Stress analysis in oral obturator prostheses, part II: photoelastic imaging

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Abstract. In part I of the study, two attachment systems [O-ring; bar-clip (BC)] were used, and the system with three individualized O-rings provided the lowest stress on the implants and the support tissues. Therefore, the aim of this study was to assess the stress distribution, through the photoelastic method, on implant-retained palatal obturator prostheses associated with different attachment systems: BOC—splinted implants with a bar connected to two centrally placed O-rings, and BOD—splinted implants with a BC connected to two distally placed O-rings (cantilever). One photoelastic model of the maxilla with oral-sinus-nasal communication with three parallel implants was fabricated. Afterward, two implant-retained palatal obturator prostheses with the two attachment systems described above were constructed. Each assembly was positioned in a circular polariscope and a 100-N axial load was applied in three different regions with implants by using a universal testing machine. The results were obtained through photograph record analysis of stress. The BOD system exhibited the highest stress concentration, followed by the BOC system. The O-ring, centrally placed on the bar, allows higher mobility of the prostheses and homogeneously distributes the stress to the region of the alveolar ridge and implants. It can be concluded that the use of implants with O-rings, isolated or connected with a bar, to rehabilitate maxillectomized patients allows higher prosthesis mobility and homogeneously distributes the stress to the alveolar ridge region, which may result in greater chewing stress distribution to implants and bone tissue. The clinical implication of the augmented bone support loss after maxillectomy is the increase of stress in the attachment systems and, consequently, a higher tendency for displacement of the prosthesis. © 2014 Society of Photo-Optical Instrumentation Engineers (SPIE) [DOI: 10.1117/1.JBO.19.6.066012]

Keywords: photoelastic imaging; dental implant; palatal obturators; maxillofacial prosthesis.

Paper 140219R received Apr. 5, 2014; revised manuscript received May 29, 2014; accepted for publication Jun. 4, 2014; published online Jun. 27, 2014.

1 Introduction

Maxillary defects may lead to serious injury in anatomical structures that have a role as denture-supporting area in edentulous patients, decreasing retention and stability of prostheses,[1–3] and drastically decreasing the quality of life of its users.[1,4–10] Therefore, the palatal obturator prostheses became an important treatment choice for the patient's rehabilitation process.[1,3,8,10–12]

However, the stability and the retention of those prostheses are a challenge and require distinctive treatment planning.[1,2] Also, it is known that maxillary defects jeopardize the obturator prostheses biomechanics because of the presence of leverage forces that drastically increase stress on bone support during chewing.[1,3,8,13]

It is known that the mechanism of stress distribution to the implants and the bone tissue is a critical issue that affects implant success or failure, because that is how the mechanical stress is transferred from the implant to the bone. Currently, photoelasticity is one of the most used experimental techniques to study the behavior of stress distribution in implantodontology.[6]

Many studies have used information and data extracted from experimental, analytical, and computational models, among them the photoelastic method, with the purpose of analyzing the stress distribution on the implants and the support tissues. The photoelastic analysis of stress was introduced in dentistry by Noonan in 1949. After this work, the photoelastic method has received increased attention in the field of restorative dentistry.[14] This technique is based on the optical property that certain transparent plastics exhibit when submitted to a state of stress/strain, resulting in changes of the refractive index (or optical anisotropy) and, consequently, in changes of color.[14–21]

Currently, the photoelastic method has been used to assess the stress in implant-supported prostheses and the bone tissue by several studies,[1,3,4,14–25] which simulated the mechanical-clinical situations presented in this type of rehabilitation. These situations include: fit and misfit framework, description of the sequence of fringes formation, size and location of misfit at the implant-abutment interface, overdenture attachment system, implants placed in the posterior edentulous jaw (fabricated with photoelastic material), parallel and tilted implants, attachment systems of facial prosthesis, connection system of cylindrical implant, and different types of connectors in implant-tooth union, among others.[15,16,18,20–22]

So, the use of attachment systems associated with implants is a new alternative to rehabilitate maxillectomized patients since it provides higher retention and stability of the prostheses[1,3,6,23–33] and improves the patient's assurance and confidence.[1,3,6,8,9,11–13]

Based on the results of these two studies,[1,19] an interest arose in how these systems would work in biomechanical combination (BOC and BOD systems) in prostheses supported by three parallel implants. The hypothesis of this study is that both attachment systems provide similar stress distribution on the implants and the support tissues, regardless of the location.

