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Abstract. The use of photoelastic analysis contributes to the rehabilitation of patients with oral-sinus-nasal sequelae, which in turn affect important functions such as chewing, swallowing, and speech. The prosthetic rehabilitation with implant-retained dentures is a suitable treatment option. The purpose of this study was to verify, by using a photoelastic analysis, the stress distribution in implant-retained palatal obturator dentures (relined or not) associated with different attachment systems (O-ring, bar-clip, and bar-clip associated with distally placed O-rings). Two photoelastic models were obtained from an experimental maxillary cast presenting an oral-nasal communication. One model had two 13-mm length implants placed on the left region. A total of eight colorless maxillary obturators were fabricated and subsequently four of them were relined with soft silicone soft, and three had attachment systems associated. The assembly (model/attachment system/prosthesis) was positioned in a circular polariscope and a 100-N load was applied at 10 mm/s. The results showed that the denture relining influenced the distribution and amount of stress on the models. The O-ring group displayed the lowest stress levels, followed by bar-clip system associated with distally placed O-rings and bar-clip groups. [DOI: 10.1117/1.JBO.17.6.061203]

Keywords: dental implant; maxillectomy; photoelastic; denture liners.

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1 Introduction

Partial maxillectomy is usually indicated to treat cases of trauma, malign and benign tumors, accidents, congenital, and acquired defects.[1–4] However, esthetic complications as a result of these treatments affect the chewing, speech, swallowing, taste, and olfaction functions. In addition, secretion from the nasal cavity may contact the oral cavity.[5–8]

The obturator denture is a common treatment of choice due to the complexity of maxillary surgical reconstruction and uncertain reestablishment of the deficient functions. The denture seals the oral and nasal cavities, recovers both chewing and speech functions, provides labial support, decreases salivation, and restores the esthetics.[9–11]

The stability and retention of maxillofacial obturator dentures is a challenge for the majority of patients and depends on the defect's size and configuration, and the remaining contour of the palate and soft tissues.[6,10,]

Photoelastic analysis is suitable in the biomedical field, through visual analysis by specific software, to analyze the resulting stress related to the applied loads to verify if these stresses can cause failures in the artificial rehabilitation as in this study with dentals implants.[12]

Different methods have been applied to investigate the stress distribution on prosthetic rehabilitations. The stress pattern on maxillary bone surrounding implants and attachment systems can be obtained by photoelasticity, finite element analysis, and strain gauges measurement.[12–18]

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The photoelasticity method has been widely applied in dentistry and allows direct observation of stress distribution on structures due to the ability of some colorless materials to generate colored pattern, also known as isochromatic fringes, during loading with polarized light.[6,12,17]

The aim of this photoelastic analysis was to evaluate the stress distribution on conventional and implant-retained palatal obturator dentures with different attachment systems (O-rings, bar-clips and bar-clip systems associated to distally placed O-rings) associated or not with reline material (soft silicone).

2 Material and Method

An experimental maxillary model with oral-sinus-nasal communication was used to reproduce two similar laboratorial models obtained with type IV dental stone (Durone, Dentsply Ind. Com. Ltda., Petrópolis, Rio de Janeiro, Brazil). The laboratorial models were duplicated with silicone to obtain the photoelastic model I (without implants).

Then, two titanium implants with 3.75 mm in diameter and 13 mm in length and 4.1 mm of platform (Neodent, Curitiba, Paraná, Brazil) were fixed in the other model in the canine and first molar regions using a parallelometer. Squared transfer copings were attached to the implants and splinted with a dental floss scaffold covered by self-polymerized acrylic resin[19–21] (Duralay Reliance Dental, MFG Co Worth, IC, USA) to obtain the photoelastic model II.

After silicone molds fabrication, the PL-2 photoelastic resin was manipulated according to the manufacturer's instructions (Vishay Measurements Group, Inc Raleigh, N.C., USA), and poured on the molds and stored in a chamber under 40 pounds

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of pressure for 24 h to avoid bubbles during resin polymerization. Then, the models were obtained.

