STRESS DISTRIBUTION AROUND IMPLANTS PRESENTING DIFFERENT INTERPROXIMAL CONTACTS – A PHOTOELASTIC ANALYSIS

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Abstract. *The use of fixed partial dentures in rehabilitations of edentulous jaw with implants is a well documented fact, although controversies still exists about splinting or not prosthetic crowns in these conditions. Thus, the aim of this study was to analyze the effect of prosthetic crowns detachment of a fixed partial denture with surface and punctual contacts by means of stress gradient evaluation determined by the technique of plane transmission photoelasticity. Three photoelastic models were created with 3 contiguous implants corresponding to posterior jaw aligned in straight line, varying the contact between the crowns (contact point = CP; contact surface = CS; splinted = SP). Three loading types were applied: a = axial in group (30 N); b = lateral with a 40º angle (10.8 N) over the implant corresponding to the first molar; c = central axial (9.8 N) over the implant corresponding to the second premolar. Thirty images were obtained of each loading type in each group (n = 270) in the circular polariscope. Fringe orders and maximum shear stress (τ) values were obtained by the computational program "Fringes" by means of photoelastic analysis of 27 points of each image and right away of 12 points in bone crest region. It was carried out the t-Student test with p<0.05 and the stress intensity calculation on specified points. The majority of the points presented statistically different (p<0.05) in different groups. The SP group presented minimum stress values in all loadings. The CS group showed more homogeneous stress distribution around the implants in all loadings and minimum stress values in the bone crest region when compared to the CP group. Within the limitations of this study, the SP group presented better results, followed by the CS group, indicating that the use of splinted prosthetic crowns and contacts by surface is possible considering only stress values. Future studies must be done to assess the results obtained in this work.*

Keyword: *Interproximal contact, Fixed partial dentures, Dental implants, Photoelasticity, Stress.*

1. INTRODUCTION

The rigid union of prosthetic crowns over multiple adjacent implants has been recommended by means of clinical considerations and *in vitro* studies (Weber and Sukotjo, 2007). This condition also has been analyzed by Weinberg (1993), who affirmed that the movement capacity of osseointegrated implants is microscope and do not favor an effective oclusal forces distribution to multiple implants in the same prosthesis. However, due to elastic strain of system components, some loading transfer may be possible splinting adjacent implants. On the other hand, the crowns union of a structure that does not present a passive framework fit, it means a perfect adaptation of the prosthesis over the implant platform, may overload the screws or even the implants (McGlumphy *et al.*, 1998). Thus, some authors have suggested that adjacent implants should be restored individually (Guichet *et al.,* 2002). The photoelastic analysis has been largely applied in Dentistry to study stress distribution around dental implants (Bernardes *et al.,* 2006). This technique consists in an optical property of materials which behave in anisotropic way under loading presenting different refraction ratings in the main stress directions (Dally and Riley, 2005).

Therefore, the aim of this study is to value the effect of splinted crowns in opposite the separating crowns of fixed partial dentures over implants placed in posterior jaw with contacts by surface and punctual by means of qualitative and quantitative stress analysis determined by the plane transmission photoelasticity technique.

2. MATERIALS AND METHOD

Brånemark system implants were used (Titamax TI Cortical Neodent®, Curitiba, Brazil) of 13.0 mm x 3.75 mm (external hex interface) with a 4.1 mm platform, which corresponded to fist premolar (1PM), second premolar (2PM) and first molar (1M) of posterior jaw. The samples consisted in three metallic structures (Ni-Cr) that simulates fixed partial dentures over three adjacent implants, varying the interproximal contact. The CP group consisted in three crowns separated by points of contact presenting 1.0 mm diameter, the CS group consisted in three crowns separated by surfaces of contact with 3.0mm diameter and the SP group consisted in three splinted crowns. The implants distribution was 5.0 mm between 1PM e 2PM implants and 5.7 mm between 2PM and 1M implants. A canine tooth was made with acrylic resin and it was placed into a hole 2.0 mm before 1PM implant (Fig. 1).

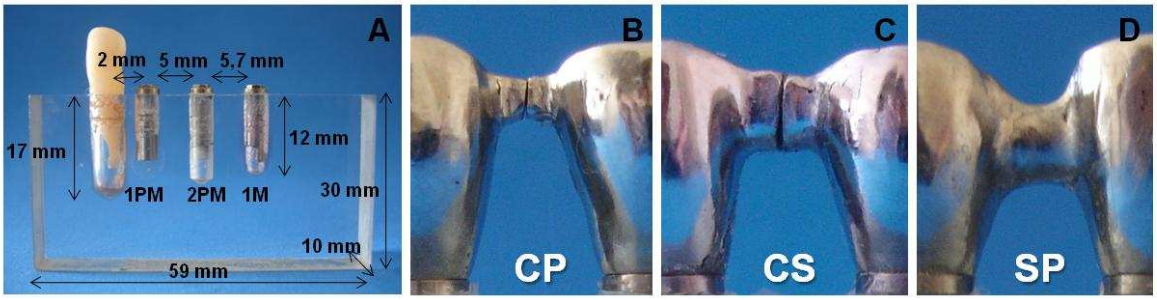

Figure 1: (A) Dimensions of the acrylic matrix; Detail of the interproximal contatcts: contact point (B), surface contact (C) and splinted (D).

