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RESEARCH ARTICLE

Photoelastic Stress in Mandibular Overdenture Retained by Two Implants

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ABSTRACT

Objectives: **The aim of this study was to verify the effect of occlusal and axial single loads in the photoelastic stress in overdenture retained by two implants placed in the anterior region of the mandible.**

Materials and Methods: **Occlusal load (10, 20, and 30 kgf) was exerted by the conventional maxillary complete denture in occlusion with the overdenture adapted in the mandibular photoelastic model. Axial single load was also exerted on the first left or right molar of the overdenture. Qualitative analysis was made in polariscope images and quantitative analysis by the FRINGES program.**

Results: **Qualitative analysis: The occlusal load showed similar stress in the region between the two implants. Axial single load induced in the first molars promoted stress in the implant apexes, and between the implant and mandible posterior region for the three loads. Quantitative analysis for occlusal load: 10 kgf (T = 265.03; N = 0.57); 20 kgf (T = 989.81; N = 2.11); 30 kgf (T = 1055.40; N = 2.26). Axial single load in the left molar: 10 kgf (T = 267.38; N = 0.57); 20 kgf (T = 270.07; N = 0.58) and 30 kgf (T = 281.84; N = 0.60). Axial single load in the right molar: 10 kgf (T = 952.14; N = 2.03); 20 kgf (T = 1038.58; N = 2.22); and 30 kgf (T = 926.92; N = 1.98).**

Conclusions: **Different photoelastic stress levels occurred in the overdenture retained by two implants when submitted to occlusal or axial single load in the first left or right molar.**

Clinical Relevance: **Artificial teeth intercuspation in the overdenture supported by two implants must have the same importance given to the vertical relationship to relieve the chewing effort.**

Keywords: Dental implant, occlusal load, overdenture, photoelastic stress.

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1. Introduction

Alveolar ridge bone loss intensity is considered a physiological process influenced by several factors [1]. Although this process cannot be interrupted, conventional complete dentures with better adaptation and retention may minimize bone atrophy [2]–[4], since the alveolar bone loss decreases the stability of complete dentures causing discomfort to the patients.

On the other hand, mandibular two-implant overdenture combined with maxillary conventional denture provide better function and oral health-related quality of life than conventional dentures [5], implant-supported overdenture provided the greatest degree of efficiency, followed by the tooth-supported overdenture and complete denture [6], and measurements of prosthesis misfit and change of marginal bone level in implants placed in the edentulous maxila showed a certain biologic tolerance for misfit and was clinically acceptable with regard to marginal bone loss [7].

Oral rehabilitation with two to four implants placed in the anterior region of the mandible to retain overdenture is feasible and clinically satisfactory. However, in each treatment, there are countless advantages and disadvantages related to load distribution on the implant, and the amount of tissue strain on the posterior residual ridge increases when the number of implants is reduced [8].

Stress exceeding the physiological limit of the alveolar bone may cause deformities in the peri-implant region, microfractures, and bone resorption. Previous studies showed that the bone density and the mineralized bone-to-implant interface are higher around the lateral loaded implant when compared to the inactivated control side. Therefore, it is possible that static load applied to the implant in the lateral direction results in a structural adaptation of the peri-implant bone [9].

When the amount of implants was compared in relation to patient's satisfaction and prosthetic complications, a previous study showed that the mandibular overdenture supported by two implants promoted better patient satisfaction in the follow-up at 12 months and better masticatory performance than mandibular overdentures supported by one implant [10]. Mandibular overdenture retained by a single implant has comparable results to those retained by two implants. However, this should be interpreted with caution, as all the included studies were considered at a high bias risk [11].

The polariscope allows to observe the stress distribution in the photoelastic model providing a specific visual display of the fringes (stress). The polariscope reveals two fringe types: Colored patterns (clear) named isochromatic fringes which represent the stress intensity; and dark lines called isoclínicas, overlapping the colored fringes and related to stress direction. In dentistry, the location and intensity of stress are the main required informations which may be measured and/or photographed.

