COMPARATIVE ANALYSIS OF STRESS DISTRIBUTION IN DIFFERENT PROSTHETIC SOLUTIONS FOR KENNEDY CLASS I BILATERAL POSTERIOR EDENTULOUS ARCHES

ANÁLISE COMPARATIVA DA DISTRIBUIÇÃO DE TENSÃO EM DIFERENTES SOLUÇÕES PROTÉTICAS PARA DESDENTADO POSTERIOR BILATERAL "CLASSE I DE KENNEDY"

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ABSTRACT: One of greatest challenges of dentists is the rehabilitation of free-end Kennedy class I and class II patients due to the improper occurrence of stress around the supporting structures of conventional removable dentures during mastication. This work aimed to compare the stress distribution in different prosthetic solutions. For this analysis, four photoelastic models (PM) were produced simulating a Kennedy class I arch with the remaining teeth 34 through 44. In all models, teeth 33, 34, 43, and 44 received metal crowns. In addition to the crowns, the A model (PMA) received a conventional removable partial denture (RPD), the B model (PMB) received a RPD associated with a semi-rigid attachment, the C model (PMC) received a RPD associated with a rigid attachment, and the D model (PMD) received a RPD associated with implant and rigid attachment. Evenly distributed loads were applied on the last artificial tooth of the prostheses. Based on the results of the distributed load, the conventional prosthesis presented the best results for all regions (averages ranging from 25.70 to 17.80), followed by the prosthesis associated with the implant, the prosthesis associated with the rigid attachment, and lastly, the prosthesis associated with the semi-rigid attachment. The same result can be observed in the localized load, where the conventional prosthesis presented superior results in all regions (averages ranging from 47.35 to 8.30), followed by the prosthesis associated with the implant, the prosthesis associated with the rigid attachment and, with the prosthesis associated with the semi-rigid attachment. Based on the data obtained, it may be concluded that the conventional RPD presented a balanced stress distribution in the three regions analyzed, and when associated with the semi-rigid attachment, it presented a more favorable behavior than that associated with the rigid attachment.

KEYWORDS: Removable partial denture. Implants. Biomechanical behavior. Attachment. Photoelasticity.

INTRODUCTION

The greatest problem associated with free-end removable partial dentures (FERPD) is the presence of a double supporting system (tooth and residual ridge), which when subjected to masticatory loads present different biomechanical behaviors, causing stress around the supporting teeth and resulting in uneven bone resorption (CUNHA et al., 2008; SILVA et al., 2011). The physiological movement ability of a supporting tooth in its alveolus, when subjected to loads, is around 0.1 mm (THIELEMANN, 1963), while the compressibility of the covering fibromucosa presents results that range depending on the ridge, with mean of 1 to 3 mm (FEINGOLD et al., 1986).

Aiming to improve the mechanical conditions of the FERPD, authors have suggested the use of a single distal implant in the free end, thus creating a posterior support, decreasing the lever effect on the abutment teeth during the process (LEWIS, 1998; CUNHA et al., 2011; VERRI et al., 2011; DE FREITAS SANTOS et al., 2011; RODRIGUES et al., 2013; MEMARI et al., 2014; SHAHMIRI et al., 2014; PIMENTEL et al., 2014; HIRATA et al., 2015; HIRATA et al. 2016) and resulting in a favorable occlusal and periodontal balance, as well as improving retention and stability when these implants are associated with an additional retention system (KELTJENS et al., 1993; LACERDA et al., 2005; LIV, 2011; RODRIGUES et al., 2013; PIMENTEL et al., 2014).

Besides the biomechanical issues reported, the removable dentures retained by clamps do not meet all the criteria related to patient aesthetics

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(SMITH et al., 2005; SHAH; ARAS, 2013). In this matter, the use of full crowns with attachment system or connectors in the supporting teeth of the removable partial denture has been considered an excellent alternative, for both improving aesthetics and allowing a more balanced distribution of masticatory efforts (PALMEIRO et al., 2015).

Considering these different treatment options that have been used to minimize the deleterious effects of the FERPD on the alveolar ridge, this study aimed to compare the stress distribution of different prosthetic solutions, which associate free-end removable partial dentures with implants and/or attachments.