After the obtaining of the silicon rubber molds (Silaex® Química LTDA, São Paulo, Brazil) by means of an articulated acrylic box and an acrylic matrix, it was obtained three photoelastic models made with flexible resin (Polipox**®** Indústria e Comércio LTDA, São Paulo, Brazil). After the 24 hours, the cure of the resin was complete and the photoelastic model could be removed from the mold with smooth movements and it was taken to a circular polariscope, with the absence of residual stresses resulting from a process called "edge effect" (Dally and Riley, 2005). The optical constant value of the photoelastic resin ($K\sigma = 0.36$) was determined using a calibration process in a compressed disc made with the same photoelastic material (Dally and Riley, 2005).

The photoelastic resin used in this study has high sensitivity but has low resistance to large deformation. Thus, the range of work force applied on this material is small and with low values. The values of applied load in this test were calibrated in such a way that could allow a better resolution of the fringe orders in the model and allow a comparative analysis of the phenomenon for the three types of crowns on implants evaluated. Three loading types were applied in each model: a = in group and axial (30 N); b = with 40^{o} angle over 1M implant (10.8 N); c = central and axial over 2PM implant (9.8 N). It was made three splinted crowns (Ni-Cr) for “a” loading, simulating an ideal occlusion condition (Misch and Bidez, 1994), where does not exist premature contacts and load transfer is related to the implant angle (Fig. 2). Thirty (30) images of each loading type in each group were obtained (n = 270) by the circular polariscope. For each new image, models were unloaded and loaded again, attempting to get the same way of contact of the loading device over the crowns.

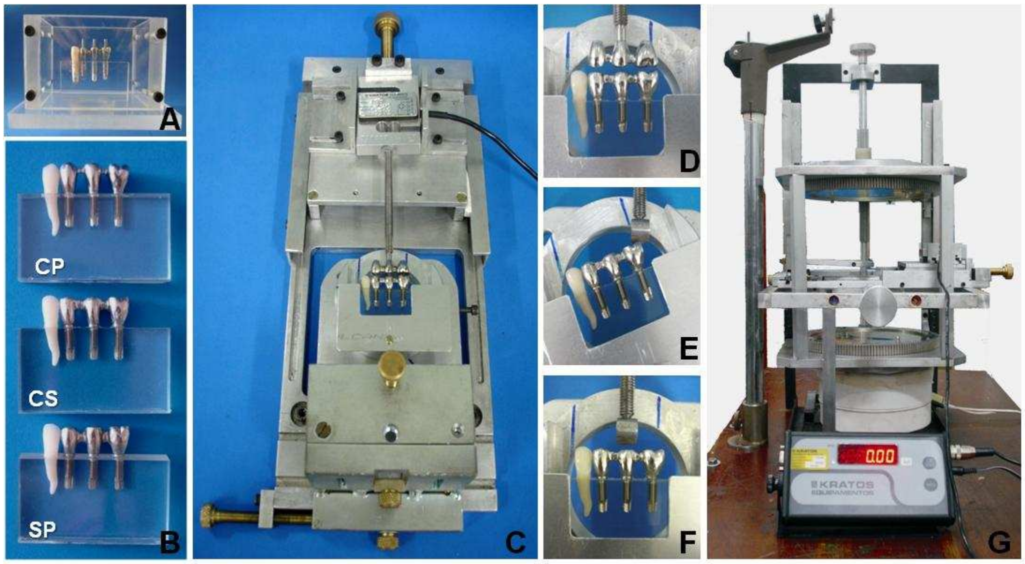

Figure 2: (A) Acrylic matrix fixed into the articulated box; (B) photoelastic models CP, CS and SP; (C) adjustable table on x, y and z directions with “a” loading; (D) “a”loading; (E) “b”loading; (F) “c”loading; (G) circular polariscope and loading cell.

Fringe orders and shear stress (τ) values were calculated by a Fringes software using the computerized photoelastic analysis determined by “Optical Law of Stress” (Dally and Riley, 2005) (Eq. 1).

$$\tau = \frac{\sigma 1 - \sigma 2}{2} \tag{1}$$

From equation (1) and equation (2) it is possible to determine the shear stress from the measured fringe orders, namely:

$$\tau = \frac{N\, f\sigma}{2b} \tag{2}$$

where σ1 and σ2 are the principal stress, fσ is the photoelastic constant of the material, N is the order of fringes and b is the thickness of the photoelastic model.