The aim of this study was to verify the effect of different load intensities in the photoelastic stress in mandibular overdenture retained by two implants placed in the mandible anterior region. The study hypothesis was that different load intensities would promote different stresses in the mandibular overdenture retained by two implants.

2. Materials and Methods

The materials used and methodology employed in the current investigation were based in previous study [12]. Conventional complete maxillary denture and mandibular overdenture were traditionally made with thermo-activated acrylic resin (QC-20; Dentsply, Petropolis, RJ, Brazil). Acrylic resin record bases (VipiCril Plus; Vipi Dental Products, Pirassununga, SP, Brazil) and wax occlusal rims (Kota, Sao Paulo, SP, Brazil) were used to relate the maxillar and mandibular stone casts in a semi-adjustable articulator (A7 Plus; Bioart, Sao Carlos, SP, Brazil).

Artificial teeth arrangement (Vivadent PE and Orthosit PE; Ivoclar Vivadent, Barueri, SP, Brazil) was made in the upper and lower wax occlusal rims. O'ring attachment system supported by hexagon external implant with 4.1 mm in diameter and 10 mm in length, and corresponding transfer system (Conexao Prosthesis System; Aruja, SP, Brazil) were used. The implants were placed in the type IV dental stone mandibular cast (Durone; Dentsply), and the transfer system was screwed in the impression copy using an acrylic resin customized tray (VipiMold; Vipi) fabricated with an access opening for the impression transfer system.

The dental stone cast with the components was replicated with a silicone impression (Silibor; Classico Dental

Fig. 1. Mandibular photoelastic model with two implants.

Products, Sao Paulo, SP, Brazil). After 24 h, the impression copy was released from the fixation screw, and the implant was placed in the silicone mold used to make the photoelastic model. The photoelastic resin (Araldite; Huntsman, Sao Paulo, SP, Brazil) is composed of a reactive liquid Gy-279 BR (derived from bisphenol A) and a hardener HY 2964 (derived from cycloaliphatic amine). The resin amount was calculated following the manufacturer's recommendations (100 parts of GY279 to 48 parts of HY2964). The capture of the O'ring attachment system previously positioned in the photoelastic model was made with self-curing acrylic resin (VipiFlash, Vipi), and the capture material region polished to stay as translucent as other regions of the overdenture.

The photoelastic model (Fig. 1) was submitted to occlusal load (10, 20, and 30 kgf) exerted by the maxillary conventional denture in occlusion [13], and the stress evaluated in different mandible locations (front, and left and right sides). Axial single load was also individually exerted on the first left or right molar to verify the behavior of the photoelastic model since laterality movements are different for each alveolar ridge and influenced by the patient's normal or parafunctional habits.

For each load type, the positions R1 to R11 were selected along the mandible. In the occlusal load were selected the positions P1, P3, and P5. For the axial single load in the left molar P3 and P5, and for the right molar P1 and P3. The regions evaluated in each position were standardized for analysis of the maximum shear stress (T).

A circular polariscope (PTH-A-01 model; Federal University of Uberlandia, MG, Brazil) was used for stress analysis and the images were taken with a digital camera (Canon EOS XSI; New York, NY, USA). The color pattern versus fringe order analysis was according to the schematic demonstration of isochromatic fringe order for maximum shear stress in Fringes program MatLab environment (Federal University of Uberlandia).

Photoelastic model images and the optical constant ($K\sigma$ = 0.468 kgf/mm) of the photoelastic resin were inserted in the FRINGES program. Based on the equations inserted and the fringe orders informed by the examiners, the FRINGES program provided the maximum shear stress (T) for each predetermined point. The load applied in each position did not exceed the ordem 4 of the fringes. After, the values of the fringe orders and shear stress were obtained for each point, and the mean value for each position and load intensity was calculated.

Single photoelastic model [14], [15] and Adobe Photoshop 7.0 software for photoelastic image analysis were considered. The method allows to verify the passivity of the structure after screwed and when the load was applied [16], [17]. Two examiners recorded the fringe orders and the direction of stress propagation. When there was no agreement between the two examiners about the reliability of the results, a third examinator was consulted.

