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Research Article

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PHOTOELASTIC STRESS IN MANDIBULAR OVERDENTURE RETAINED BY FOUR IMPLANTS

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ABSTRACT

Aim: This study verified the photoelastic stress in mandibular overdenture retained by four implants. **Materials and Methods:** Four implants were placed in the anterior region of the mandibular photoelastic model at 12mm distance among them. Occlusal load with intensities of 10, 20 or 30 kgf were exerted in the mandibular photoelastic model by the maxillary complete denture in maximum intercuspation. Axial single loads with same intensities were also exerted on the first left or right molar of the overdenture. Qualitative analysis was made using polariscope and quantitative analysis with images obtained by the FRINGES program. **Results:** Qualitative analysis: Occlusal force, similar stress between the central implants and in the posterior region of the model that increased with the force increase (Anterior view). Stress in the apex of the distal implant and in the posterior region of the model that increased with the force increase (Left view). Stress between the right implants, in the apex of the distal implant and in the posterior region of the model that increased with the force increase (Right view). Quantitative analysis for occlusal load: 10 kgf (T=230.05; N=0.49); 20 kgf (T=1057.75; N=2.26); 30 kgf (T=1105.17; N=2.36). Axial single force in the first left molar: 10 kgf (T=870.08; N=1.68); 20 kgf (T= 886.67; N=1.88); 30 kgf (T=919.86; N=1.97). Axial single force in the first right molar: 10 kgf (T=975.19; N=2.05); 20 kgf (T=998.22; N=2.13); 30 kgf (T=1016.38; N=2.17). **Conclusion:** The stress on overdentures retained by four implants were differently influenced by the different force types and load intensities.

Keywords: Dental prosthesis. Dental implants. Photoelasticity. Mandibular overdenture.

INTRODUCTION

Alveolar bone loss worses the retention and stability of complete conventional denture, causing discomfort for the patients. Unfortunately, the alveolar bone ridge has a continuous reduction due to a normal physiological process, and the magnitude is considered dependent of some associated variables (1,2). Intermittent pressure causes greater alveolar bone loss than continuous pressure, and the intensity of the bone loss is closely related to the use of denture than by the presence of disuse atrophy (3). In addition, chewing function may be recovered by the denture best adapted and minimize the process of atrophy that never is interrupted. However, the factors that most influence the loss of the alveolar bone are not completely known (4,5). Osseointegrated dental implant improves the retention and stability levels of the prosthesis, consequently improving the chewing efficiency of the implant-retained overdenture wearers (6). In addition, dental studies has shown that the dental implant also improves the chewing function of patients with mandibular over denture placed in alveolar crest severely reabsorbed (6,7).

The support of mandibular overdentures is obtained with single or multiple implants and the clinical decision for the choose of the number of implants is based on several main factors, as biomechanical, condition of the alveolar crest and economic reasons for each individual clinical case. For mandibular overdenture, the factors alveolar bone loss, possible clinical complications, and patient's satisfaction appear to be closely related to the number of placed implants (8). Furthermore, the prosthetic framework, osseointegrated implant and alveolar bone are subject to stresses exerted by chewing force promoting different levels of undesirable alveolar bone loss (9-11).

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Therefore, deformities at peri-implant region, microfractures and bone resorption may occur when the physiological limit of the alveolar bone is overlapped. Previous study showed that the bone density and mineralized bone-implant interface are higher around the lateral loaded implant compared to inactivated side of the implant. It is also possible that static load applied on the implant in lateral direction may promote better structural adaptation at peri-implant region (12). A study using 3D finite element in three different simulated biting situations exerted in 2-, 3- or 4- implant under vertical loading of 100N showed that the increment in the implant number and splinted attachment type caused lower stresses in mandibular overdenture (13).

A way to verify the stress in complex mechanical structures is the photo elastic analysis. Photoelastic method allows to observe the distribution of stresses in all structure, enabling a general insight into the behavior of the model and providing a display of stresses in the model using polariscope. Two types of fringes (stress) are revealed using the polariscope: colored patterns (clear) which are the isochromatic fringes, representing the intensity of the stresses; and the isoclinic (dark lines), overlapping the colored fringes related to stress direction. In dentistry, the main information's required are location and intensity of stress that may be measured and/or photographed.

The purpose of this study was to evaluate the photoelastic stresses induced on mandibular over dentures retained by four implants by the conventional maxillary denture and single axial forces exerted on first left or right molar of the overdenture. The study hypothesis was that different forces and force magnitudes would promote different stresses on overdentures retained by four implants.

