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RESEARCH ARTICLE

Photoelastic Stress Induced by Maxillary Denture on the Mandibular Denture and Overdentures Lined with Silicone-based Material

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ABSTRACT

Objectives: **This study evaluated the stress induced by maxillary denture over mandibular denture and overdentures lined with silicone-based material.**

Materials and Methods: **Three maxillary dentures, a mandibular denture, an overdenture supported by a single implant, and other supported by two implants were made for the following groups: MCD—Mandibular complete denture lined with silicone-based material, OSI—Overdenture lined with silicone-based material supported by single implant, and OTI—Overdenture lined with silicone-based material supported by two implants. The mandibular photoelastic model was axially loaded by the maxillary denture with intensities of 10, 20, or 30 kgf. Photoelastic analysis took place with the maxillary denture in maximum intercuspation with the mandibular prostheses.**

Results: **Photoelastic analysis showed that the 10 kgf load promoted in the mandibular denture greater stress along the photoelastic model mainly in the anterior region. Stress occurred around the single implant with higher intensity at the apex. Stress occurred between the two implants and no stress was shown along the implants and apices. For 20 kgf, stress occurred in the anterior region of the mandible denture; Higher stress is shown around the single implant and apex and smaller at the mandible left side. Stress occurred between the two implants, and few stress at the apex of the left implant. For 30 kgf, stress occurred in the anterior region of the mandible with more intensity on the left side. Stress is shown around and at the implant apex and both mandible frontal sides. Stress is shown between the two implants and little stress at the apex of the left implant.**

Conclusions: **The lined overdentures supported by single or two implants exhibited stress concentration in the implant region compared to lined mandibular denture showing stress along the mandible body. The stress in the overdentures occurred mainly around the single implant or between the two implants. The increase in load intensity had little influence on the increase in stress for the prostheses with lined bases.**

Clinical Relevance: **Intercuspation in the overdenture must have the same importance given to the vertical relationship to relieve the chewing effort in overdenture lined with silicone-based material.**

Keywords: Base liner, Implant, Overdenture, Photoelastic stress.

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1. Introduction

The conventional complete denture was for many years the only rehabilitative treatment option for toothless patients. However, this prosthetic treatment was not well accepted by most patients due to negative issues, such as a lack of better retention, stability, comfort, and safety for those who cannot adapt to complete dentures due to fear, anxiety, and depression [1].

The most critical factors currently alleged by users of rehabilitation with conventional complete dentures continue to be retention and stability, which are directly related to the anatomy of the residual alveolar ridge, condition of the mucosa, quantity, and quality of saliva, presence of neuromuscular disorders and level of tolerance of the patient.

With the advent of osseointegrated dental implants, it was possible to improve the quality of life of edentulous patients with conventional complete dentures. This modality of dental rehabilitation has improved oral efficiency, providing better retention, stability, and masticatory function to complete denture wearers. The acceptance of the dental implant allowed researchers to participate in the technical evolution of several implant systems, clinical treatment concepts, and laboratory techniques. Therefore, clinical results from increasing applications of advanced technology to improve implant fit have been promising [2].

The biomechanical function of implants is different from natural teeth and there is a significant correlation between trabecular bone volume and bone mineral density, with trabecular bone volume varying significantly between and within the jaws [3]. In addition, there is also the possibility of implant overload being transferred to the alveolar bone, exceeding the physiological limit, causing failures of the osseointegration and prosthetic rehabilitation.

Furthermore, vertical or oblique forces applied on overdenture with ball/O-ring or bar-clip fixation promote different values of stress on both implants [4]. Teeth move in the alveolar bone due to the resilience of the periodontal ligament. Despite limited alveolar bone restriction, implants can migrate in bone and the applied forces seem to stimulate bone thickening, which could explain why implants migrate without affecting stability [5]. Therefore, the balance in the distribution of masticatory forces through the prosthesis and from this to the implants and alveolar bone is of significant importance in maintaining the osseointegration of the implant [6].

There are basic concepts for the treatment of edentulous patients with dental implants when one or multiple implants are placed in the mandible with the intention of retaining overdentures. Although the treatments are clinically feasible and present satisfactory results, there are different advantages and disadvantages in each clinical case, which should lead to an indication of the treatment. Different treatments were used according to the clinical condition of the patient and the particular needs of each case. Previous studies suggested the use of overdenture supported by a single implant placed in the median region of the mandible with marked alveolar bone resorption or the impossibility of installing two or more implants in more posterior locations of the alveolar ridge. Therefore, mandibular single implant-retained overdenture may also be a viable treatment option for a specific group of patients [7].