2 Materials and Methods

An experimental maxillary model with oral-sinus-nasal communication was used to reproduce one laboratorial model confectioned with type IV dental stone (Durone, Dentsply Ind Com Ltda., Petrópolis, Rio de Janeiro, Brazil). Through this model, the photoelastic model with implants was obtained. For this, three implant analogues (Neodent, Curitiba, Paraná, Brazil) were inserted in the laboratorial model, which had three perforations that were parallel to each other (regions of upper incisive, canine, and first molar). After perforation and insertion using a paralelometer, the implant analogues were fixed with Duralay acrylic resin (Duralay Reliance Dental MFG Co. Worth, Illinois), so that the analogue platform remains at the same level of the alveolar ridge.

Squared transfer posts (Neodent, Curitiba, Paraná, Brazil) were placed and screwed to the analogues. These transfers were connected to each other with dental floss and Duralay acrylic resin. The laboratorial model with placed transfers was duplicated with fluid silicon (Sapeca Artesanato, Bauru, São Paulo, Brazil) in order to obtain its negative impression. After the silicon had set, the transfer screws were removed, obtaining a negative impression with placed transfers. External hexagon implants with 3.75-mm diameters and 13-mm lengths (Neodent, Curitiba, Paraná, Brazil) were attached and screwed to these transfers. At this moment, the correct position of the implants to transfers was checked and the negative impression was filled with PL-2 photoelastic resin (Vishay Measurements Group Inc. Raleigh, North Carolina, USA), manipulated and tooled according to the manufacturer's instructions. Later, the assembly (negative impression + photoelastic resin) was stored in a chamber under 40 pounds of pressure to avoid bubbles during resin polymerization. After the PL-2 resin polymerization, the model was carefully separated from the negative impression and sanding and polishing procedures were performed with fine grit sandpapers (600, 800, 1200, 1500).[1,3,9]

Concerning the models, a photoelastic model was confectioned (standardized measures) for each type of implant and prosthetic restoration (crowns with standard heights). Several samples were not made because the model response (fringe patterns), regarding the type of applied load, will always be the same within the methodology that was used.

The laboratorial model with implant analogues was used to fabricate the obturator prostheses. Two prostheses were fabricated using different attachment systems: BOC—splinted implants with a bar connected to two centrally placed O-rings, and BOD—splinted implants with a bar-clip (BC) connected to two distally placed O-rings (cantilever).

The obturator prostheses were fabricated with artificial teeth with 20 deg of cusp inclination (Trilux Vipi Produtos Odontológicos, Pirassununga, São Paulo, Brazil) and colorless heat-polymerized resin (Vipi Produtos Odontológicos, Pirassununga, São Paulo, Brazil) so as to not influence the results of the images obtained during the method application.[1]

The obturator prostheses were adapted to the photoelastic models with the attachment system. Each assembly (photoelastic model/attachment system/prostheses) was positioned in a circular polariscope into a glass with mineral oil, to minimize the refraction of white light (Photoflood 500 WGE Lighting General Electric, Cleveland, Ohio) that uniformly focuses on the recipient with the photoelastic model. Thus, a 100-N load at 10 mm/s was applied on the opposite side of the communication in the region of incisive, canine, and first molar, by using a universal testing machine (EMIC-DL 3000, São Paulo, São Paulo, Brazil). The images were recorded by a digital camera (Nikon D80, Nikon Corporation, ChitodaKu, Tokyo, Japan) and transferred to a computer for qualitative analysis by Adobe Photoshop CS version 8.0.1 software (Adobe Systems, San Jose, Califórnia).[1,3,9]

Photographic records of all models were analyzed to verify the direction and intensity of stress based on qualitative analysis. That analysis consisted of the higher the N (fringes order) and the number of fringes, the greater the stress intensity. Additionally, the closer the fringes are to each other, the higher the stress concentration is.[1]

The photoelasticity has some limitations as does any laboratory study. The qualitative photoelastic analysis was used in the present study. Therefore, it is not possible to quantify the stress magnitude and the results usually do not present statistical analysis.

The isochromatic fringes are described by their concentration and intensity (qualitative analysis), depending upon the order (N) and number of fringes. Fringes that are closer to each other present higher stress concentrations.