MATERIAL AND METHODS

Materials and methods used in the current investigation were based in previous study (13). Three mandibular overdentures and a conventional maxillary complete denture were traditionally made with

QC-20 thermo-activated acrylic resin (Dentsply, Petropolis, RJ, Brazil). Acrylic resin record bases (VipiCril Plus; Vipi Dental Products, Pirassununga, SP, Brazil) and wax occlusal rims (Kota, SaoPaulo, SP, Brazil) were used for maxillomandibular relation in semi-adjustable articulator (A7 Plus; Bioart, Sao Carlos, SP, Brazil).

Plastic artificial teeth (Vivadent PE and Orthosit PE; Ivoclar Vivadent, Barueri, SP, Brazil) arrangement was made on the maxillary and mandibular 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 in the study. The implants were placed 12 mm in distance between them on the mandibular type IV dental stone cast (Durone; Dentsply), and the transfer system screwed in the impression copy by using acrylic resin tray (Vipi Flash; Vipi) fabricated with an access opening for impression transfer system. The stone model with the components was replicated with silicone impression material (Silibor; Classico Dental Products, Sao Paulo, SP, Brazil). After 24h, the impression copy was released from the fixation screws and the implants placed in the silicone mold used to make the photoelastic model.

The photoelastic resin used (Araldite; Huntsman, Sao Paulo, SP, Brazil) is composed of a reactive liquid Gy-279BR (derived from bisphenol A) and a hardener HY 2964 (derived from cycloaliphatic amine). The amount of the resin was calculated following the manufacturer's recommendation (100 parts of GY279 to 48 parts of HY2964). The curing occurs at room temperature allowing the production of transparent photoelastic models. The capture of the O'ring attachment system that was previously positioned on the photoelastic model was made by using self curing acrylic resin (Vipi Flash, Vipi), and polished to stay as translucent as other regions of the prosthesis. The photoelastic model (Figure 1) was submitted to forces of 10, 20 or 30 kgf exerted on the central portion of the dental stone model of the maxillary denture related in maximum intercuspation with the mandibular overdenture, according to previous studies (13,14). With same intensities of the occlusal forces, axial single forces were individually exerted on the first right or left molar and the stresses evaluated in the same side of the force application.

Figure 1. Mandibular photoelastic model with four implants placed in the anterior region.

The points from R1 to R11 were selected along of the photoelastic model, comprising the anterior and lateral positions. Three positions were considered for the occlusal load (P1, P3 and P5), two for the right molar (P1 and P3) and two for left molar (P3 and P5). The evaluated regions in each location were standardized so that they did not alter the taking position of the photoelastic images. In this way, it was possible to obtain standard points in the structures for the analysis of the maximum shear stress (T). A circular polariscope (PTH-A-01 model; Federal University of Uberlandia, MG, Brazil) analyzed the stresses and a digital camera (Canon EOSXSI; New York, NY, USA) takes the images. The color pattern and fringe order analyzes were according to schematic demonstration of isochromatic fringe order for maximum shear stress in Fringes program (MatLab environment; Federal University of Uberlandia), based in the comparison among fringe orders. Images of the photoelastic model and the optical constant ($K\sigma$=0.468kgf/mm) of the photoelastic material were inserted in the FRINGES program. Based on the equations inserted and the fringe orders informed by the examiner, the FRINGES program evaluated the maximum shear stress (T) in the predetermined points. The force was applied so that the fringe orders in each position did not exceed the fringe order 4. After, each image was analyzed and the values of the fringe orders and shear stress were obtained for each point, and the mean values for each position and force intensity were calculated.

Stresses were evaluated to identify the fringe orders and compare the concentrations occorred on implant and alveolar crest of the model. The following criteria were considered in the study: (1) single photoelastic model (15,16) and (2) Adobe Photoshop 7.0 software analysed the photoelastic images. Images of the stresses permitted to verify the passivity of the structures after screwed or when the force was applied (17,18). Resultant fringe orders (N) and the direction of stress propagation were photographed, quantitatively evaluated and recorded. Two evaluators analyzed the stresses and when there was doubts about the reliability of the results between them, a third evaluator was consulted.

RESULTS

Qualitative analysis
Occlusal force

Figure 2 shows the anterior view of the photo elastic model with four implants submitted to occlusal forces of 10, 20 and 30 kgf, respectively. Similar stress occured between the central implants and in the posterior region of the model in all force intensities, increasing with the force increase.

Figure 2. Anterior view of the photoelastic model with four implants submitted to occlusal force (10, 20 and 30 kgf, respectively).