Studies showed that a single implant is adequate for overdenture retention, showing greater success compared to overdentures supported by several implants, and a therapeutic alternative for elderly patients with discomfort and functional difficulties with the complete mandibular denture [8]–[10]. However, a single implant with an oxidized surface supporting an existing denture in a small group of patients with poor prosthetic adaptation may provide beneficial treatment with minimal financial expenses [11].

On the other hand, it has been claimed that overdentures supported by two implants would be the treatment of choice for the rehabilitation of edentulous mandibles [12]. However, the factors that may limit acceptance of the use of overdentures by patients continue to be surgery to place the implants and costs. On the other hand, treatment with single-implant retained overdentures has currently been accepted by patients when the alveolar bone quantity for mandible midline implant placement is smaller compared to rehabilitations with multiple implants [13].

Although studies have shown that overdentures retained by a single implant could achieve clinical results similar to those presented by several implants [10], age, gender, alveolar bone volume, and life quality do not seem to influence the primary stability of the implant, and no clear correlation has been established between the values of the stability quotient and the implant diameter [14], conditions still necessary today for the indication of the procedure.

The complex problems associated with implant-supported rehabilitations can be analyzed by photoelasticity, finite element, or extensometer. The photoelastic process is quite interesting as it allows observing the behavior and distribution of stresses occurring in the model. Therefore, the photoelastic analysis is an easy method to perform and is based on the principle of transforming internal mechanical stress produced in complex geometric structures through visible light patterns that indicate the location and magnitude of stresses.

Due to these characteristics, the method is used in Civil and Mechanical Engineering and applied in Dentistry in the division of Restorative Dentistry, Periodontics, Complete Denture and Removable Partial Prosthesis, since biomechanical factors also occur in the buccal environment. In this sense, photoelasticity has been used to analyze the stresses induced in implant-supported rehabilitations and alveolar bone support in studies that simulate the existing clinical mechanical conditions in this type of rehabilitation [15]–[17], as it is an analysis method that allows direct stresses visualization.

In this way, a relationship is established between the photoelastic model and the corresponding situations of the oral structures. As an example, the behavior of support structures adjacent to the root of the tooth is subjected to the action of stresses [18]. In this technique, the internal stress in the photoelastic model can be measured and photographed, while graphs and other schemes of force distribution from numerical data are required in other methods.

Research has analyzed stress in implant-supported mandibular overdentures with different methods. Based on these considerations, the aim of this study was to evaluate the photoelastic stress exerted by the maxillary complete denture on the mandibular complete denture and overdentures retained by one or two implants with bases lined with silicone-based material.

The hypothesis of the work was that the occlusal loads exerted by the maxillary complete denture would promote different stresses on the mandibular complete denture and overdentures supported by single or two implants.

2. Material and Method

The complete maxillary and mandibular denture bases, as well as the overdentures (single or two implants) bases, were traditionally made with thermo-activated acrylic resin (QC-20; Dentsplay, Petropolis, RJ, Brazil) on type IV dental stone casts (Durone; Dentsply, Petropolis, RJ, Brazil). The height of the dental stone molds (mandibular complete denture and overdentures) was increased without changing the original form of the alveolar ridge, in order to maintain the same mold position during the photoelastic analysis. Acrylic resin record bases (Vipi Cril; Vipi Dental Products, Pirassununga, SP, Brazil) and wax occlusal rims (Kota, Sao Paulo, SP, Brazil) were used for the maxillo-mandibular relationship in semi-adjustable articulator (A7 Plus; Bioart, Sao Carlos, SP, Brazil).

Artificial teeth arrangement (Vivadent PE and Orthosid PE; Ivoclar Vivadent, Barueri, SP, Brazil) was made in the maxillary and mandibular wax occlusal rims. O'ring attachment system supported by hexagon external implants with 4.1 mm in diameter and 3.85 mm in length and corresponding transfer system (Conexão Prosthetic Systems, Aruja, SP, Brazil) were placed on the mandibular stone models (Durone; Dentsplay).