The stress distribution is observed through isochromatic fringes, whose order is counted based on fringe transition:[15,34,35]

Fringe order $N = 0$ (black zone)

Fringe order $N = 1$ (red-blue transition)–low intensity

Fringe order $N = 2$ (red-green transition)–median intensity

Fringe order $N = 3$ (green-pink transition)–high intensity

To facilitate, the analysis was divided according to the number of fringes with high intensity (green-pink transition) and to the stress distribution area. All images were evaluated by the same person.[1,3,9]

3 Results

Based on the images, a greater number of high stress fringes was observed in the BOD system, followed by the BOC system (Table 1). Additionally, it was possible to observe that the association of the O-ring (centrally or distally placed on the bar) with

Table 1 Number of photoelastic fringes with high intensity (green-pink transition) according to the crowns in which the load was applied.

Attachment system	Axial load		
	Crown		
	16	13	11
BOC	4	4	6
BOD	5	5	5

Fig. 1 Stress distribution in the model with splinted implants with a bar connected to centrally placed O-rings (BOC).

the bar allows lower stress to the support tissues than the isolated BC system, described in part I of the study.[1]

In the models with implants, regardless of the attachment system, a higher number of fringes was located at the apical region of the implant to which the load was applied (Figs. 1 and 2).

4 Discussion

The hypothesis that both attachment systems provide similar stress distribution on the implants and the support tissues, regardless their location, was not accepted, since the BOD system exhibited higher stress concentration than the BOC system (Table 1).

The results showed a greater number of high stress fringes on the BC system, followed by the BOD system, the BOC system, the O-ring system (OR), and the conventional obturator prostheses (without implants), respectively (Table 1; Pesqueira et al.[1]).

Despite the obturator prostheses without implants having exhibited the lowest stress values, as observed in part I of the study,[1] it is known that the maxillary defects jeopardize the obturator prostheses biomechanics, drastically decreasing their stability and retention during chewing.[1–8,13]

Therefore, the use of implants as support components of prostheses to partial or total maxillectomized patients' rehabilitation has been growing, since it provides higher retention and stability of the prostheses, reducing their movement.[1–4,9,10,13] However, a distinctive planning is determinant for clinical success and has to be based on the patient's specific anatomic conditions,[8] implants, and attachment systems to be selected.[23–33]

According to our study, the attachment system directly influences stress distribution to the implants and the support tissue, and each one has different stress values.

The knowledge of stress transmitted by the assembly—prostheses, attachment system, and implant—to the bone tissue is essential for its correct biomechanical work. The excess of stress transmitted to the implants and attachment systems may cause system fatigue and consequent fracture on the implant components and overload them and the bone tissue, which would also result in a possible loss of osseointegration, causing prostheses instability and retention loss.[1,3,9]

In part I of the study,[1] two attachment systems (O-ring; BC) were used. Also, the system with three individualized O-rings provided the lowest stress on the implants and the support tissues. Additionally, in another study, Pesqueira et al.[19] assessed the stress distribution through the photoelastic method, on implant-retained palatal obturator prostheses over two parallel implants and one tilted using four different attachment systems (three individualized O-rings, OR; bar clip, BC; O-rings positioned at the center of the bar, BOC; O-rings positioned in distal cantilever, BOD) and conventional obturator prostheses (without implants). The authors concluded that the BOC and the BOD systems presented intermediate stress values when compared with the BC and the OR systems.

In our study, the use of O-rings connected with a bar (Fig. 1) or with a BC (Fig. 2) decreased stress values, when comparing it to an isolated BC system (part I of the study[1]). These results corroborate with some studies,[14,18,19] which consider that the attachment system with a bar connected to distally placed O-rings produced lower stress values than other systems. Studies[13,27,29,30,31] justify that the O-ring attachment systems homogeneously distribute the stress over the bar and have great resilience. In our opinion, the BOD system exhibited higher stress values than the BOC system because the cantilever extension allows higher leverage in that region which, consequently, increases the stress. In addition, the clip presence in the center of the bar also adds stress to the system.