Figure 3 shows the left side view of the photoelastic model with four implants submitted to occlusal forces of 10, 20 and 30 kgf, respectively. Stress occurred in the apex of the distal implant and in the posterior region of the model, increasing with the force increase.

Figure 3. Left side view of the photoelastic model with four implants submitted to occlusal force (10, 20 and 30 kgf, respectively).

Figure 4 shows the right side view of the photoelastic model with four implants submitted to occlusal forces of 10, 20 and 30 kgf, respectively. Stress between the right implants, in the posterior region of the model and in the apex of the distal implant, increasing with the force increase.

Figure 4. Right side view of the photoelastic model with four implants submitted to occlusal force (10, 20 and 30 kgf, respectively).

Force on first left molar

Figure 5 shows the photoelastic model with four implants submitted to axial single force on first left molar with 10, 20 and 30 kgf. Stress occurred in the apex of the distal implant and between the distal implant and in the posterior region of the model, increasing with the force increase.

Figure 5. Left side view of the photoelastic model with four implants submitted to axial single force on the first left molar (10, 20 and 30 kgf, respectively).

Force on first right molar

Figure 6 shows the photoelastic model with four implants submitted to axial single force on first right molar with 10, 20 or 30 kgf. Stress occurred in the apex of the distal implant, and between the lateral implant and posterior region of the model, increasing with the force increase.

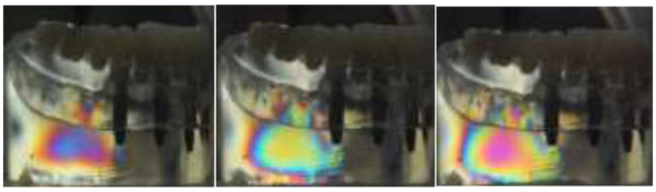

Figure 6. Right side of the photoelastic model with four implants submitted to axial single force on the first right molar (10, 20 and 30 kgf, respectively).

Quantitative analysis

Table 1. Means of shear stress (T) and fringe order (N) for overdenture supported by four implants submitted to occlusal force.

Occlusal force (kgf)					
10		20		30	
T	N	T	N	T	N
230.05	0.49	1057.75	2.26	1105.17	2.36

Table 1 shows the means of shear stress (T) and fringe order (N) for overdenture supported by four implants under occlusal force. Increase of shear stress (T) and fringe order (N) values were shown with the force increase.

Table 2. Means of shear stress (T) and fringe order (N) for overdenture supported by four implants submitted to axial single force on the first left molar.

Axial single force on the first left molar (kgf)					
10		20		30	
T	N	T	N	T	N
870.08	1.68	886.67	1.88	919.86	1.97

Table 2 shows the means of shear stress (T) and fringe order (N) for overdenture supported by four implants submitted to axial single force on the first left molar. Similar shear stress (T) and fringe order (N) values were shown for 10 and 20 kgf, and higher increase for 30 kgf.

Table 3. Means of shear stress (T) and fringe order (N) for overdenture supported by four implants submitted to axial single force on the first right molar.

Axial single force on the first right molar (kgf)					
10		20		30	
T	N	T	N	T	N
957.19	2.05	998.22	2.13	1016.38	2.17

Table 3 shows the means of shear stress (T) and fringe order (N) for overdenture supported by four implants submitted to axial single force on the first right molar. Increase of shear stress (T) and fringe order (N) values was shown with the force increase.

DISCUSSION

The literature shows that the photoelastic analysis method has been utilized to study the biomechanical behavior of prostheses during occlusal loading (15-20). In the current study, different forces and force intensities promoted different stresses on the photoelastic model alveolar ridge when the mandibular overdenture was submitted to occlusal force or axial single force exercised on left or right molar.

Therefore, similar stress occured between the central implants and in the posterior region of the model in all force intensities, increasing with the force increase (Figure 2). Stress occurred in the apex of the distal implant and in the posterior region of the model, increasing with the force increase (Figure 3). Stress between the right implants, in the posterior region of the model and in the apex of the distal implant, increasing with the force increase (Figure 4). Stress occurred in the apex of the distal implant and between the distal implant and in the posterior region of the model, increasing with the force increase (Figures 5 and 6). The axial single forces on left or right molars promoted higher stress when compared to occlusal forces with the prostheses in occlusion. Since the different forces and force magnitudes showed different stress levels, the study hypothesis was accepted.