MATERIAL AND METHODS

The Checklist for Reporting In-vitro Studies (CRIS Guidelines) (KRITHIKADATTA et al., 2014) was used to assist the performance of the research and reporting the results obtained.

Preparation of models

For the development of this research, four types of photoelastic models (PM) were produced simulating the partially edentulous arches without bilateral posterior tooth support (mandibular Kennedy class I) - models A (PMA), B (PMB), C (PMC), and D (PMD). The first three models represent a mandibular Kennedy class I arch without the posterior teeth 35, 36, 37, 45, 46, and 47, and without implants. The last model represents a mandibular Kennedy class I arch without the posterior teeth 35, 36, 37, 45, 46, and 47, and with Titamax CM Cortical 3.75 x 7.0 mm implant (Neodent Curitiba, PR, Brazil) installed in the region corresponding to the first molars. In addition to these general features, the models presented the following specific characteristics:

- Photoelastic model A (PMA) - Teeth 33, 34, 43, and 44 received full metal crowns prepared for Roach retainer T in the direct abutment teeth (34 and 44).
- Photoelastic model B (PMB) - Teeth 33, 34, 43, and 44 received full metal crowns with SR3.0 h=3 mm semi-rigid extracoronal attachments (CNG Soluções Protéticas, SP, Brazil) in teeth 34 and 44.
- Photoelastic model C (PMC) - Teeth 33, 34, 43, and 44 received full splinted metal crowns in each segment with Omega M h=3 mm rigid intracoronal attachments (CNG Soluções Protéticas, SP, Brazil) in the direct abutments 34 and 44.
- Photoelastic model D (PMD) - Teeth 33, 34, 43, and 44 received full metal crowns with Omega M h=3 mm rigid intracoronal attachments and an intermediate o'ring attachment (Neodent Curitiba, PR, Brazil) in the direct abutments (teeth 34 and 44) over the implants.

Characteristics assessed and the production of photoelastic models

The different settings used in this study were assessed by analyzing the stress gradient in preset internal points of photoelastic models, obtained according to the method described next.

Working models for the production of metal frames

The models used as base for the production of photoelastic templates were obtained using a toothed mouth from a P-Oclusal articulated dummy, 2008 model (P-Oclusal Produtos Odontológicos Ltda, São Paulo, SP, Brazil).

The mandibular arch of the P-Oclusal dummy was prepared to be used as reference for obtaining the photoelastic models described previously. Hence, initially the posterior and canine acrylic teeth were removed. The respective holes of the "alveoli" of teeth 35, 36, 37, 45, 46, and 47 were filled with #7 pink wax (Polidental Ind. e Com. Ltda, São Paulo, SP, Brazil), keeping the alveoli of teeth 33, 34, 43, and 44, thus becoming a fully dentate model in a Kennedy class I model. This arch was molded with irreversible hydrocolloid Hydrogum (Zhermack, Badia Polesine, RO, Italy), resulting in a mandibular Kennedy class I model.

In order to fill in the holes of teeth 33, 34, 43, and 44, acrylic resin teeth (P-Oclusal Produtos Odontológicos Ltda, São Paulo, SP, Brazil) were selected and they matched the dimensions presented by the artificial teeth of the model, which were adapted to the "alveoli" and fixed to them using #7 pink wax.

The plaster model obtained was the reference for producing the photoelastic models. However, in order to prevent interfering with the light passing in the posterior region of the model during the tests, a buccal expansion of the arch in the posterior region was performed from the distal teeth 34 and 44, without interfering with the anterior region. Hence, the #7 pink wax model was encased, which allowed the leaking of a new plaster layer and increased the opening between the hemiarches in a sufficient angle to allow passing the light in the region of interest.

After this step, the model was encased with #7 pink wax and molded with blue silicone (Poliopox Ind. e Com. Ltda, Cesário Lange, SP, Brazil), providing a silicone mold that allowed obtaining the four working plaster models used for the production of the removable partial dentures.

