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Photoelastic Study of the Support Structures of Distal-Extension Removable Partial Dentures

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Abstract

Purpose: The double system of support, in which the distal-extension removable partial denture adapts, causes inadequate stress around abutment teeth, increasing the possibility of unequal bone resorption. Several ways to reduce or more adequately distribute the stress between abutment teeth and residual ridges have been reported; however, there are no definitive answers to the problem. The purpose of this study was to analyze, by means of photoelasticity, the most favorable stress distribution using three retainers: T bar, rest, proximal plate, I bar (RPI), and circumferential with mesialized rest.
Materials and Methods: Three photoelastic models were made simulating a Kennedy Class II inferior arch. Fifteen dentures with long saddles, five of each design, were adjusted to the photoelastic patterns and submitted first to uniformly distributed load, and then to a load localized on the last artificial tooth. The saddles were then shortened and the tests repeated. The quantitative and qualitative analyses of stress intensity were done manually and by photography, respectively. For intragroup analyses the Wilcoxon test for paired samples was used, while for intergroup analyses Friedman and Wilcoxon tests were used to better identify the differences ($p < 0.05$).
Results: The RPI retainer, followed by the T bar, demonstrated the best distribution of load between teeth and residual ridge. The circumferential retainer caused greater concentration of stress between dental apexes. Stress distribution was influenced by the type of retainer, the length of the saddle, and the manner of load application.
Conclusions: The long saddles and the uniformly distributed loads demonstrated better distribution of stress on support structures.

Removable partial dentures (RPDs) with dental and mucosal support are devices of great complexity that, despite recent technological advances, constitute a challenge to the professionals who need to use the procedure. The difficulties are mainly due to differences in the behavior of the support structures when submitted to occlusal forces.[1,2] On one hand, the abutment tooth presents a limited movement of around 0.1 mm; on the other hand, the mucosa, which varies in compressibility from 0.4 to 4 mm, has an average resilience of 1.3 mm.[3] This means that the mucosa confers a freedom of movement to the saddle approximately 13-fold higher than that allowed by the dental organ in its alveolus.

This double system of support, where the distal-extension RPD adapts, causes the occurrence of inadequate stress around abutment teeth, increasing the possibility of unequal bone resorption. This phenomenon usually starts at the saddle and can progress to the abutment tooth.[4] In more advanced stages, periodontal ligament inflammation and even periodontal abscess and tooth loss can occur.[5-8] Several ways to reduce or more adequately distribute the stress between abutment teeth and residual ridges have been reported, including the reduction on the number of artificial teeth,[6] the use of long saddles,[4,9-12] reduction of the occlusal surfaces of artificial teeth,[4,13] occlusal equilibrium,[8] and variation in retainer design;[14-16] however, there are no definitive answers to the problem.

RPDs are still the treatment of choice for those patients who desire to have replacement teeth for functional or esthetic reasons but cannot receive dental implants due to general health reasons or financial limitations. Thus, knowledge of biomechanical aspects that directly compromise the success of the dental treatment with this type of removable denture is important. The aim of this study was to use photoelasticity to compare three types of retainers commonly used in clinical practice (T bar,[17] RPI,[14,16] and mesialized rest Akers circumferential retainers[18]) associated with two saddle lengths and two forms of load application.[19]

Materials and methods

Photoelasticity is an experimental technique for the analysis of tension and deformation of materials and is particularly useful for devices and structures that present complex geometry. The greatest advantage of this method is the visualization of internal tensions that can be both measured and photographed. Because it is an indirect method, models that accurately reproduce the original must be made, especially when quantitative measurement of tension is required.[14]

Photoelastic models

Photoelastic models were made simulating a Kennedy Class II mandibular arch. These arches consisted of two parts: one right half-arch made in flexible photoelastic epoxy resin (0488, Redelease Ltda., São Paulo, Brazil) and one left half-arch made in chemically activated colorless acrylic resin (Dental Vipi, Rio de Janeiro, Brazil). To obtain these arches, we started from a mandibular Columbia model (Columbia Dentoform Corp., New York, NY) which was duplicated in hard plaster (Gesso-Rio Indústria Brasileira, Rio Claro, Brazil), and this copy was then transformed into a Kennedy Class II model by the avulsion of the molars and of the right second premolar. After removing irregularities in the toothless area arising from tooth avulsion, a silicone matrix (Elite Double 8, Zhemack SPA, Badia Polesine, Italy) was made to allow the reproduction of the Class II models necessary for this study.

