stress (2 fringes) was observed on the body of the left. No fringes were observed on the right edentulous ridge and moderate order stress (between 1 and 3 fringes) was observed on the left. Low stress (1 fringe) was noted in the mandibular trigon, as indicated by the arrow.

Figure 2 shows that for PAPI3, the load of 3 bars generated similar stress patterns as seen with PAPI2.

For Model 2 - PAAI, the angled implant model submitted to photoelastic analysis (Figure 3), the regions selected for analysis were the same as those used for Model 1.

In Figure 3, low stress can be observed for PAAI0 (1 fringe or less) on the body of the implants. No discernable stress was noted on either edentulous ridge.

In Figure 3, which shows PAAI1 with 1 bar load, an increase was observed in stress pattern when compared with PAAI0. Low stress (1 fringe) was visualized on the apical region, with moderate stress (between 1 and 3 fringes) on the mesial body of the

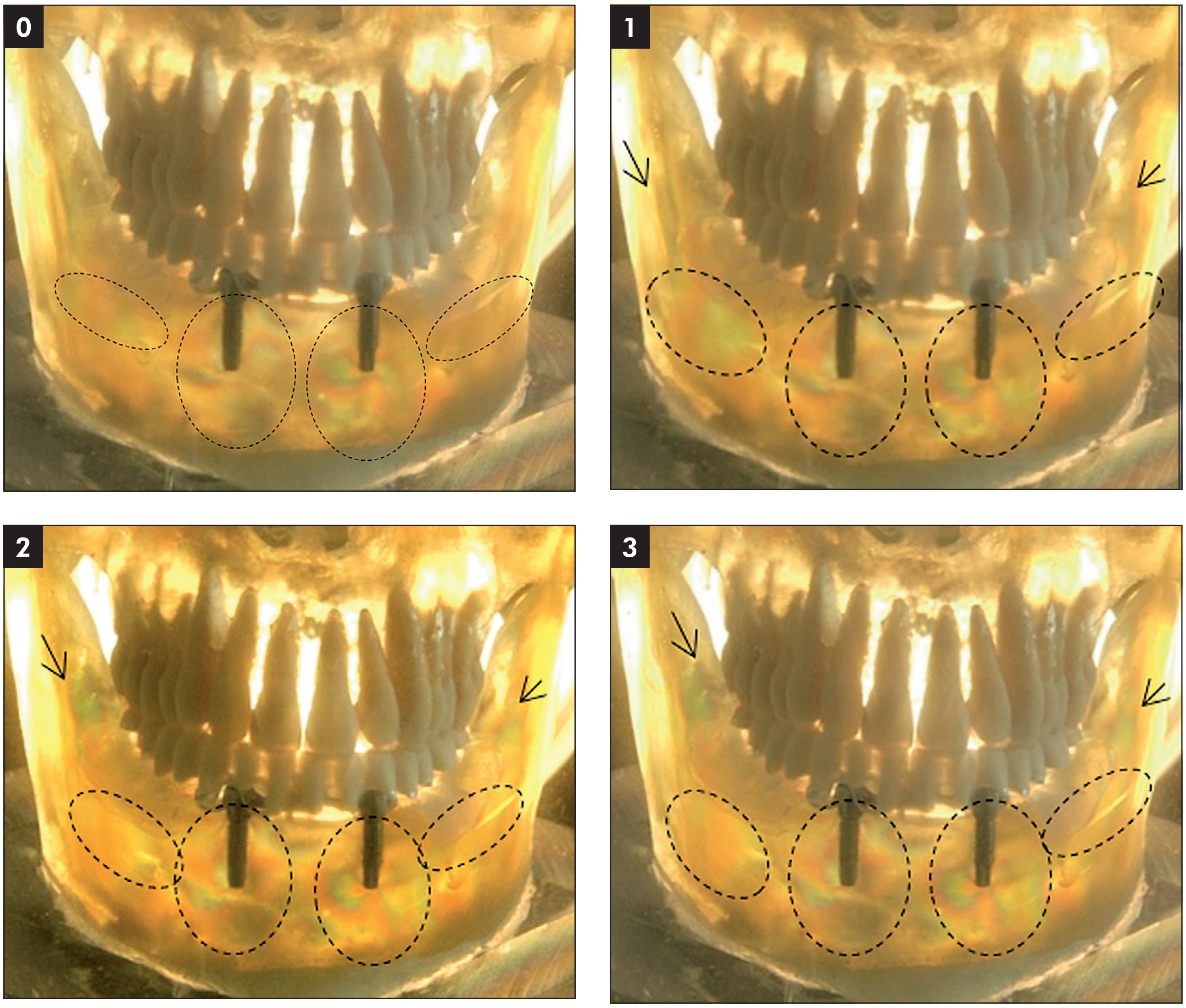

Figure 2 - PAPI: Bar-clip overdenture on two parallel implants, followed by load application.

right implant. Moderate stress was observed on the body of the left implant; this stress was more sparse in its mesial region and more delimited and intense in its distal region. The fringes formed by the right and left implants merged in the mental region. Low stress (1 fringe or less) was observed on the right and left edentulous ridges.