It is important to note that several factors must be considered when selecting the attachment system: the available surface area, the need for prostheses support, the retention level to be obtained, and the stress distribution to the implants and the bone tissue.[11,23] The differences among them are in material type, components' resilience and shape, and type of association between attachment systems, implants, and remaining teeth. Each one of the attachment systems has different biomechanics.[13,28]

The clinical implication of the augmented bone support loss after maxillectomy is the increase of stress in the attachment systems and, consequently, a higher tendency for the prosthesis's displacement. Concerning the limitations of this study, the photoelastic analysis has some restrictions because it is an indirect technique that requires models of similar

Fig. 2 Stress distribution in the model with splinted implants with a bar connected to distally placed O-rings (cantilever) (BOD).

reproduction to oral structures so they can be compared. The limit of external force to be applied must be considered. That force should not exceed the resistance threshold of the photoelastic material, which could alter the results or cause its break. Additionally, although some materials used for making experimental models present an elastic modulus similar to the bone tissues, they cannot emulate actual models, lacking differentiation between cortical and trabelular bone, for example, which alters the magnitude of the stress produced by loading. However, the stress location and magnitude are slightly modified when compared to real models.[15,18,22]

5 Conclusion

We conclude that:

- The attachment system directly influenced stress distribution of implant-retained palatal obturator prostheses.

- The O-rings, centrally placed on the bar, homogeneously distribute the stress when compared with a BC connected to distally placed O-rings (cantilever).

- When using the implants to rehabilitate maxillectomized patients, the O-rings—isolated or connected with a bar–allow higher prostheses mobility and homogeneously distribute the stress to the alveolar ridge region, which may result in greater chewing stress distribution to the implants and the bone tissue.