Two natural mandibular teeth, one canine and one premolar, were selected and used as references for the teeth included in the photoelastic model. Of the natural teeth, only the radicular area was preserved, being those joined to crowns made out of acrylic resin and molded using the right mandibular canine and first premolar of the Columbia model. After uniting the natural root with the acrylic crown, these teeth were reproduced in Duralay chemically activated red acrylic resin (Reliance Dental Mfg. Co., Worth, IL). Three copies of each tooth were made. The artificial teeth were positioned into the silicone matrix, the roots were lubricated with Vaseline (Indústria Farmacêutica Rioquímica Ltda, São José do Rio Preto, Brazil), and the model was filled with type IV plaster (Polidental Ind. & Com. Ltda, São Paulo, Brazil). This procedure was repeated three times, forming three Class II models with artificial teeth in the interior, one for each type of retainer used (T bar, RPI, and circumferential), all with mesialized rest. These retainers were tested with two saddle lengths under two forms of load. In addition to the rests, guide planes were made on the axial surfaces of the direct and indirect abutments. For the T-bar and circumferential retainers, these planes were made on the lingual surfaces, while for the RPI retainers the planes were made on the lingual surfaces of the indirect abutment and on the distal surface of the direct abutment.

For each of the models a new matrix was made, this time in IQ 428 silicone (Aerojet Brasileira de Fiberglass, São Paulo, Brazil). These matrices allowed the construction of the models necessary for the manufacture of the RPD framework.

A total of 15 frameworks (Fig 1) were constructed using a Co-Cr alloy (Degussa AG Geschaftsbereich Dental, Hanau, Germany). After building the matrices, the artificial teeth were removed from the interior of the model and duplicated in AG 80 silver alloy (La Croix Ligas Odontológicas, Rio de Janeiro, Brazil). The choice to use metallic teeth was made due to metal's greater resistance to the retainers, in contrast to teeth made of resin that could suffer abrasion during the test, thereby influencing the results.

To obtain the photoelastic models, the three IQ 428 silicone matrices were filled with type IV plaster resulting in three plaster models. The latter were cut in the median line, and the right hemi-arches were cut and regularized with pink wax 7 (Polidental Ind. & Com. Ltda) to form an even surface without curvatures. The plaster matrices were then used to make three new IQ 428 silicone matrices into which the metallic teeth were positioned. Flexible epoxy photoelastic resin was prepared according to manufacturer's instructions in quantity sufficient for making the three models necessary for the photoelastic study.

Left hemi-arches were made by depositing the colorless chemically activated acrylic resin into the first IQ 428 silicone matrices. After resin polymerization, right (photoelastic material) and left (acrylic resin) hemi-arches were united, thus forming the models for the tests.

Framework adjustment and load transmission

Frameworks were adjusted to their respective models in a way as to avoid tension, and the saddle of acrylic resin was fixed over the framework. After this step, the crowns of the second premolar and the first and second right molars (obtained from the Columbia model) were mounted. To apply the loads, a surveyor was adapted with an acrylic platform on the superior end of its analyzing rod, to allow the addition of weight. On the mandibular end of this rod, a device in the form of a pin was adapted to allow the load application. An aluminum plate was placed behind the model to reflect the light.

The test models, together with the load system (Fig 2) were brought to the reflection polariscope developed at the School of Mechanical Engineering at the Faculty of Dentistry, Federal University of Uberlandia, Brazil. A standard load of 20 N was applied, causing stress on the photoelastic models. The effects were observed in eight distinct points, numbered from 0 to 7. In the dental apices region, point 0 was positioned 3 mm above the apices of the premolar's roots, and the other points were equidistant. In the region of the residual ridges, point 0 was mesiodistally positioned on the center of the residual ridges and on the vestibular fornix region of the dental cast, and the other points were equidistant. The load was applied first uniformly distributed and then localized on the last artificial tooth (second molar) of the long saddle models. Then the saddles were shortened until the distal surface of the second molar and the tests were repeated.