An acrylic perforated guide for each overdenture support type (single or two implants) was made to aid the correct implant placement. The transfer system was screwed in analogs in the impression copy for model duplication using an acrylic resin customized open tray (Vipi Mold; Vipi), and the parallelism was checked with eyeliner.

The sets of prostheses were divided into 3 groups: CMD—Complete mandibular denture, OSI—Overdenture with a single implant placed in the middle line of the mandible, and OTI—Overdenture with two implants with a 20 mm distance between them placed in the anterior region of the mandible. The mandibular models of the OSI and OTI groups were molded with elastomeric material (Silibor; Classico Dental Products, Sao Paulo, SP, Brazil) proportioned, and manipulated in accordance with the manufacturer's recommendations, and used to transfer the implant position to the photoelastic model.

The photoelastic resin (Araldite; Huntsman, Sao Paulo, SP, Brazil) was prepared by mixing Gy-279 BR (reactive liquid derived from Bisfenol A) with HY 2964 (hardener derived from cyclo aliphatic amine) in the ratio of 100 to 48 parts, placed in the silicone mold with a syringe and stored in a closed glass container to prevent contamination.

According to the manufacturer's recommendation, the polymerization takes place at room temperature in 24 hours producing a transparent photoelastic model.

Following, the O´rings were captured and the capsules were positioned. The mandibular prosthesis bases were lined with silicone-based material (Sofreliner MS, Tokuyama Dental Corporation, Tokyo, Japan) 2 mm thick in order to simulate the oral mucosa [4] since the mandibular complete denture is characterized by the mucous support of the alveolar ridge.

The complete mandibular denture and overdentures were submitted to occlusal loads with intensities of 10, 20, or 30 kgf. The forces were exerted by the complete maxillary denture in maximum intercuspation with the mandibular prostheses [19]–[20].

The photoelastic stress analysis used was four-dimensional with the help of a circular polariscope (PTH-A-01 model; Federal University of Uberlandia, MG, Brazil) coupled to FD-717 digital camcorder (Sony; Orange, CA, USA) that allows viewing the fringes and recording the images with digital photographs. This method allows for analysis and comparison, making it possible to identify the stress magnitude, as well as to register the distance among the fringes and assess the stress concentration. This technique determines the fringes order (Fringes Program; MatLab, Federal University of Uberlandia) by the qualitative method using photographic records and the direction of the stress propagation. Therefore, the higher the fringe number (N), the greater the stress magnitude (T), and the closer the fringes, the higher the stress concentration [20].

The images were evaluated with the Adobe Photoshop 7.0 software, facilitating the visualization, localization, understanding, and interpretation of the stress intensity/concentration around the implants. Photographic images were used to confirm the results obtained by the polariscope with direct stress visualization on the photoelastic model during the occlusal loading. After prosthetic structure adaptation on the photoelastic model was verified the passivity level [21]. The white light spectrum showed typical coloring for the fringe orders: $N = 0$ (black); $N = 1$ (red/blue transition); and $N = 2$ (red/green transition). The red/green transition determined the fringes with whole orders.

3. Results

3.1. *Qualitative Analysis*

Fig. 1 shows the frontal view of the photoelastic models for the mandibular complete denture (MCD), overdenture supported by a single implant (OSI), and overdenture supported by two implants (OTI) submitted to occlusal loads exerted by the maxillary complete denture. For 10 kgf force, the stress occurred in the frontal region of the mandibular complete denture with higher intensity at the left side (Fig. 1A). Stress is shown around the single implant with higher intensity at the apex and left frontal region of the mandible (Fig. 1B). Stress is shown between the two implants, and no stress at the implant apexes (Fig. 1C).

Fig. 2 shows the frontal view of the photoelastic models for the mandibular complete denture (MCD), overdenture supported by a single implant (OSI), and overdenture supported by two implants (OTI) submitted to occlusal loads exerted by the maxillary complete denture. For 20 kgf force, stress occurred in the frontal region of the mandibular complete denture with more intensity on the left side (Fig. 2A). Stress is shown around the single implant with more intensity at the apex and left frontal region of the mandible (Fig. 2B). Stress is shown between the two implants, and small stress at the apex of the left implant (Fig. 2C).