Each model from the silicone mold received specific changes for the anchorage of the removable partial denture, which were placed in either acrylic teeth or the edentulous ridge area. In all models, the artificial acrylic teeth were prepared for full metal crowns. For each planning, the crowns received specific changes that produced the working models for the removable partial dentures - MA, MB, and MC. Specifically for the MD model, two Cone Morse implants (Titamax CM Neodent, Curitiba, PR, Brazil) were installed, with dimensions of 3.75 mm x 7.00 mm, in the regions corresponding to teeth 36 and 46. These implants were installed according to the same standard protocol sequence established for installing implants in patients. Thus, four models were obtained for the production of four metal frames, called MA (Figure 1a), MB (Figure 1b), MC (Figure 1c), and MD (Figure 1d).

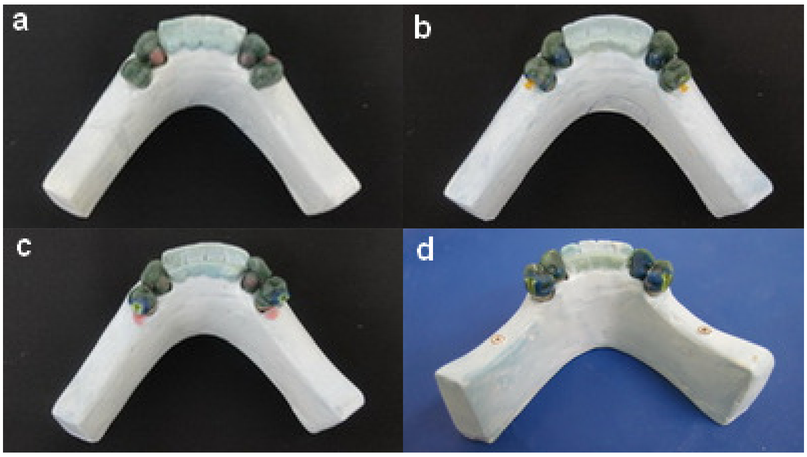

Figure 1. Working models obtained from the silicone mold. a) MA model; b) MB model; c) MC model; d) MD model.

Obtaining photoelastic models

In order to prevent the acrylic resin teeth from being in direct contact with the photoelastic resin and to get closer to the oral conditions, the periodontal ligament was simulated using regular-consistency polyether Impregum (3M ESPE, São Paulo, SP, Brazil).

From the working models, the silicone matrices IQ 428 (Aerojet, São Paulo, SP, Brazil) were produced. For the arch with implants installed, the silicone matrix produced had two mold transfers and its base included a hole that allowed adapting the screwdriver to access the bolts of the mold transfers. To produce the matrix, a collapsible square box was produced in acrylic resin, measuring 9.0 cm x 8.0 cm x 7.2 cm, in which a plaster model was placed with the acrylic teeth in position, and blue silicone (Polipox Ind. e Com., Cesário Lange, SP, Brazil) was poured in the ratio of 491 g of silicone for 10 g of catalyst (Polipox Ind. e Com. Ltda, Cesário Lange, SP, Brazil). The silicone was handled according to the manufacturer's instructions to prevent the capture of bubbles. This procedure was performed for the four plaster models.

After 24 hours, the models were removed from their respective matrices through which the photoelastic models were obtained. Considering the objective was having the implants and the resin teeth inside the photoelastic models, the implants were fixed in the matrix with the mold transfers and the acrylic resin teeth were positioned in the negatives of the abutment teeth.

With teeth and implants properly positioned, the flexible photoelastic resin (Polipox Ind. e Com. Ltda, Cesário Lange, SP, Brazil) was handled according to the manufacturer's instructions, led to a vacuum for removing bubbles, and slowly poured in the molds to prevent the capture of bubbles. The bubbles produced in this process were carefully removed with an orthodontic wire.

After 24 hours, the models were removed from their respective matrices. Figure 2 illustrates the photoelastic models obtained for the tests.