3. Results

3.1. Qualitative Analysis

Occlusal Load: Fig. 2 shows the front view of the photoelastic model with two implants placed in the anterior region of the mandible submitted to occlusal load (10, 20, and 30 kgf, respectively). The stress concentration occurred in the region between the two implants. Similar stress was promoted by the three loadings.

Occlusal Load: Fig. 3 shows the left side view of the photoelastic model with two implants placed in the anterior region of the mandible submitted to occlusal load (10, 20, and 30 kgf, respectively). Greater stress concentration occurred in the posterior region of the left implant, and the stress increased with the increase of the load, mainly for 30 kgf.

Occlusal Load: Fig. 4 shows the right side view of the photoelastic model with two implants placed in the anterior region of the mandible submitted to occlusal load (10, 20, and 30 kgf, respectively). Similar stress concentrations occurred in the implant apex and between the implant and the posterior region of the mandible for the three loads.

Load in the First Left Molar: Fig. 5 shows the left side of the photoelastic model with two implants placed in the anterior region of the mandible submitted to axial single load in the left molar (10, 20, and 30 kgf, respectively). Greater stress occurred in the apex and lateral posterior region of the left implant with the three load intensities.

Load in First Right Molar: Fig. 6 shows the right side of the photoelastic model with two implants placed in the anterior region of the mandible submitted to axial single load in the first right molar (10, 20, and 30 kgf, respectively). Little and similar stress occurred around the right implant and posterior region of the mandible in the three loads.

3.2. Quantitative Analysis

Table I shows the means of shear stress (T) and fringe order (N) for overdenture retained by two implants submitted to occlusal load. Shear stress increase (T) and fringe order (N) were shown with the load intensity increase.

Table II shows the means of shear stress (T) and fringe order (N) for overdenture retained by two implants submitted to axial single load in the first left molar. Similar stress (T) and fringe orders (N) were shown for the three loads.

Table III shows the means of shear stress (T) and fringe order (N) for overdenture retained by two implants submitted to axial single load in the first right molar. Similar stress (T) and fringe orders (N) were shown for the three loads.

Fig. 2. Front view of the photoelastic model with two implants submitted to occlusal load (10, 20, and 30 kgf, respectively).

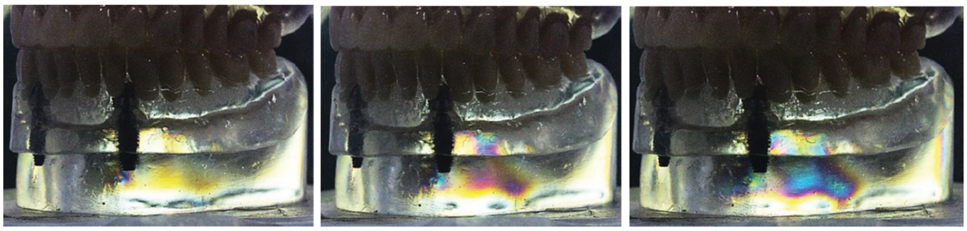

Fig. 3. Left side view of the photoelastic model with two implants submitted to occlusal load (10, 20, and 30 kgf, respectively).

Fig. 4. Right side view of the photoelastic model with two implants submitted to occlusal load (10, 20, and 30 kgf, respectively).

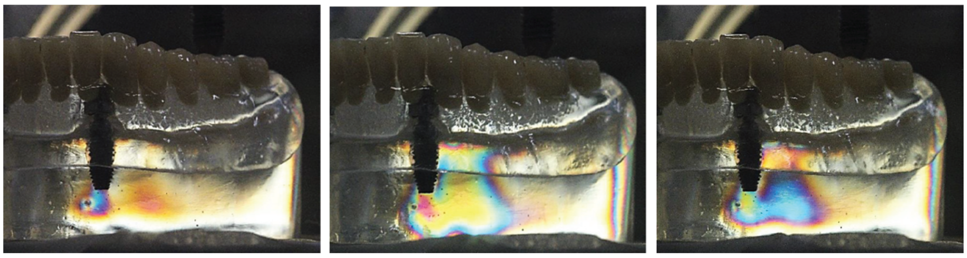

Fig. 5. Left side of the photoelastic models with two implants submitted to single load in the first left molar (10, 20, and 30 kgf, respectively).