Fig. 3 shows the front view of the photoelastic models for the mandibular complete denture (MCD), overdenture supported by a single implant (OSI), and overdenture supported by two implants (OTI) submitted to occlusal loads

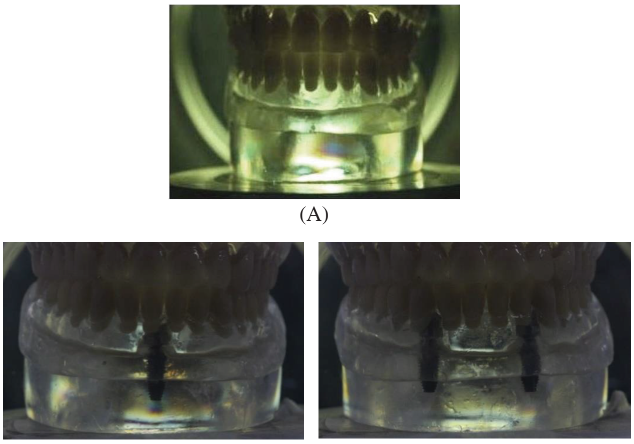

Fig. 1. (A) Mandibular complete denture. (B) Overdenture with a single implant. (C) Overdenture with two implants.

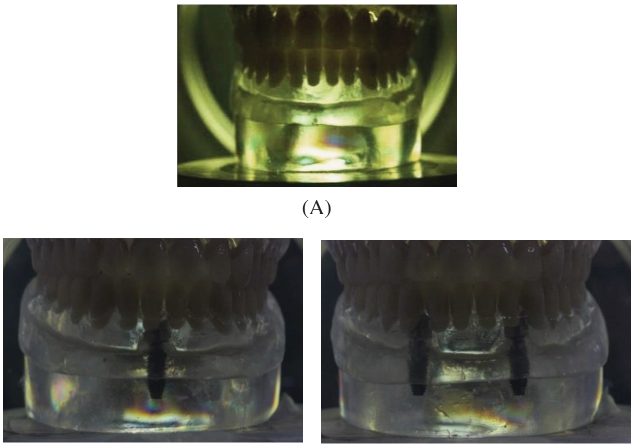

Fig. 2. (A) Mandibular complete denture. (B) Overdenture with a single implant. (C) Overdenture with two implants.

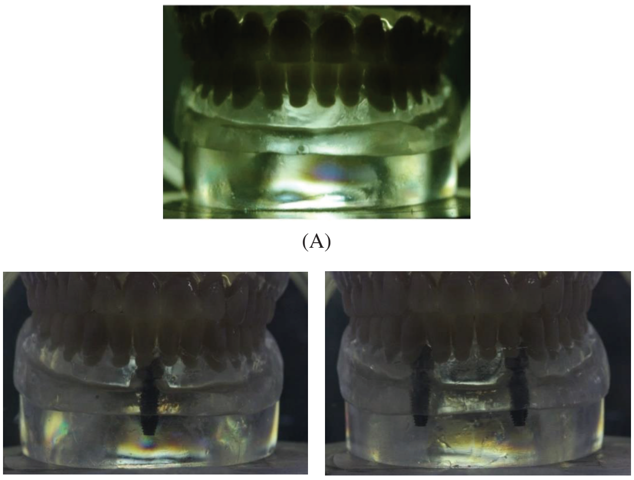

Fig. 3. (A) Mandibular complete denture. (B) Overdenture with a single implant. (C) Overdenture with two implants.

exerted by the maxillary complete denture. For 30 kgf load, stress occurred in the frontal region of the mandibular complete denture with more intensity on left side (Fig. 3A). Stress is shown around the implant and apex, and frontal region of the mandible (Fig. 3B). Stress is shown between the two implants, and small stress at the apex of the left implant (Fig. 3C).

4. Discussion

The biomechanical behavior of the prostheses occurs when submitted to occlusal loads exerted in maximum intercuspation [19]. This methodology applied to dental implants showed significant differences in fringe orders according to the way the implants are placed in the photoelastic resin model. In addition, the implant installation showed that pre-tapping and careful screwing down reduced the stresses. Tightening the screw forcefully, higher stress arose at the margin of the implant site. With minor horizontal load levels, higher stress concentration arose at the implant margin on the compression side, demonstrating the importance of the implant design and installation practice in the stress transfer to the surrounding alveolar bone [22].

On the other hand, the photoelastic method has some limitations, requiring also accurate reproduction of the original structure analyzed. The common clinical assumption is that the stress induced by the prosthesis should be widely distributed through the alveolar bone. This concept assumes that a greater implant number would decrease the force intensity supported by each implant, resulting in better stress distribution.