The laboratorial models (with and without implants) were used to fabricate the obturator dentures. A total of eight dentures were fabricated. Then, four obturator dentures were fitted to the photoelastic models with and without attachment systems and the other four dentures were directly relined with soft silicone (Sofreliner, Tokuyama Dental Corporation, Tokyo, Japan) in the region of oral-sinus-nasal communication under a load of 12.5 N and immersed in distilled water at 37 ± 2°C until the material set as recommended by the manufacturer[22] and then fitted to the photoelastic models.[20,21]

A conventional obturator denture (mucosa-supported) was fabricated for group I (with no attachment system), while the other three obturator dentures were associated with different attachment systems: bar-clip associated to distally placed O-rings (group II), O-ring (group III), and bar-clip (group IV) (Neodent, Curitiba, Paraná, Brazil). The groups V, VI, VII, and VIII followed the same sequence but the dentures were relined with Sofreliner silicone.[21] The obturator dentures were fabricated with colorless heat-polymerized resin and artificial teeth with 20 deg of cusp inclination.[20,21] The welding technique with burner (NP Solder, New Delhi, India) was used to obtain the bar-clip attachment system and to avoid stress in the photoelastic model II. Casting procedures can generate stress and fringes that would affect the results. In addition, the bars were positioned 2 mm from the alveolar crest to mimic a clinical condition.

The obturator dentures were adapted to the photoelastic models with and without attachment systems. Each assembly (prosthesis/photoelastic model with and without attachment systems) was positioned in a circular polariscope adapted to a universal testing machine (EMIC DL 3000, São Paulo, SP, Brazil). The assembly was placed into a glass with mineral oil to minimize the refraction of white light,[20,21,23] thereby, facilitating the photoelastic observation (Photoflood 500 W-GE Lighting General Eletric, Cleverland, Ohio, USA) that uniformly focuses on the recipient with the photoelastic model. Thus, a load of 100 N at 10 mm/s was applied in the first molar region of each obturator denture. Stresses were photographically recorded. The images were recorded by a digital camera (Nikon D80, Nikon Corporation, Chitoda-Ku, Tokyo, Japan) and transferred to a computer for qualitative analysis by using image software (ADOBE Photoshop CS version 8.0.1, Adobe Systems, San Jose, California, USA).[16]

Photoelastic stress analysis was used as a method of stress investigation. Photoelasticity is based on the phenomenon that certain birefringent materials, when loaded and observed under polarized white light, display colored patterns or fringes.[24,25]

"Isochromatic fringe" is the name given to each complete band of colors produced in this manner. The total number of isochromatic fringes observed is directly proportional to the stress in the photoelastic resin model and areas of high stress concentration are represented by fringes that close to each other.[24,25]

"Fringe order" is the numerical value assigned to an observed fringe based on its position in the color sequence. The higher the number of fringes, the greater the stress order. The tint of passage is a sharp dividing zone between red and blue in the first-order fringe, red and green in the second-order fringe, and pink and green in the third- and fourth-order fringes. The first tint of passage corresponds to order one fringe, the second tint of passage to order two fringe, and etc.[24,25]

3 Results

The results were based on the photographs of stress patterns in the photoelastic models according to fringes orders after loading.

In the photoelastic model without implants (Fig. 1), photoelastic fringes were observed in the molar region where the load was applied both in the model without [Fig. 1(a)] and with [Fig. 1(b)] denture relining.

In the bar-clip associated with the distally placed O-rings model (Fig. 2), photoelastic fringes spread to the apical region of the implant placed in the first molar and in the region between the implants were observed. However, the rebased model [Fig. 2(b)] displayed lower stress on the implant apex (with predominant first order fringes—red) when compared to the non-relined model in which second order fringes were noted (red–green) [Fig. 2(a)].

In relation to the model containing the O-ring system (Fig. 3), fringes were observed in the apex of the implant in the first premolar region and in small amount in the anterior region of the model without denture relining [Fig. 3(a)]. The relined model exhibited first order fringes [Fig. 3(b)] while the non-relined model displayed second order fringes.