A mesh of 27 points of analysis was determined by a external file to standard the regions of analysis (Fig. 3A). Aiming to examine critical areas in the bone crest of the implants a mesh of 12 points was also made for the 1M implants (CPb, CSb and SPb) and 2PM (group CPc and CSc) (Fig. 3B). Aiming to verify the existence or not of statistically significant differences, between each of the 27 points got in the 30 images of the three groups and the also the 12 points of the bone crest, it was applied the parametric *t*-Student test ($p<0.05$). It were done a data normalized process through the area under the mean shear stress (τ) for each group, called “pseudo-energy”.

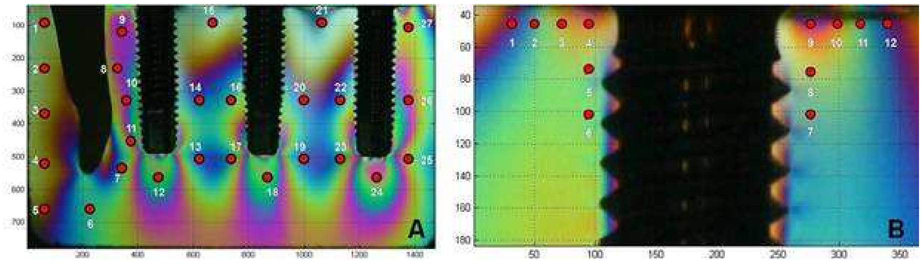

Figure 3: (A) Mesh of 27 points; (B) mesh of 12 points – zoom of the bone crest region

3. RESULTS

For “a” loading, the stress distribution in the implants of groups CP, CS and SP can be seen in figure 4, where it can be noticed the similarity between them in a qualitative analysis. Most points when compared between types of interproximal contact, were statistically different ($p<0.05$). Points around the implants in the CSa group had lower levels of stress when compared to the CPa group (except points 18, 24, 26, 27). For this type of loading, the implants of the extremities presented higher stress levels in all groups. In the SPa group, the central implant (2PM) had the lower stress levels (33.7 kPa) (Fig. 5).

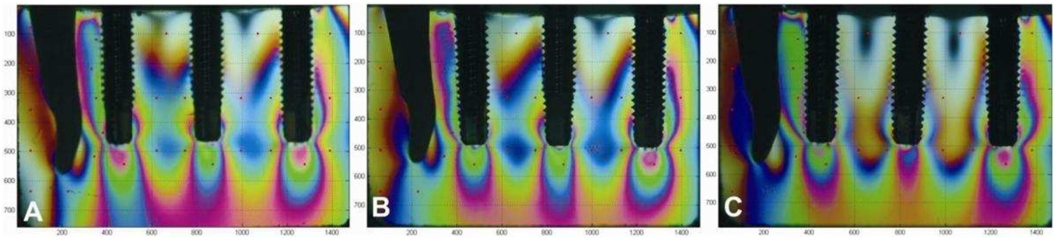

Figure 4: representative images of stress distribution on groups CPa (A), CSa (B) and SPa (C).

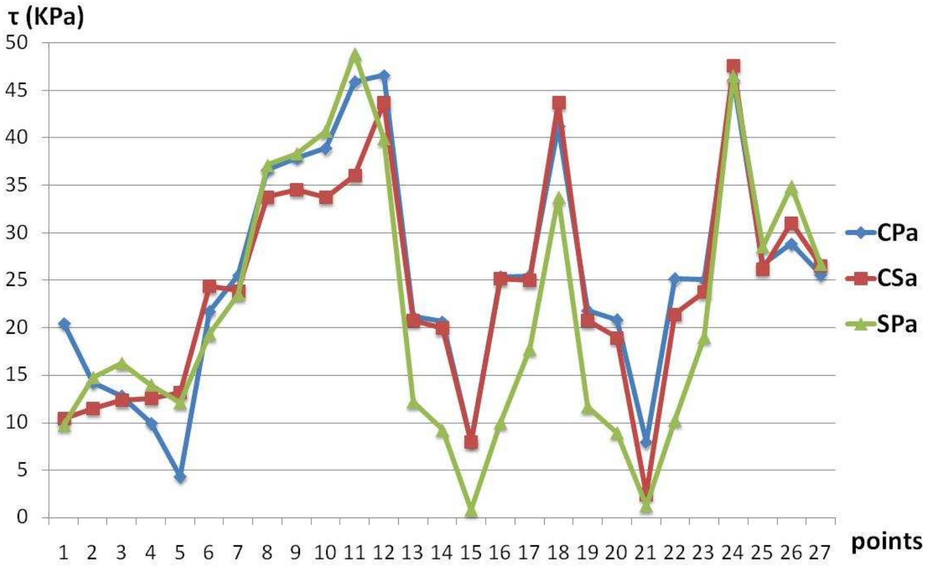

Figure 5: Means values of shear stress (τ) for “a” loading.