To obtain the qualitative data, a camera (Nikon F90X, adapted with a 70210 lens, Nikon, Japan) was mounted over a

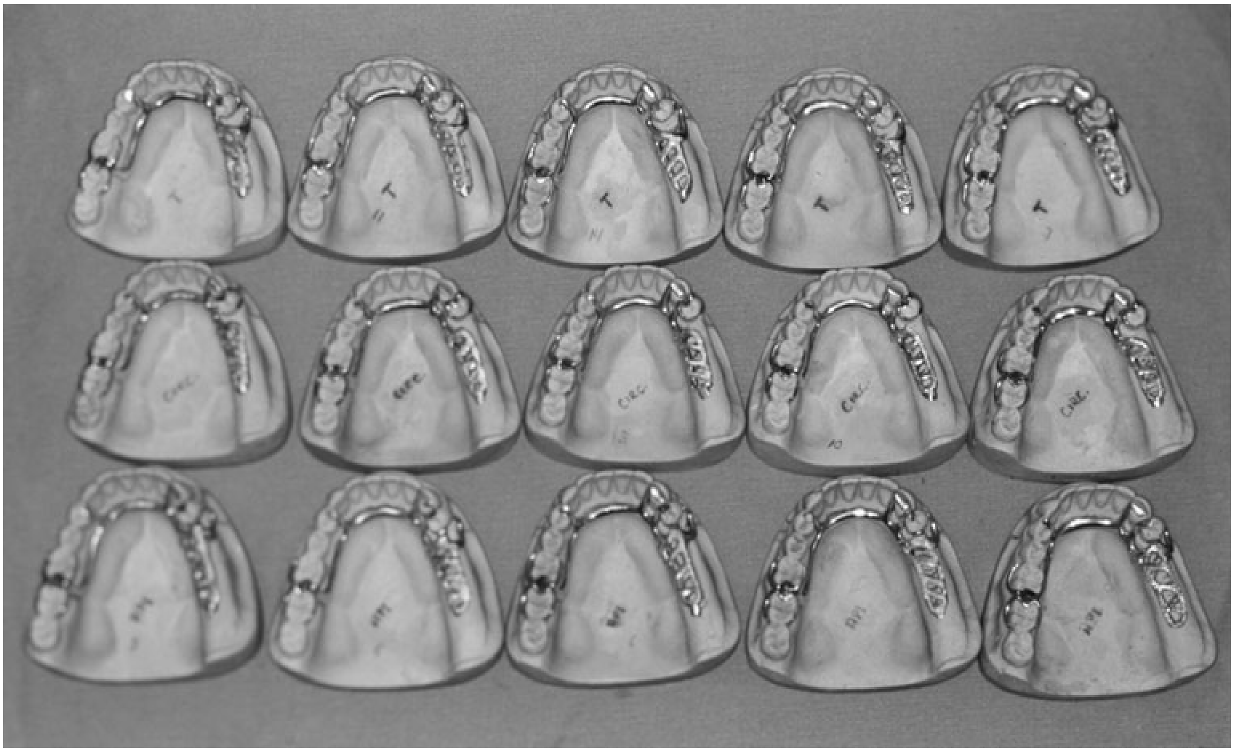

Figure 1 Models with their respective frameworks.

tripod and maintained in a standard position. Photography was made of each test for posterior analysis.

For the quantitative data, a manual reading was made in which the fringe orders (N) and the tension intensity were calculated for every point. To calculate tension intensity, the following formula: σ_1-σ_2 = KσN/2b, where σ_1-σ_2 represents the difference between the main tensions or the intensity of tension; Kσ represents the optical constant relative to the tensions (0.433 for the material used); N represents the fringe order at the point; b is the thickness of the model (17 mm). For the reflection photoelasticity, b values must be multiplied by 2.