The bar-clip model (Fig. 4) also exhibited fringes in implant apex area (first order fringes) and in the anterior cervical region of the first premolar implant (second order fringes) [Fig. 4(a)]. In the rebased model stress there was a decrease (first order fringes) [Fig. 4(b)].

4 Discussion

Although convention dentures have been used as a treatment of choice to rehabilitated maxilectomized patients, loss of denture's support, retention, and stability are common problems.[26]

Since 1970 when the concept of osseointegration was developed by Branemark and colleagues, the implants have been successfully used to retain fixed and removable dentures both intra- and extra-orally. When associated with attachment systems, removable dentures provide improved stability and support.[27]

The literature is still scarce in comparing the effect of such attachment system on the retention, maintenance, and longevity of maxillofacial prosthesis.[28]

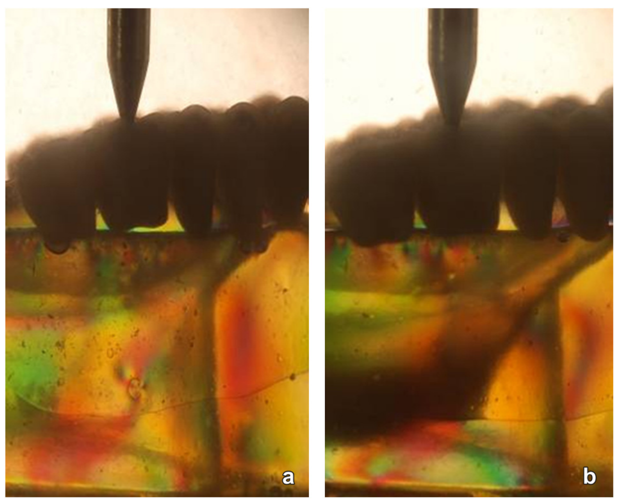

Fig. 1 Stress distribution on the convention denture model; opposite side to the oro-nasal communication (a) without, and (b) with soft relining material.

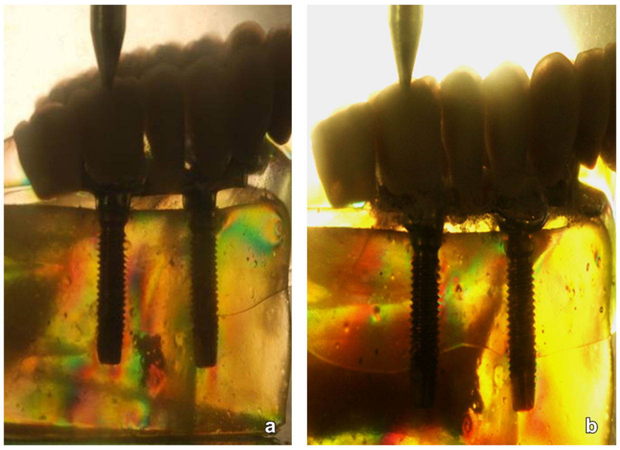

Fig. 2 Stress distribution on the bar-clip system associated to distally placed O-rings model (a) without, and (b) with soft relining material.

This study examined the stress distribution in eight obturator dentures using three different attachment systems (O-ring, bar-clip associated to distally placed O-rings, and bar-clip), without (IA, IIA, IIIA, and IVA) and with (IB, IIB, IIIB, and IVB) denture reline. Models were loaded with a 100-N load on the first molar region and the photoelastic fringes demonstrated the stress into the simulated bone material adjacent or not to the implants.

In relation to the stress distribution among the different attachment systems, the bar-clip system showed the highest stress, followed by the bar-clip associated to distally placed O-rings and O-ring system (Figs. 2 to 4).

Kenny and Richards[17] evaluating implant-supported overdentures through the method of photoelasticity observed that the O-ring system transferred less stress to the implants when compared with the bar-clip system; similar results were reported by Tokuhisa et al.[29] that evaluating three attachment systems (O-ring, bar-clip, and magnets), showed that the O-ring system proved to be advantageous over other systems, reducing stress and promoting good stability. The female component of the O-ring system may be the driven force toward the stress reduction. The rubber from the female component absorbs and distributes the stress more homogeneously, which corroborates with the outcomes of the present study.