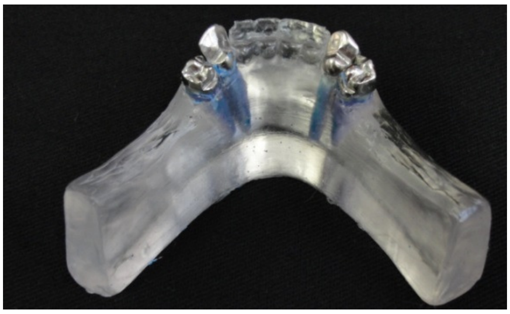

Figure 2. Finished photoelastic model A (PMA).

Prosthesis adjustments and load transmissions

The metal frames obtained from the working models were properly adjusted to the photoelastic templates, so that the insertion would not cause stresses on the abutment teeth. The pink acrylic resin bases chemically activated (Dencril Plásticos Ltda, SP, Brazil) were produced over the grids, and the Trilux artificial teeth (Euro Vipi, SP, Brazil) were mounted on the resin bases, forming the saddle for the removable partial dentures that were properly adjusted to their photoelastic models, also preventing the stress concentration that might affect the tests.

The male attachment components and the retention components associated with the implants were fixed to the base of the prosthesis using self-polymerizing colorless acrylic resin. Figure 3 shows the retention component adapted to the implants and the o'ring attachment capsules (Neodent Curitiba, PR, Brazil) captured within the acrylic base.

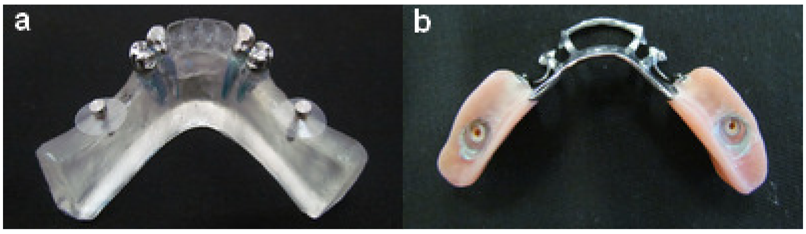

Figure 3. a) Photoelastic model D (PMD) with o'ring attachment positioned on the implant; b) RPD with female component of the o'ring attachment captured.

After finishing, the MA, MB, MC, and MD models adapted to the load system were taken to the polariscope for determining the photoelastic parameters and stress intensities.

A device was designed and built for load application to the photoelastic models. The system designed is composed by a 500-N load cell (KRATOS), a mobile load applicator post with axial movement and fixed by a bolt, a horizontal and vertical movement base, and a KRATOS signal indicator. The load was applied axially in the photoelastic models, aiming to obtain fringe patterns in the regions analyzed. The objective was to simulate a specific loading condition to compare the different prosthetic solutions.

The load applicator post received an acrylic resin device composed in the upper part by a horizontal rectangular platform, from which come out four vertical posts that will seat on the acrylic resin teeth of the RPD and on the metal crown of the first premolar. To determine the best position of the photoelastic model, a self-polymerizing acrylic resin shield was produced so that the model would be fixed during the tests. This was useful for analyzing all models in the same position. The loads were concentrated in the region of the second molar and distributed evenly on four points in the regions of the first premolar, second premolar, first molar, and second molar, in the working side. Figure 4 illustrates the photoelastic model and the load device properly positioned in the transmission polariscope.

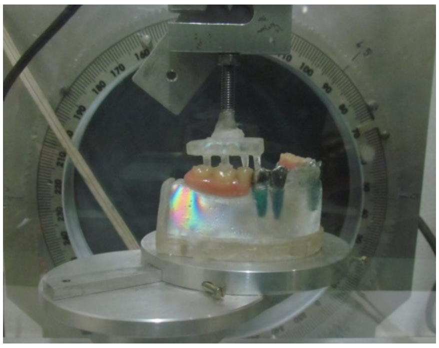

Figure 4. Photoelastic model and load application device taken to the transmission polariscope.

The photoelastic images were obtained with a professional digital photo camera (Sony DSC-H3, Minato, Tokyo, Japan). Initial photographs were produced for the four models without loading, aiming to show the complete absence of stress in the models. Twenty images were produced with consecutive axial and compression loading and unloading for each model. The load was fixed in 30 N.