Based on this concept, the current study evaluated the photoelastic stress on mandibular complete denture and overdentures supported by single or two implants with bases lined with silicone-based material. Considering that the maxillary denture loading with the same intensity promoted different stresses on the different mandibular prosthesis types, the study hypothesis was not accepted.

For the force with 10 kgf intensity, the stress induced by the maxillary denture occurred in the frontal region of the mandibular denture, and on both sides of the mandible body (Fig. 1A). This result is not surprising, since it was expected that the stress concentration was similar for both sides of the mandible midline due to the morphological characteristics of the frontal region of the mandibular alveolar arch. In addition, the mandibular complete denture base is strongly characterized by the mucous support. This fact also indicates that the lining of the mandibular denture with silicone-based material absorbed and better distributed the stress along the ridge of the alveolar crest.

In the overdentures, the stress is concentrated around the single implant (Fig. 1B) or between the two implants (Fig. 1C). These results seem to indicate that the implant acts as a stress concentrator; therefore, difficulting the stress distribution to more posterior regions of the mandible.

Biomechanically, it is possible to believe that two implants would be safer for the maintenance of osseointegration in clinical use, since the stress occurred mainly between the two implants, relieving the stress in the apexes. On the other hand, the stress concentration around and at the apex of the single implant was significant in this support type and could compromise the osseointegration in the long term. However, a previous study alleged that cannot be concluded that bone loss, patient satisfaction, or a number of complications are significantly related to the number of implants supporting the overdenture [23].

A case report showed that overdentures supported by a single implant placed on the mandibular midline region is an appropriate treatment for compromised atrophic mandibles with the impossibility of placing implants on more distalized regions [7], and clinical studies also showed that overdenture with a single implant has been a viable treatment for edentulous patients [24]–[26].

However, the current study showed the possibility of single implant placement in specific clinic cases since the force intensity increase exerted by the maxillary complete denture did not increase significantly the stress concentration level. On the other hand, the stress promoted by the single implant would also indicate that a mandibular denture would be a more adequate option when there is not enough alveolar bone for two-implant placements since the mandibular denture is mucous supported favoring the stress distribution along the ridge of the alveolar crest.

In addition, it is also expected that the stress decreases in each implant when the force is exerted on various implants supporting overdentures. On this consensus, a previous study showed an unacceptably high failure rate (37.5%) for overdentures retained by a single implant [11], since the retention and stability of overdentures are significantly affected by the number and implant distribution and abutment type [27]. Another factor that could influence the stress concentration would be that different implant-abutment interfaces under an off-center load showed different stress concentrations, while one-piece and external-hex implants resulted in higher stress levels, and the centralized axial loads produced similar results [28].

An interesting study comparing the effect of two Branemark, IMZ, or ITI implants placed in the interforaminal region connected with a bar concluded that the method would be proper for the support of mandibular overdenture. However, the ITI implant appears to be the implant of choice for mandibular overdenture therapy, since only one operation is required [29]. Another study showed that ball attachments were the most common type of abutment for 2 implants; however, rehabilitations with 2 implants showed more complications and required more maintenance according to the connection type [30].

In general, the results showed that the maxillary denture occlusal loading promoted different stress levels in the different mandibular prosthesis types lined with silicone-based material. This study showed also that the more significant aspect of the stress distribution in mandibular prostheses would be the load exerted intensity. Different stress concentrations induced by the maxillary denture occurred in each prosthesis type. However, the aim of this study was not to assess the retention level of the mandibular prostheses related to stress concentration and types, since the mandibular denture loses mucosal support over time and the overdentures supported by implants are subject to loss of osseointegration.

A review evaluating different unsplinted attachment systems in 2-implant-retained mandibular overdentures resulted in better patient-reported outcomes in two-implant-retained mandibular overdentures [31]. This mentioned fact is considered as a limitation of the study, and other variables as different associations between attachment systems and number/implant types could be investigated.

5. Conclusion

Within the limitations of this in vitro study, it was possible to conclude that: The lined overdentures supported by single, or two implants exhibited stress concentration in the implant region compared to the lined mandibular denture showing stress along the mandible body. The stress in the overdentures occurred mainly around the single implant or between the two implants. The increase in load intensity had little influence on the increase in stress for the prostheses with lined bases.

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Conflict of Interest

Authors declare that they do not have any conflict of interest.

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