Statistical analyses

First, these data were evaluated by the variance test for normality, which indicated that these data did not follow a normal distribution, even after logarithmic conversion. Based on this, nonparametric tests were used to analyze the data. For the intragroup analyses the Wilcoxon test for paired samples was used, while for the intergroup analyses Friedman and Wilcoxon tests were applied to better identify the differences.[20] For all tests, the significance level was established as $p < 0.05$, 2-tailed.

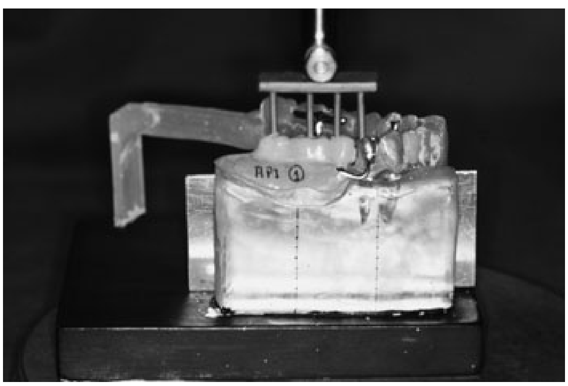

Figure 2 Photoelastic model with the load application system.

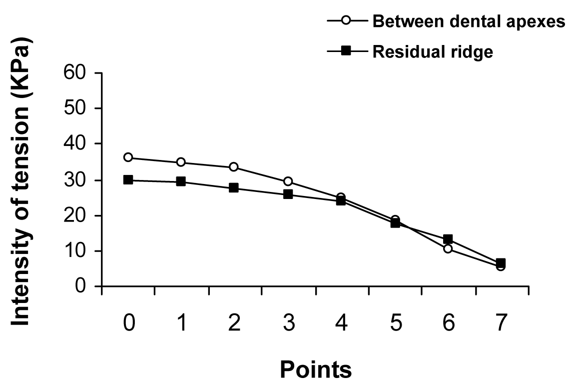

Figure 3 Intensity of tension between dental apexes and on the residual ridge after the application of uniformly distributed load on the T-bar retainer with long saddle.

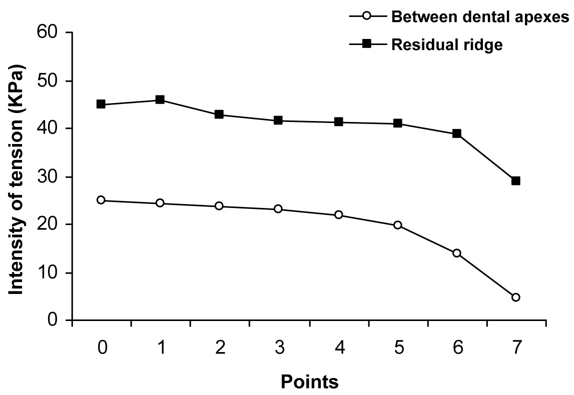

Figure 4 Intensity of tension between dental apexes and on the residual ridge after the application of load on the last artificial tooth—T-bar retainer with long saddle.

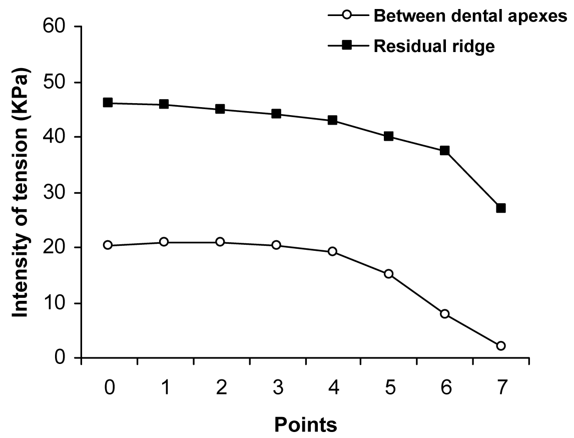

Figure 6 Intensity of tension between dental apexes and on the residual ridge after the application of load on the last artificial tooth (T-bar retainer with short saddle).