Two types of loading were assessed: concentrated load applied on the region of the second molar and distributed load applied on the first premolar, second premolar, first molar, and second molar, in the working side. The images showed fringes, as shown in Figure 5. The fringes show the maximum and minimum shear stress levels when the model is under loading.

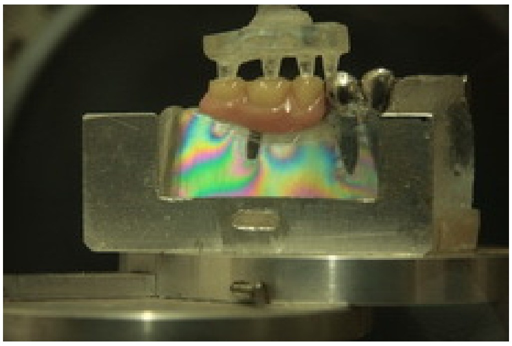

Figure 5. Photoelastic fringes obtained after loading the photoelastic model with implant.

Figures 6a and 6b illustrate the points analyzed. These figures show the distribution of stresses and fringe orders for each one of the photoelastic models analyzed under loading.

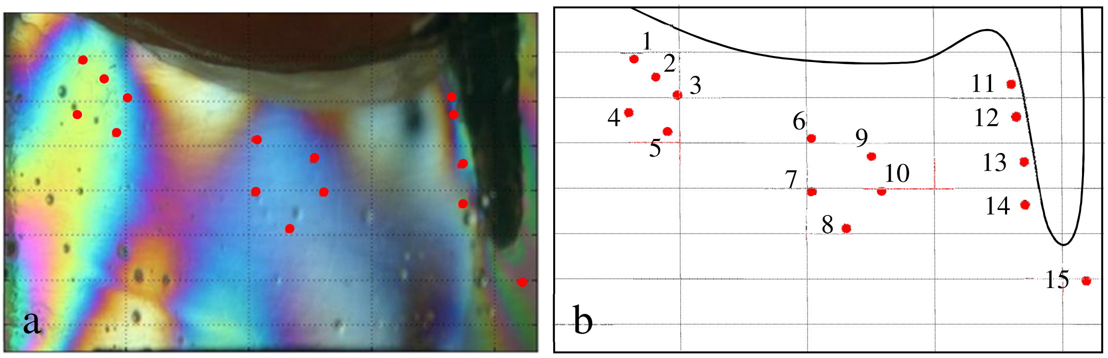

Figure 6. a) Stress distribution after the application of distributed load in the photoelastic model with conventional FERPD; b) Scheme of the points analyzed.

The method used was photoelasticity, which allows visualizing the stress distribution in the entire structure, providing an overview of the stress behavior, showing quality, quantity, and force distribution in an object (KENNEY; RICHARDS, 1998; TURCIO et al., 2009). The choice of the photoelastic method for performing this research was inspired by the most diverse studies in the different fields of Dentistry (MATHIAS, 2001; COSTA, 2002; BERNARDES et al., 2006; COSTA et al., 2009; SILVA et al., 2010), showing its adequacy to the type of study proposed in this article.

Data analysis

The stress distributions and fringe analysis were performed using the computer program "FRINGES", developed in the Mechanical Designs Laboratory Professor Henner A. Gomide at the School of Mechanical Engineering of the Federal University of Uberlândia (UFU), MG, Brazil. The images obtained were sent to a computer. In order to be used by the software, the images were cut to the same dimensions and cut-off points, thus preventing discrepancies in the results.

The quantitative results were obtained through the calculus of the shear stress means of each one of the points, in the twenty photographs of each photoelastic model. The stress distribution in the photoelastic models was determined by loading, first distributed in the direct abutment teeth and artificial denture teeth simulating a normal occlusion, and later through localized loads on the second molar simulating an early contact, as described in the literature.

RESULTS E DISCUSSION

The present study compared the stress distribution of different prosthetic solutions, associating free-end removable partial dentures with implants and/or attachments. The RPD associated with an implant placed in the region of the alveolar ridge provided satisfactory stress distribution and it may be an excellent rehabilitation alternative for free-end patients, especially due to the bone resorption of the ridge associated with the conventional removable dentures, which occurs over time and overloads the direct abutment teeth involved in the planning.