When a load of 2 or 3 bars was applied, PAAI2 and PAAI3, as shown in Figure 3, showed low stress (1 fringe) on the apical region, with moderate stress (3 fringes) on the mesial body of the right implant. Moderate stress was observed on the body of the left implant (3 fringes); this stress was more sparse in its mesial region and more delimited and intense in its distal region. The fringes formed between the implants in the mental region were more intense. Low stress (1 fringe or less) was observed on right and left edentulous ridges.

Discussion

The advantages of treatment with overdentures[1,2,4] are important for explaining their popularity, as well as why the authors chose this type of treatment.

Furthermore, this study compared the load transfer of an implant-retained mandibular overdenture, with vertical and 10° inclined implants, so it was possible to verify the effects of nonaxial load.

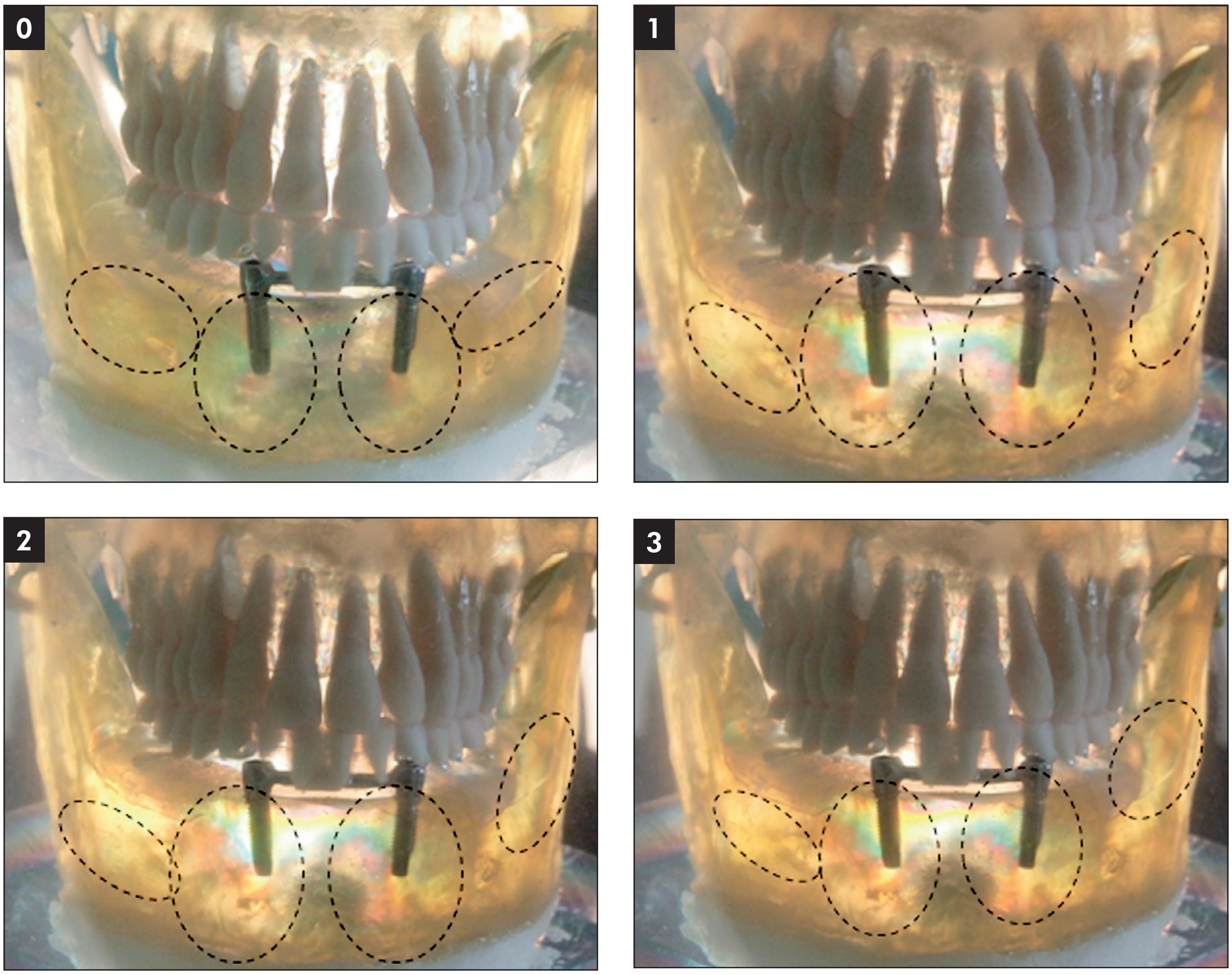

Figure 3 - PAAI: Bar-clip overdenture on two angled implants, followed by load application.

The PAPI0 model, shown in Figure 2, presented low to moderate stress concentrated in the regions of the implants. Therefore, the evaluations of stress behaviors were undertaken starting with this initial image. The initial fringes patterns were the result of:

- photoelastic resin component manipulation and homogenization;
- denture adjustments on the photoelastic models; and
- denture fixation on the cranium acrylic base.