Results

All models were examined photoelastically before and after the positioning of the partial dentures to ensure the nonexistence of tension. Therefore, whichever tensions originated on the models were attributed to the applied load. The quantitative data obtained were plotted on graphs, and the qualitative data were represented in a picture to show the stress distribution when using the T bar, the RPI, and the circumferential, all with long saddle and uniformly distributed load.

The results obtained for the T bar with long saddles is shown in Figures 3 and 4. These data shows that when the loads were uniformly distributed, the values of tension intensity were greater between dental apices than in the residual ridges, though not significantly. On the other hand, when the load was applied to the last artificial tooth, a significant reduction in the tension intensity between the dental apices and a significant increase in the residual ridges was observed.

Figures 5 and 6 illustrate the results obtained with the T-bar retainer with short saddles. When the load was uniformly distributed, there was a greater concentration of tension in the residual ridge and a reduction between the dental apices, both statistically significant.

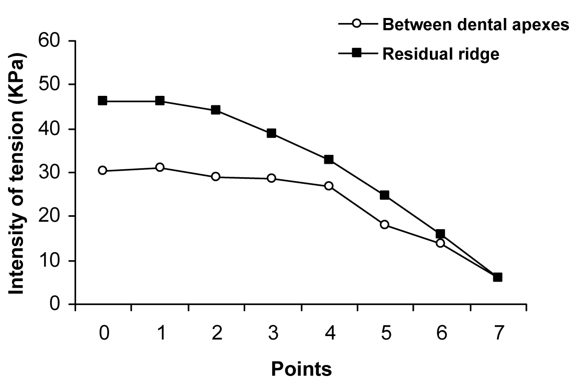

Figure 5 Intensity of tension between dental apexes and on the residual ridge after the application of uniformly distributed load on the T-bar retainer with short saddle.

The results obtained for the RPI retainer with long saddles are expressed in Figures 7 and 8, and show that when the load was uniformly distributed, there was a greater concentration of tension on the residual ridge, statistically significant when compared with the dental apices. When the load was localized on the last artificial tooth, there was lower tension intensity between dental apices and higher concentration of tension in the residual ridge, both statistically significant.

Figures 9 and 10 show the results obtained for the RPI retainer with short saddle. These data show that when the load was uniformly distributed there was significantly more tension intensity on the residual ridges compared to both the values obtained for the dental apices (short saddles) and dental apices and residual ridges in dentures with long saddles. On the other hand, when the load was localized on the last artificial tooth of the dentures with short saddles, there was significantly higher the intensity of tension on the residual ridges, while between dental apices there was a significantly lower intensity of

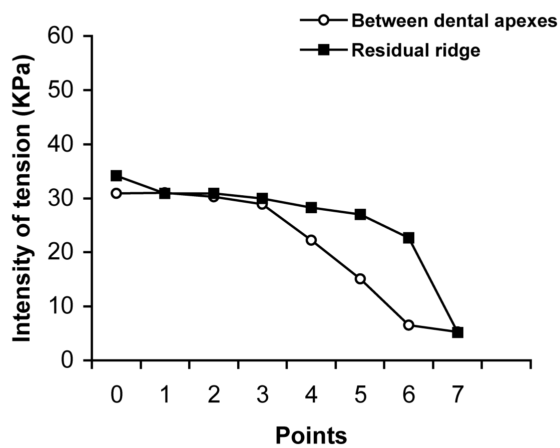

Figure 7 Intensity of tension between dental apexes and on the residual ridge after the application of uniformly distributed load on the RPI retainer with long saddle.