The following graph shows the results obtained after loading and unloading. Figures 7 and 8 represent, respectively, the distribution of stresses obtained by region, considering the distributed and localized loads for each working model used.

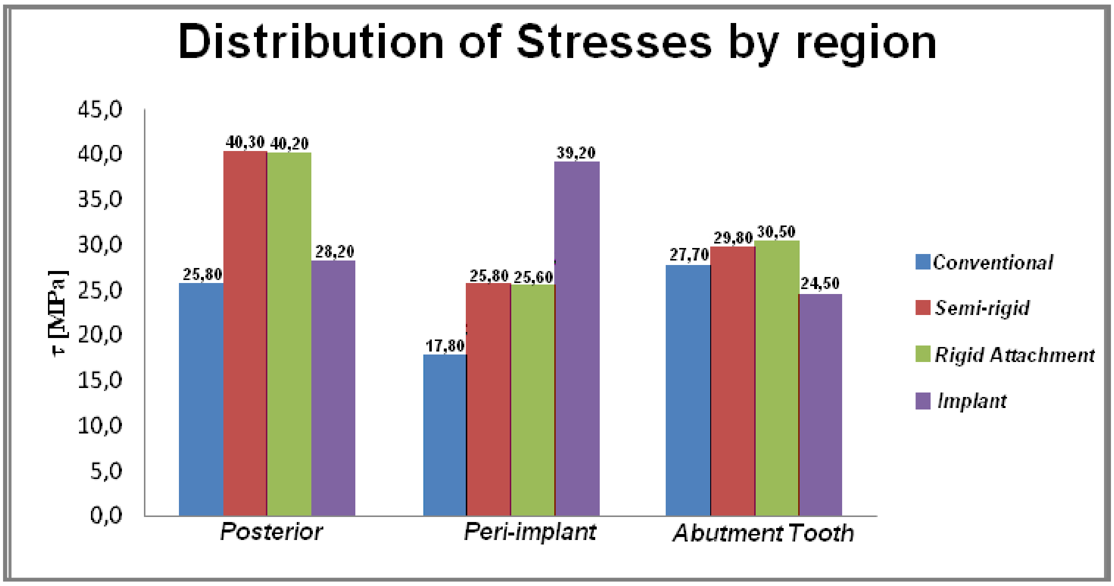

Figure 7. Mean stress distribution by region considering the distributed load.

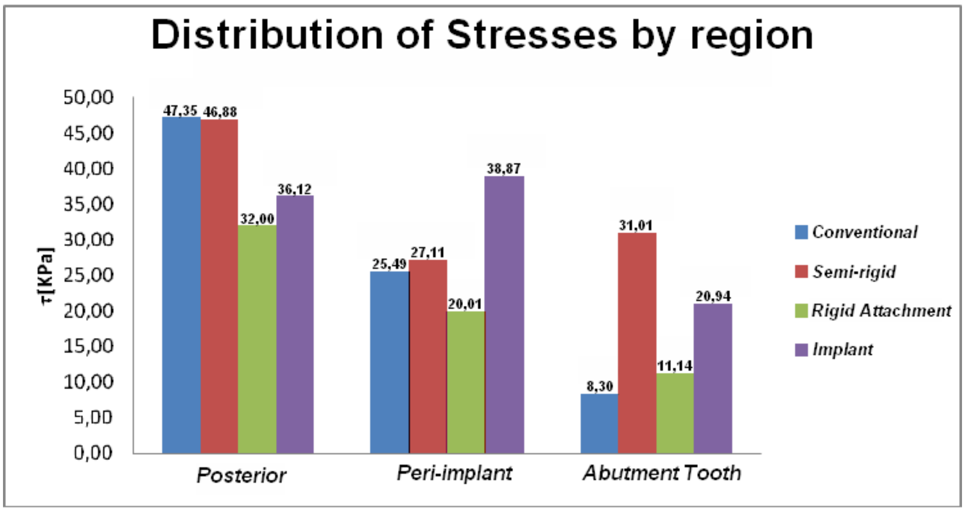

Figure 8. Mean stress distribution by region considering the localized load.