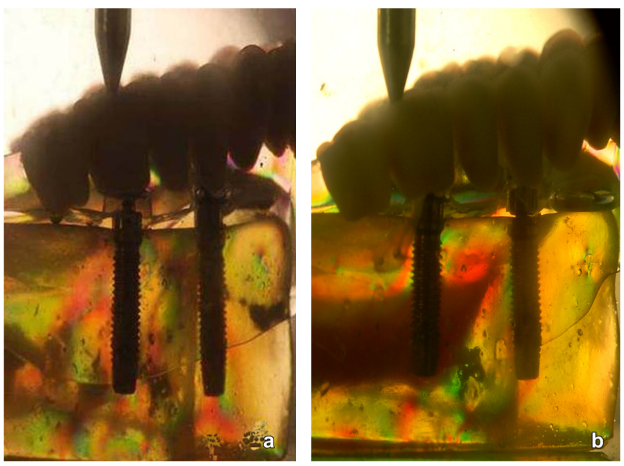

Fig. 3 Stress distribution on the O-ring model (a) without and (b) with soft relining material.

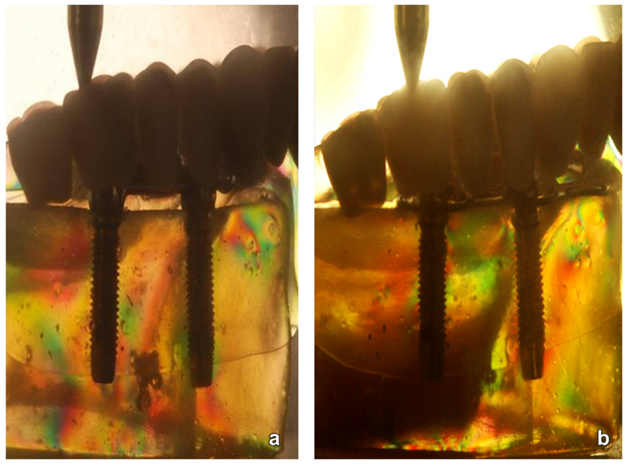

Fig. 4 Stress distribution on the bar-clip model (a) without, and (b) with soft relining material.

Celik and Uludag[14] evaluated four attachment systems on implant-retained overdentures by photoelastic models and concluded that the bar-clip system associated with two distally placed O-rings produced lower stress values when compared to other systems (O-ring). Therefore, the splinting of the implants favored the stress transfer. The authors reported that the use of distal O-rings in the bar clip system creates a fulcrum line in the most distal portion, promoting denture rotation around this fulcrum anteroposteriorly, and due to the resilience of the O-ring rubber, the magnitude of stress in the implant is reduced. It is in agreement with the results of the present study which shows a rotation around the fulcrum, but in our case it was in the laterolateral direction.

In the present study, the use of lining material to rebase the obturator denture reduced the stress levels in all groups. According to Prado Ribeiro et al.[21] the effectiveness of lining materials is attributed to its viscoelastic properties and is mainly related to the flexibility of the material, which improves absorption and redistribution of the energy generated by occlusal forces.[30] It is known that the lower the hardness of such material, the greater the capacity to absorb and distribute energy produced by the forces of mastication during denture function.[31] Being the resilient soft liner used average; there was a slight decrease of stress as compared with the only prosthesis made with acrylic resin. Oliveira et al.[32] also reported the importance of resilient materials to absorb functional efforts.

We observed in this study that it is very important to indicate the most suitable treatment option in patients with oral communication and that the presence of soft liners decreases the stress on the simulated bone material after loading application on the palatal obturators, but use only the acrylic resin as a base so these prostheses do not become frustrating.

5 Conclusion

Based on these results, we conclude that the relining material with soft prosthesis reduced and optimized stress distribution on the supporting bone tissue, despite the presence of implants and attachment systems in which first order fringes were predominate. The O-ring system displayed the lowest stress values in the implants and supporting tissue, followed by the bar-clip system associated to distally placed O-ring, and bar-clip system.

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