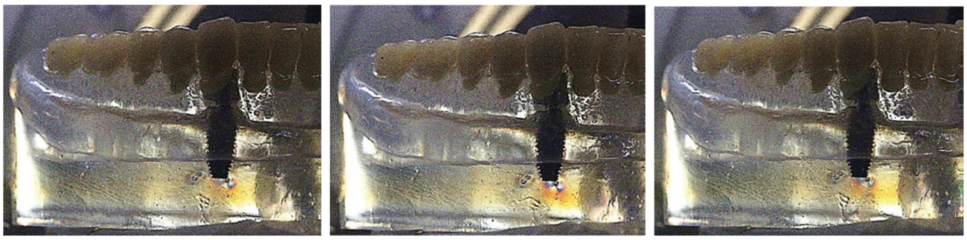

Fig. 6. Right side of the photoelastic model with two implants submitted to axial single load in the first right molar (10, 20, and 30 kgf, respectively).

TABLE I: Means of Shear Stress (T) and Fringe Order (N) for Overdenture Retained by Two Implants Submitted to Occlusal Load

Load (kgf)					
10		20		30	
T	N	T	N	T	N
265.03	0.57	989.81	2.11	1055.40	2.26

TABLE II: Means of Shear Stress (T) and Fringe Order (N) for Overdenture Retained by Two Implants Submitted to Axial Single Load in the First Left Molar

Load (kgf)					
10		20		30	
T	N	T	N	T	N
267.38	0.57	270.07	0.58	281.84	0.60

TABLE III: Means of Shear Stress (T) and Fringe Order (N) for Overdenture Retained by Two Implants Submitted to Axial Single Load in the First Right Molar

Load (kgf)					
10		20		30	
T	N	T	N	T	N
952.14	2.03	1038.58	2.22	926.92	1.98

4. Discussion

The literature has shown that photoelastic analysis has been utilized to show the biomechanical behavior of prostheses with different implant-retained overdenture designs [15]–[19]. A customized strain-gauged abutments study showed that different load locations promoted significant differences among the different overdenture attachment systems [20]. In addition, single-implant overdentures with dome-type magnet or ball attachments had biomechanical effects similar to two-implant overdentures in terms of lateral forces to the implant and denture base movements under molar load [21].

The current study showed that different occlusal and axial single loads exerted on the overdentures retained by two implants promoted different stresses in the photoelastic model. Thus, stress concentration occurred in the region between the two implants and similar stress was promoted by the three loads (Fig. 2). Greater stress concentration occurred in the posterior region of the left implant, and the stress increased with the increase of the occlusal load, mainly for 30 kgf (Fig. 3). Similar stress occurred in the right implant apex and between implant and the mandible posterior region for the three loads (Fig. 4). Greater stress occurred in the apex and lateral posterior region of the left implant with the three load intensities (Fig. 5). Little and similar stress concentration occurred around the right implant and posterior region of the mandible for the three loads (Fig. 6). Shear stress increase (T) and fringe order (N) were shown with the load intensity increase (Table I), and similar stress (T) and fringe orders (N) were shown for the three loads (Tables II, III).

Stress images along the implant, apex, and mandible region between implants suggest that this retainer type acts as a tension concentrator. Therefore, considering that the results showed different stresses in the overdenture retained by two implants when submitted to occlusal force or axial single force on the first left or right molar, the study hypothesis was accepted.

Based on these considerations, it is possible to verify that the stress was also influenced by the different load types and application regions. A previous study showed that the photoelastic stress in the peri-implant region due to axial force exerted on the right molar was not influenced by the implant number [17]. In general, the load location and attachment type are significant factors; however, force and moment were greater when the load was applied directly over the implant or between implants in the middle-anterior region [20].