It may be noticed that the highest shear stress levels in the photoelastic model PMA (conventional), when applying the distributed load, occurred in the posterior ridge and in the distal region of the abutment tooth. However, even with the differences between the points analyzed, the distribution was rather balanced, agreeing with the results of previous studies that have also used this type of model (COSTA, 2002; COSTA et al., 2009).

For the PMB (semi-rigid) with distributed load, the highest shear stress levels occurred in the posterior ridge. These data agree with the results obtained by Pellecchia et al. (2000) and Wang et al. (2011), who concluded that the stress levels on the last abutment tooth might be reduced with a resilient extracoronal attachment, due to the greater effort distribution for the edentulous distal ridge.

For the rigid attachment in the PMC model, the highest stress levels occurred in the posterior ridge. Froner (1999) affirmed that from a certain load amount, both the semi-rigid extracoronal and the rigid intracoronal attachments did not relieve stresses on the supporting teeth. This result may be found in this research, which shows approximate stress levels in the region of the abutment tooth for all types of attachments analyzed.

Observing the stress distribution in the PMD photoelastic model and comparing it to the others that were previously analyzed, it is noticed that the implant installation promoted a decrease of shear stresses in the posterior ridge and an increase of the stress levels in the central ridge, which is the implant region, confirming the results obtained by Matias (2001).

Implant installation provided an improved distribution of stresses in all regions analyzed when compared to the other models. This was also found by Keltjens et al. (1993) and Giffin (1996), who concluded that implant installation on the base of the free-end RPD might prevent resorption on the base of the RPD and reduce stresses in the supporting teeth, thus eliminating most of the problems caused by the use of free-end RPD. Therefore, Kennedy class I patients may be benefited by the association of RPD with implants, which may eliminate the lever movement of the prosthesis using an adequate retention system in the free end. This alternative changes the condition of the Kennedy class I patient to a class III condition, with the advantage of improving chewing efficiency and prosthesis stability and aesthetics, depending on the position of such implant and the type of attachment used.

The conventional RPD model installed in a regular ridge presented a rather satisfactory biomechanical behavior with even distribution of stresses in the three regions analyzed. Clinically, it is noticed that the conventional RPD satisfies patients regarding function and, lastly, aesthetics, when these are produced according to the principles and foundations of retention, stability, and aesthetics (BEZZON et al. 1997; COSME et al. 2006; WU et al. 2012). However, over time it is worth noting that using this device will necessarily cause resorption of the remaining alveolar process, which will promote higher loading on direct abutment teeth. Hence, several measures have been proposed aiming to minimize alveolar bone resorption and consequently the lateral loads on the direct abutment teeth involved in prosthesis planning. Among these measures are the reduction of the number of artificial teeth (CHRISTENSEN, 1962), use of large bases (CHRISTENSEN, 1962; NAIRN, 1966; TAYLOR, 1982), reduction of the occlusal surface of artificial teeth (KRATOCHVIL, 1963; TAYLOR, 1982), occlusal harmony (TODESCAN, 1996), and variations in retainer design (KRATOCHVIL, 1963; THOMPSON, 1977).

Based on this and in comparison to the conventional RPD, the use of implant in the posterior region may be an excellent alternative due to the change in prosthesis support, which besides having dental and fibromucosal support, now also rely on an implant as a form of receiving and transferring masticatory loads to the remaining alveolar process. Besides the improvement in support conditions, such planning will allow an increase in the retention level and stability, as well as a greater longevity to the rehabilitation treatment, keeping the remaining structures in healthy conditions for longer (LEWIS, 1998; CUNHA et al., 2011; VERRI et al., 2011; DE FREITAS SANTOS et al., 2011; RODRIGUES et al., 2013; MEMARI et al., 2014; SHAHMIRI et al., 2014; PIMENTEL et al., 2014; HIRATA et al., 2015; HIRATA et al. 2016).