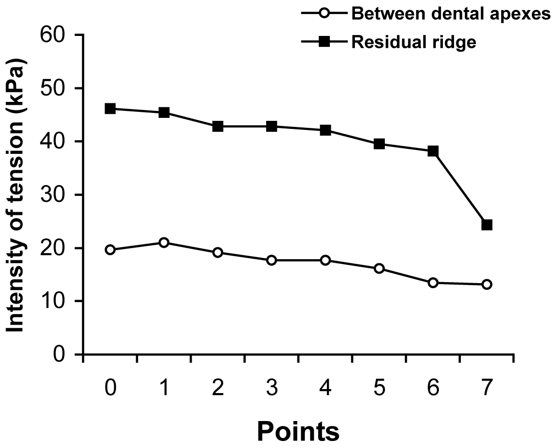

Figure 8 Intensity of tension between dental apexes and on the residual ridge after the application of load on the last artificial tooth (RPI retainer with long saddle).

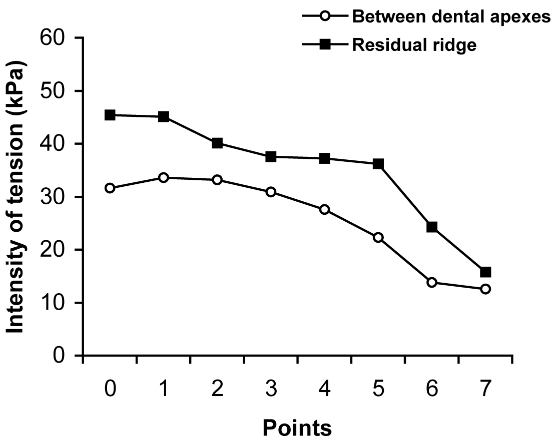

Figure 9 Intensity of tension between dental apexes and on the residual ridge after the application of uniformly distributed load on the RPI retainer with short saddle.

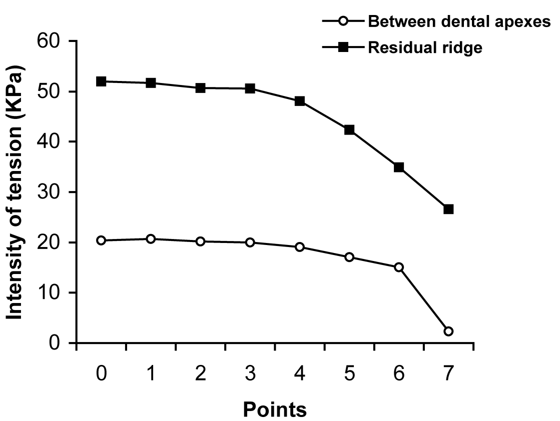

Figure 10 Intensity of tension between dental apexes and on the residual ridge after the application of load on the last artificial tooth (RPI retainer with short saddle).

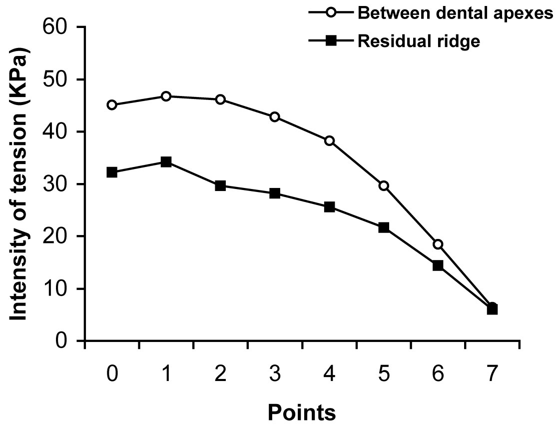

Figure 11 Intensity of tension between dental apexes and on the residual ridge after the application of uniformly distributed load on the circumferential retainer with long saddle.

tension when compared to the uniformly distributed loads, both for long and short saddles.

The results obtained for the circumferential retainer with long saddle are shown in Figures 11 and 12. In these experiments, we observed that when the load was applied uniformly there was a significantly greater concentration of tension between dental apices than that on the residual ridges. When the load was applied to the last artificial tooth, there was an increase in the intensity of tension on the residual ridge and a decrease between the dental apices.

Figures 13 and 14 show the data obtained for the circumferential retainer with short saddles. The intensity of tension observed when the load was uniformly distributed was high between both the dental apices and the residual ridges. When the load was applied on the last artificial tooth, there was a significant reduction in tension intensity between dental apices, while the values for the residual ridges were similar to those obtained for the uniformly distributed load.