An investigation showed that compressive force applied at different sites has significant influence on different mandibular overdenture attachment systems (21). Conversely, in the current study the overdentures were retained with standardized attachment system and submitted to occlusal forces exerted by the maxillary denture or axial single forces on the first left or right molars. Thus, it is possible to believe that the stresses were not significantly influenced by the location or inclination of the forces, but the different stress concentrations were due to the different force types.

An earlier study also showed that the number of implants has not significant effect on the stress values in the peri-implant region when the first molar was subjected to axial load. However, different types of implant-supported prostheses promoted different stress values (18). In addition, it is necessary a balanced occlusion to obtain retention and stability in implant-supported overdentures when occlusal forces are clinically applied (22).

Occlusal forces and axial single forces with different intensities promoted different shear stress (T) and fringe order (N) values on the photoelastic model alveolar ridge. Thus, increase of (T) and (N) values were shown with the force increase (Table1). Similar (T) and (N) values was shown for 10 and 20 kgf forces and increase for 30 kgf (Table 2). Increase of (T) and (N) values was shown with the force increase (Table 3).

An interesting result obtained in previous study showed that there is no clear correlation between implant stability quotient and implant diameter (23). This fact seems to support the findings of the current study, mainly when the intensity increase of the occlusal force was related to the different concentrations of the stress.

Higher stress concentration was promoted by the axial single force on the first molar of both sides of the mandibular photoelastic models (Figures 5 and 6). Previous study showed that the chewing resulted in lower vertical force compared to maximum biting in centric occlusion when the load transmission exerted in the implant supported overdentures was measured in vivo (24). In addition, when the effect of the force site on the stress was examined, the force on the first molar produced the highest stresses on the implants (25), which seems to corroborate the results of this current study. Stress along and at apices of the implant occurs because this prosthetic support acts as a concentrator of stress. This condition prevents or difficults the homogeneous transference of the stress to regions farther from the photoelastic model, resulting in less relief of the stress on the peri-implant region. However, without additional studies with different methodologies would not be prudent to believe that the increase of the stress on overdentures would result in injury for the osseointegration in long term, since the chewing exerts an intermittent loading on the implant-supported prosthesis.

Lateral or tangential force applied to the right or left first molar may promote bascule motion over the implant, causing additional stress on the force application side. Even with the increased force, different stress concentration occurred in each side of the model, suggesting an unequal biomechanical behaviour of the mandibular overdenture.

The force intensity applied in each loading was similar for both model sides. However, other variables as little differences in volume, height and width of the alveolar ridge of the photoelastic model may be responsible by the different results, since the photoelastic model was obtained from a patient's alveolar arch impression, and these variables commonly occur in clinical situation. This assumption should be verified in studies using finite element analysis and clinical trials, since the retention and stability of the implant-supported overdenture are also significantly affected by number and distribution of the implants, and abutment types (26).

When the location of the implant was considered, previous work showed that the alveolar bone behavior was not influenced by the implant number and attachment types, and the use of two implants would be recommended in the canine region instead of four implants, when the locator attachment was considered better (27). Conversely, the amount of tissue stress on the posterior residual ridge increased when the number of abutments was reduced (28).

In addition, implant micromovement varied with the lateral force applied in bovine bone (5 N = 39 μm, and 30 N = 157 μm), and the bone type also influenced the amount of movement (29). Probably, the aforementioned studies did not consider that the stress levels could be also influenced by the different inter-implant distances and side of the photoelastic model submitted to loading (30), which seems to corroborate the results of this current study in relation to axial single force on the first molars. Another factor to be considered is that during the chewing there are forces of centric occlusion and lateral movements that could influence differently the intensity of the concentrated stresses. Moreover, laterality movements during tooth occlusion are different for each mandible side and depend or are influenced by the patient's normal or parafunctional habits.

It has been also alleged that the most common mechanical implant complications (incidence >15%) for overdentures are loosening of the retention, implant loss, and clip/attachment fracture (31). Finite element study comparing stress patterns induced by ball attachments to retain mandibular over dentures supported by one, two, or four dental implants showed that increasing the number of implants reduced the stress, but the implants receive greater stress concentration (32). Based on these affirmations, further studies should be developed to establish correlation between different mechanical failures in overdentures supported by four implants. A possible unequal alignment between the sides of the photoelastic model should be considered a hidden variable of the study. However, the photoelastic stress between different overdenture types would be considered as a limitation of the study.

CONCLUSION

Different stresses at inter-implant regions were shown in overdentures retained by four implants under different occlusal forces. Different inter-implant stresses and model posterior region were observed under axial single forces on the first right or left molar.

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