When subjected to both loads, the posterior region presented the highest shear stress levels, but in the localized load in the region of the second molar, there was a lower rate of stress concentration in the region of the abutment tooth and a significant increase in stress in the posterior region. When extrapolating these data to clinical conditions, this situation, which clinically simulates prematurity, will promote a fast bone resorption of the remaining posterior bone and subsequent overloading on the abutment teeth that may be lost by excessive load. It is worth noting the importance of proper occlusal adjustment when installing these prosthetic devices, which prevents the establishment and progression of the condition analyzed (KRATOCHVIL, 1963; THOMPSON, 1977; TAYLOR, 1982; TODESCAN, 1996; COSTA, 2002; COSTA et al., 2009).

For the rigid intracoronal attachment, the highest shear stress levels for localized load in the region of the second molar occurred in points 2 through 5, which correspond to region 1 - posterior ridge. When extrapolating these data to the clinical application, the excessive pressure in this region will promote the acute and fast resorption, which will consequently promote greater gingival occlusal movement of the prosthesis, carrying the direct abutment tooth laterally. The absence of an abutment tooth in the distal region associated with the resilience difference between the mucosa and the periodontal ligament produces a lever system due to the compression forces that may damage the supporting tissues (LAGANÁ; ZANETTI, 1995). Hence, tooth implants have been used as a treatment alternative for the rehabilitation of partially edentulous patients with arches classified as Kennedy class I.

Similar to other studies, the present one is not free from limitations. Because it is a laboratory study, clinical studies that may assess the behavior of the different prosthetic solutions analyzed over time along with user responses are encouraged in order to apply the results hereby obtained to the clinical practice. However, this study is original and contributes to the scientific literature by proposing a new rehabilitation mode aiming to minimize bone resorption in patients who wear free-end removable partial dentures.

CONCLUSION

The conventional RPD presented a balanced stress distribution in the three regions analyzed, and when associated with the semi-rigid attachment, it presented a more favorable behavior than that associated with the rigid attachment, considering it had an improved stress distribution in all regions analyzed. However, both of these prosthetic solutions presented an inferior biomechanical behavior when compared to the conventional RPD and the RPD associated with implant.

RESUMO: Um dos maiores desafios para os cirurgiões-dentistas consiste na reabilitação de pacientes com extremidade livre classe I e classe II de Kennedy, devido à ocorrência inadequada de tensão em torno das estruturas de suporte das próteses removíveis convencionais durante o processo da mastigação. O objetivo deste trabalho foi analisar comparativamente a distribuição de tensão em diferentes soluções protéticas. Para essa análise, foram confeccionados quatro Modelos Fotoelásticos (MF) simulando um arco classe I de Kennedy, e tendo como dentes remanescentes do dente 34 ao 44. Em todos os modelos, os dentes 33, 34, 43 e 44 receberam coroas metálicas. Além das coroas, o modelo A (MFA) recebeu uma Prótese Parcial Removível (PPR) convencional, o modelo B (MFB) recebeu uma PPR associada a encaixe semirrígido, o modelo C (MFC) recebeu uma PPR associada a encaixe rígido e o modelo D (MFD) recebeu uma PPR associada a implante e encaixe rígido. Foram aplicadas cargas uniformemente distribuídas e localizadas no último dente artificial das próteses. Baseado nos resultados da carga distribuída, a prótese convencional apresentou os melhores resultados para todas as regiões (médias variando entre 25,70 e 17,80), seguida da prótese associada ao implante, a prótese associada ao encaixe rígido e, finalmente, com a prótese associada ao encaixe semirrígido. O mesmo resultado pode ser observado na carga localizada, onde a prótese convencional apresentou resultados superiores em todas as regiões (médias variando entre 47,35 e 8,30), seguida da prótese associada ao implante, a prótese associada ao encaixe rígido e, finalmente, com a prótese associada ao encaixe semirrígido. Baseado nos dados obtidos pôde-se concluir que a PPR convencional apresentou uma distribuição equilibrada de tensões nas três regiões analisadas e, quando associado à fixação semi-rígida, apresentou um comportamento mais favorável do que aquele associado à fixação rígida.

PALAVRAS-CHAVE: Prótese parcial removível. Implantes. Comportamento biomecânico. *Attachment*. Fotoelasticidade.

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