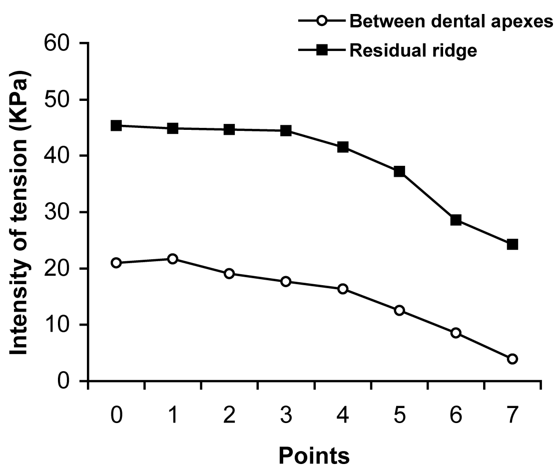

Figure 12 Intensity of tension between dental apexes and on the residual ridge after the application of load on the last artificial tooth (circumferential retainer with long saddle).

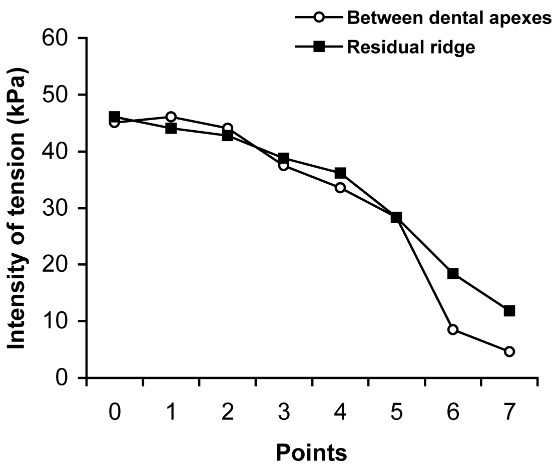

Figure 13 Intensity of tension between dental apexes and on the residual ridge after the application of uniformly distributed load on the circumferential retainer with short saddle.

Discussion

The main objective of a denture is to maintain the equilibrium between the health and the function of the stomatognathic system, preserving its remaining structures in a healthy condition and providing agreeable esthetics.[1,2] When a partial fixed or removable denture is made, an additional load is placed on the abutments during function, which corresponds to the absent teeth. Therefore, when planning a denture, harmony between the additional loads and the capacity of the periodontium to support them must be found.

When speaking of distal-extension RPDs, this harmony is somewhat more difficult to achieve due to differences in the mechanical behavior of the support structures when submitted to occlusal loads.[3,4] A rigid union between the tooth and the saddle of the denture, by means of the minor connectors of the clasps applied on the abutments, induces lateral forces on the latter, tractioning them in the direction of the prosthetic space.[1-14]

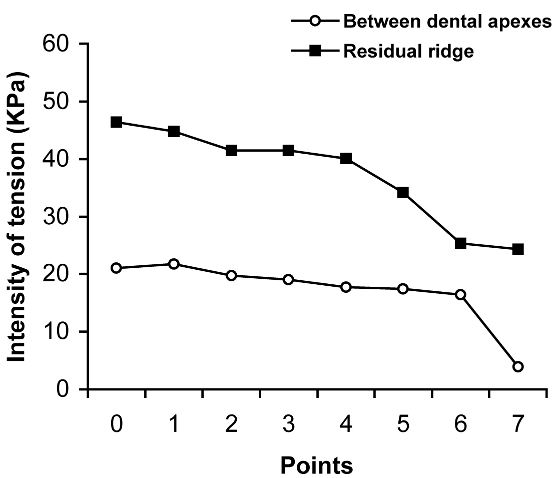

Figure 14 Intensity of tension between dental apexes and on the residual ridge after the application of load on the last artificial tooth (circumferential retainer with short saddle).