References

1. A. A. Pesqueira et al., "Stress analysis in oral obturator prostheses: imaging photoelastic," *J. Biomed. Opt.* **18**(6), 061203 (2013).
2. S. M. Ortegon, J. W. Martin, and J. S. Lewin, "A hollow delayed surgical obturator for a bilateral subtotal maxillectomy patient clinical report," *J. Prosthet. Dent.* **99**(1), 14–18 (2008).
3. M. C. Goiato et al., "Photoelastic analysis to compare implant-retained and conventional obturator dentures," *J. Biomed. Opt.* **17**(6), 061203 (2012).
4. M. C. Goiato et al., "Photoelastic analysis of stress distribution in different retention systems for facial prosthesis," *J. Craniofac. Surg.* **20**(3), 757–761 (2009).
5. O. C. Dilek and E. Tezulas, "A mini implant-supported obturator application in a patient with partial maxillectomy due to tumor: case report," *Oral Surg. Oral Pathol. Oral Radiol. Endod.* **103**(3), e6–e10 (2007).
6. B. Bagis, E. Aydoğan, and U. Hasanreisoğlu, "Rehabilitation of a congenital palatal defect with a modified technique: a case report," *Cases J.* **1**(1), 39 (2008).
7. M. C. Goiato et al., "Retention systems to implant-supported craniofacial prostheses," *J. Craniofac. Surg.* **20**(3), 889–891 (2009).
8. E. Bedrossian and P. I. Brånemark, "Systematic treatment planning protocol for patients with maxillofacial defects: avoiding living a life of seclusion and depression," *Atlas Oral Maxillofac. Surg. Clin. North Am.* **20**(1), 135–158 (2012).
9. C. T. Nguyen, C. F. Driscoll, and D. P. Coletti, "Reconstruction of a maxillectomy patient with an osteocutaneous flap and implant-retained fixed dental prosthesis: a clinical report," *J. Prosthet. Dent.* **105**(5), 292–295 (2011).
10. M. C. Goiato et al., "Patient satisfaction with maxillofacial prosthesis. Literature review," *J. Plast. Reconstr. Aesthet. Surg.* **62**(2), 175–180 (2009).
11. B. Lethaus et al., "Surgical and prosthetic reconsiderations in patients with maxillectomy," *J. Oral. Rehabil.* **37**(2), 138–142 (2010).
12. J. Irish et al., "Quality of life in patients with maxillectomy prostheses," *Head Neck.* **31**(6), 813–821 (2009).
13. F. Keyf, "Obturator prostheses for hemimaxillectomy patients," *J. Oral. Rehabil.* **28**(9), 821–829 (2001).
14. M. Sevimay et al., "Three-dimensional finite element analysis of the effect of different bone quality on stress distribution in an implant-supported crown," *J. Prosthet. Dent.* **93**(3), 227–234 (2005).
15. A. A. Caputo, "Stress analysis," Seminário de Biomateriais, Science Section. Abstracts, UCLA School of Dentistry, Los Angeles (1993).
16. K. Akça, M. I. Fanuscu, and A. A. Caputo, "Effect of compromised cortical bone on implant load distribution," *J. Prosthodont.* **17**(8), 616–620 (2008).
17. R. Tiossi et al., "Comparison of the correlation of photoelasticity and digital imaging to characterize the load transfer of implant-supported restorations," *J. Prosthet. Dent.*, pii: S0022-3913(13)00372-7, [Epub ahead of print] (2014).
18. A. Pesqueira et al., "The use of stress analysis methods to evaluate the biomechanics of oral rehabilitation with implants," *J. Oral Implantol.* **40**(2), 217–228 (2014).
19. A. A. Pesqueira et al., "Stress analysis in oral obturator prostheses over parallel and tilted implants: photoelastic imaging," *J. Biomed. Opt.* **18**(10), 106009 (2013).
20. S. J. Sadowsky and A. A. Caputo, "Effect of anchorage systems and extension base contact on load transfer with mandibular implant-retained overdentures," *J. Prosthet. Dent.* **84**(3), 327–334 (2000).
21. M. C. Goiato et al., "Methods used for assessing stresses in buccomaxillary prostheses: photoelasticity, finite element technique, and extensometry," *J. Craniofac. Surg.* **20**(2), 561–564 (2009).
22. K. T. Ochiai et al., "Photoelastic stress analysis of implant-tooth connected prostheses with segmented and no segmented abutments," *J. Prosthet. Dent.* **89**(5), 495–502 (2003).
23. V. A. Barão et al., "Finite element analysis to compare complete denture and implant-retained overdentures with different attachment systems," *J. Craniofac. Surg.* **20**(4), 1066–1071 (2009).
24. G. Meniccuci et al., "Mandibular implant-retained overdenture: finite element analysis of two anchorage systems," *Int. J. Oral Maxillofac. Implants.* **13**(3), 369–376 (1998).
25. J. A. Porter, V. C. Petropoulos, and J. B. Brunski, "Comparison of load distribution for implant overdenture atachments," *Int. J. Oral Maxillofac. Implants.* **17**(5), 651–662 (2002).
26. M. C. Cehreli et al., "A systematic review of marginal bone loss around implants retaining or supporting overdentures," *Int. J. Oral Maxillofac. Implants.* **25**(2), 266–277 (2010).
27. G. Celik and B. Uludag, "Photoelastic stress analysis of various retention mechanisms on 3-implant-retained mandibular overdentures," *J. Prosthe. Dent.* **97**(4), 229–235 (2007).
28. R. Kenney and M. W. Richards, "Photoelastic stress patterns produced by implant-retained overdentures," *J. Prosthet. Dent.* **80**(5), 559–564 (1998).
29. V. A. Barão et al., "Effect of different mucosa thickness and resiliency on stress distribution of implant-retained overdentures-2D FEA," *Comput. Methods Programs Biomed.* **92**(2), 213–223 (2008).
30. K. M. Lyons, J. Beumer, and A. A. Caputo, "Abutment load transfer by removable partial denture obturator frameworks in different acquired maxillary defects," *J. Prosthet. Dent.* **94**(3), 281–288 (2005).
31. Z. Ben-Ur, C. Gorfil, and A. Shifman, "Anterior implant-supported overdentures," *Quintessence Int.* **27**(9), 603–606 (1996).
32. M. Tokuhisa, Y. Matsushita, and K. Koyano, "In vitro study of mandibular implant overdenture retained with ball, magnet, or bar attachments: comparison of load transfer and denture stability," *Int. J. Prosthodont.* **16**(2), 128–134 (2003).
33. M. Daas et al., "A complete finite element model of a mandibular implant-retained overdenture with two implants: comparison between rigid and resilient attachment configurations," *Med. Eng. Phys.* **30**(2), 218–225 (2008).
34. J. F. Brodsky, A. A. Caputo, and L. L. Furstman, "Root tipping: a photoelastic-histopathologic correlation," *Am. J. Orthod.* **67**(1), 1–10 (1975).

35. R. A. Markarian et al., "Stress distribution after installation of fixed frameworks with marginal gaps over angled and parallel implants: a photoelastic analysis," *J. Prosthodont.* **16**(2), 117–122 (2007).

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