These initial fringes appeared although all care was taken to prevent them. Thus, the sequence adopted for analyzing the results was planned to evaluate the intensity of stresses generated during load applications, while always considering the stresses initially present in the models.

In Model 1 - PAPI, when submitted to loads of 0 to 3 bars, stress concentration was observed at the implant apex and in the edentulous ridge region. The presence of stress at the implant apex is explained by implants having the tendency to intrude when submitted to load. Resin resistance hinders this implant penetration into photoelastic resin due to its hardness. Thus, areas of stress are generated at the apex, and as a result, photoelastic fringes occur.[22,23]

There is a principal difference in the fringe pattern along the implant body when the load is applied vertically on the denture occlusal plane. The stress concentration on implants is not reduced; otherwise, there would be a greater stress concentration at the apex.[13] This reaction does not occur when the load is applied at a point on the posterior teeth. In this situation, the bar clip retention system tends to rotate, and the stress tends to be transferred perpendicularly to the posterior region of the ridge.[19] Federick and Caputo, in 1996,[12] evaluated stress distribution in overdentures anchored by different retention systems. The load was applied on the premolar and second molar. The authors concluded that the more posteriorly the load was applied, the greater the stress concentration was on the posterior alveolar ridge, and the lower the stress was on the anterior region of the implants. Thus, some reports in the literature have described greater stress concentrations on the posterior edentulous ridges and lower stress concentrations on the anterior region, where the implants are placed.[17,24] This situation was not observed in this study.

The difference in stress concentrations, when compared to the posterior edentulous ridges and the anterior region, could be explained by load application having occurred vertically on the overdenture occlusal plane.[21] Kenney and Richards[13] concluded that the greater stress concentration on the anterior region, where the implants were placed, was due to their being joined by a bar-clip retention system, which transmitted a greater stress concentration to the supporting tissue, compared to the posterior alveolar ridge. Ochiai *et al.*,[5] in 2004, compared stress transmission to the alveolar ridge when overdentures were retained by bar-clip and O-ring retention systems. The bar-clip system was responsible for a greater stress concentration on the anterior region, where the implants were placed.[21] Similar results were reported by Thayer and Caputo in 1977,[22] when they described a stress concentration along the posterior ridges and a higher stress concentration on the root apex because the overdenture was retained using the Dolder bar system.

The literature has also reported that lower stress concentrations on the posterior alveolar ridge might have occurred due to the interposition of a layer of silicone, which was applied to simulate the oral mucosa. The capacity of silicone to absorb stress likely reduced the stress concentration on the posterior ridges.[16,24]

PAAI0, the angled implant model with load absence submitted to photoelastic analysis, as shown in Figure 3, presented more concentrated fringes in the implant region and no discernable stress on the posterior ridge. The stress pattern observation was undertaken considering the same observations made for the residual stresses in PAPI0.

Model 2 - PAAI, when submitted to loads of 0 to 3 bars, showed an increase in stress concentrations in the implant region and low stress on the posterior ridge. Thayer and Caputo, in 1977,[22] affirmed that after load application, implants tended to intrude into the photoelastic resin. This implant penetration was hindered by the resin resistance, resulting in a photoelastic fringe at the implant apex. When the implant was angled and received perpendicular force on the overdenture occlusal plane, the same tendency of intrusion occurred. However, it tended to descend in an inclined manner, so the fringe formations occurred not only at the apex but also along the distal face of the implant. This fringe occurred because the implant did not tend to intrude vertically, parallel to the load applied.[12] Moreover, Menicucci *et al.*[25] affirmed that stress concentration occurred in the anterior mandible region when overdentures were anchored by a linked retention system, such as the bar-clip. Mandible deformation during load application generated torsion in the mental region, where the implants were placed, which might explain the high stress concentration.

Celik and Uludag[21] affirmed that when the implants were angled, their apices were in a closer position, causing the stresses to aggregate or concentrate in this region, which explains the higher stress concentration. This finding is in accordance with photoelastic model 1, with parallel implants, provided that in this model, the stress concentration in the anterior region was less, compared with Model 2.

Experimental models, such as those made with photoelastic resin, are widely used in dentistry to evaluate prosthetic biomechanical and stress concentrations, and such a model was used in this study to analyze overdentures and a bar-clip system. However, this method presents limitations; for example, the resin used for simulating the bone structure presents differences when compared with real tissue.[23,24] The photoelastic analysis assumes that all structures are isotropic and homogeneous. In addition, the contact between the implant and the photoelastic resin, which simulates bone tissue, is considered 100% along the entire implant body. In *in vivo*, it does not occur, because osseointegration is a dynamic process.[5,25,26] Furthermore, three-dimensional photoelastic analysis was undertaken using images that are two-dimensional.[13] The simulated loads were applied vertically,[5,13] although it is known that mastication forces occur in many directions. The method to obtain a transfer impression from the stone mandible with the implant replica was selected because it mimics the real situation.[16]

Conclusion

Within the limitations of this study, it was concluded that PAPI showed better stress transfer compared with PAAI, since the forces oriented along the axis were better absorbed by the bone.

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