In this study, various factors that influence distal-extension RPDs, and therefore their support structures, were analyzed, looking for alternatives that allow for a better distribution of the forces and a greater integration between the prosthesis and the biology of the tissues and the physiology of the stomatognathic system. The results obtained for the T-bar retainer showed a better distribution of tensions when the loads were uniformly distributed in the dentures with long saddles. This means that the ample covering of the basal area allowed for a better distribution of the load per unit area, as suggested by others.[4,10-12] Even with the long saddle, when the load was concentrated on the last artificial tooth, there was a greater concentration of tensions on the residual ridge. This fact demonstrates the importance of the correct occlusal adjustment on the distribution of stress.[14] The occlusal harmony between the denture and the antagonist arch contributes to the healthy condition of the remaining structures.

For the RPI retainer, the best distribution of forces was observed when the load was uniformly distributed on the dentures with long saddles. These data reinforce the comments already made for T-bar retainers. Generally speaking, in the RPI retainer, the tensions concentrated mostly on the residual ridges. This behavior is in accordance with the objective of the retainer, idealized by Kratochvil[14] and later modified by Krol,[15] which is to reduce stress on the abutment. Obviously this must not occur at the cost of overload on the residual ridge, as observed when the loads were localized on the last artificial tooth, both for the long and short saddles, or even when the loads were uniformly distributed in short saddles, where there was a greater concentration of tension on the residual ridges.

The results obtained for the circumferential retainer demonstrated that, even with the long saddles, there was a high concentration of tension between the dental apices when the load was uniformly distributed. This may be due to a greater rigidity of this particular retainer when compared with bar retainers, which may cause a larger dislocation of the direct abutment in the direction of the prosthetic space.[12,18,19] When the load was uniformly distributed on the dentures with short saddles, the values of tension intensity between dental apices and residual ridges were very close, suggesting an equilibrated distribution of tensions with this design; however, it is important to note that not only the distribution, but also the intensity of tension must be considered, since high tensions can be deleterious to the structures responsible for the support of the prosthesis.

Considering the distribution of stress and the measurements of tension intensity obtained for the three retainers, the RPI retainer showed the best performance, followed by the T-bar and the circumferential retainers, in accordance with other reports.[8,14-16,18,19] Interestingly the RPI retainer was more effective only when the long saddle was used and when the load was uniformly distributed. Conversely, when the loads were localized and the saddles shortened, the performance of the RPI retainer was inferior to the T bar. This suggests that when looking for a better and more equilibrated distribution of tensions, we should make use of a wide range of resources, as isolated actions such as the use of the correct extension of the saddle, an incorrect adjustment of occlusion, or the use of more flexible clasps without a proper saddle length may not be completely effective.

Analyzing saddle length, we observed that the best stress distribution occurred with the use of long saddles, with an ample covering of the basal surface.[4,10–12] In general, the short saddles increased the concentration of stress over the residual ridges, independent of the type of load applied. In clinical conditions, this overload on the ridge leads almost inexorably to a rapid and accentuated bone loss, which consequently will lead to the loss of the abutment support.

In relation to the load, the best performance was observed when the load was uniformly distributed, as suggested elsewhere.[10] The localization of the loads on the last artificial tooth induced a greater concentration of tensions on the residual ridge. Considering that the abutment is a more adequate element to receive and neutralize tensions than the alveolar mucosa, one can imagine that, if the distribution cannot be homogeneous, the overload should not fall on the least effective support.[8,19] As these data obtained in this study are experimental,[6–11,14,16] it is important to associate these results with clinical observations,[8,18,19] which will allow a better discernment in the planning of distal-extension RPDs.

Conclusions

The results of this study lead to the following conclusions:

1. The distribution of tensions in the photoelastic models was influenced by the type of retainer, the length of the saddle, and by the form of load application.
2. In relation to the retainer, a more equal distribution of forces between the support structures was seen in the RPI retainer, followed by the T-bar and by the circumferential retainers.
3. As for the saddle length, a more equal distribution of forces between the support structures was observed on the long saddles, as the dentures with short saddles induced a greater concentration of tensions on the residual ridge.
4. When considering the type of load, the best distribution of tensions occurred when the load was uniformly distributed, while the load localized on the last artificial tooth induced greater concentration of tensions on the residual ridges.

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