Different loads and intensities promoted different stress on the photoelastic model. Shear stress increase (T) and fringe order (N) were observed when the occlusal load increased (Table I). On the other hand, similar stress (T) and fringe orders (N) were shown for the three single loads exerted in the left or right molar (Tables II, III).

It was alleged that the chewing resulted in less vertical force transmitted to implant supported overdentures compared to maximum biting in centric occlusion [22]. There were no differences in induced axial force for the various anchorage devices; however, there were differences in bending moment. Although there is a tendency for better axial load sharing with bars and better sharing of bending moments with ball attachments, these differences were not significant [23]. In addition, no evidence was confirmed that there are differences in marginal peri-implant bone loss between single implant prostheses and multiple screw-retained prostheses [24].

The lowest stress and the best stability of implants in mandibular overdentures were obtained when two implants were inserted in lateral incisor areas with shorter attachments placed parallel to the long axes of the teeth [25]. It would be reasonable to affirm that the stress in the mandibular overdenture due to the occlusal load increase would not result in severe bone injury harming the osseointegration in the long term.

The single load applied to the first left or right molar caused stress on the implants and posterior mandible region when the sides were compared with greater intensity on the left side (Fig. 5). This fact is difficult to explain due to the standardization of the photoelastic models and application of the loads. For this reason, this fact should be investigated by further studies using finite element analysis to verify the effects of unilateral single forces on the peri-implant region in relation to the arch shapes of different mandibular models.

Another interesting fact was that the ball attachments in overdenture retained by two implants were associated with significant mandibular denture base deformation over the implants compared to Locator attachments [26]. Unlike, the ball system was shown to introduce a lower amount of stress to the posterior mandibular residual ridge when compared to a bar and clip system [27].

Patients with implant-retained overdentures had better health-related quality of life when compared to conventional dentures. The number of incorporated implants in the Locator-retained overdenture also influenced the increase in life quality; however, four implants had a significant advantage over two implants [28].

Although the retention and stability of a simulated overdenture supported by two implants are significantly affected by implant location and abutment type [29], implant-retained overdenture provides stronger bite force, and could potentially concentrate hydrostatic stress inside the mucosa and cause greater residual ridge resorption when compared to conventional denture [30].

Despite the stability and enhanced masticatory function, the overdentures retained by two and four implants show higher hydrostatic stress in the mucosa of the posterior ends of the mandible due to the cantilever effect when compared to conventional dentures. Therefore, the hydrostatic pressure in the mucosa signifies a critical indicator of severe mandibular ridge resorption posterior in implant-retained overdentures [31]. In addition, neither attachment wear nor an increase in rotational movement in 2-implant-supported overdenture due to a 1-mm decrease in the posterior residual mucosal support caused significant changes in the peri-implant region [32].

Previous studies showed no difference between individuals with mandibular overdenture supported by one or two implants immediately loaded in relation to implant survival rates, peri-implant bone loss, and patient satisfaction [33]. On the other hand, a 3D-finite element study showed that the stresses produced in the hard and soft bones were higher in single implant-retained mandibular overdenture while stresses produced around the denture, as well as implant, were higher in two-implant retained mandibular overdenture [34], while an *in vivo* study showed that the retention and patient's satisfaction were influenced by the different attachment systems when two implants were placed in the inter-foramen region to support mandibular overdenture [35].

Based on the discussed considerations, further investigations should be developed to establish possible correlations between the variables of the current study and biomechanical failures in overdenture retained by two implants. Possible unequal alignments between sides of the mandibular alveolar ridges could be considered as negative factors influencing the induced stresses *in vivo*.

5. Conclusion

Different force intensities promoted different photoelastic stress levels in overdentures retained by two implants when submitted to occlusal load or axial single load in the first left or right molar.

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Conflict of Interest

The authors declare that there is no conflict of interest known.

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