The evaluation of the different groups in “a” loading (CPa, CSa and SPa) was performed considering all points, by normalized process using lower value of the graph area (SPa = 568.76) (Tab. 1).

Table 1: Graph’s area - a; Normalized areas - a.

Comparative areas - “a” load			**Normalized areas - “a” load**		
CPa	**CSa**	**SPa**	**CPa**	**CSa**	**SPa**
661,63	632,69	568,76	1,16 (16,32%)	1,11 (11,23%)	1,00 (0%)

For “b” loading, the distribution of stress in the implants of groups PC, SC and ES can be seen in Figure 6. It is possible to observe that the 1PM and 2PM implants were minimally required in the CP and CS group. In SP group there was a change in the stress distribution since the mesial of 1M implant had lower stress levels (point 20 = 1.31 kPa), and there was a higher stress distribution around the tooth and the 1PM and 2PM implants. The values of shear stress at points around the 1M implant (points 21 to 27) were lower in the CSb group. When the groups CPb x SPb and CSb x SPb were compared, most points were statistically different (p <0.000) (Fig. 7). The values of the area under the stress curves were normalized by the group that received lower value of the graph area (SPb = 219.32) (Tab. 2).

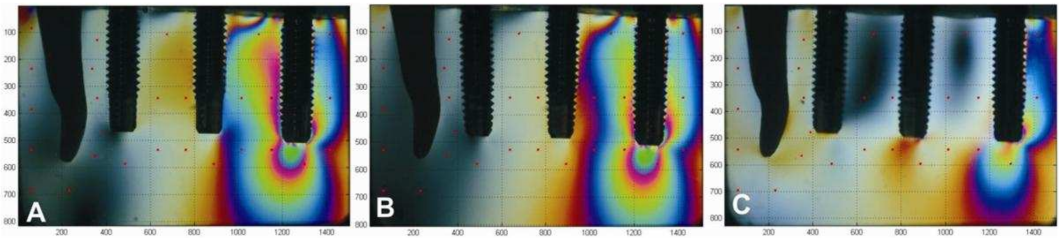

Figure 6: representative images of stress distribution on groups CPb (A), CSb (B) and SPb (C).

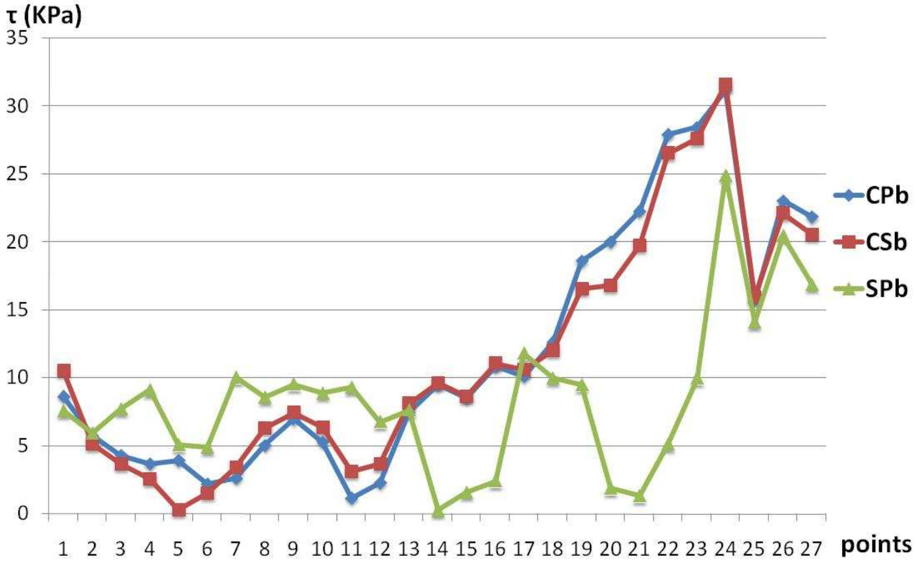

Figure 7: Means values of shear stress (τ) for "b" loading.

Table 2: Graph's area - b; Normalized areas - b.

Comparative areas - "b" load			Normalized areas - "b" load		
CPb	CSb	SPb	CPb	CSb	SPb
305,52	296,68	219,33	1,39 (39,29%)	1,35 (35,26%)	1,00 (0%)

In the region of the 1M implant's bone crest (zoom) submitted to lateral loading (b) there is less stress gradient in the mesial of the implant of SPb group (point 4 = 4.23 kPa). On the implant's distal, the stress level between the groups is similar (point 9). The CSb group had lower concentrations in all 12 points when compared to CPb group (Fig. 8).

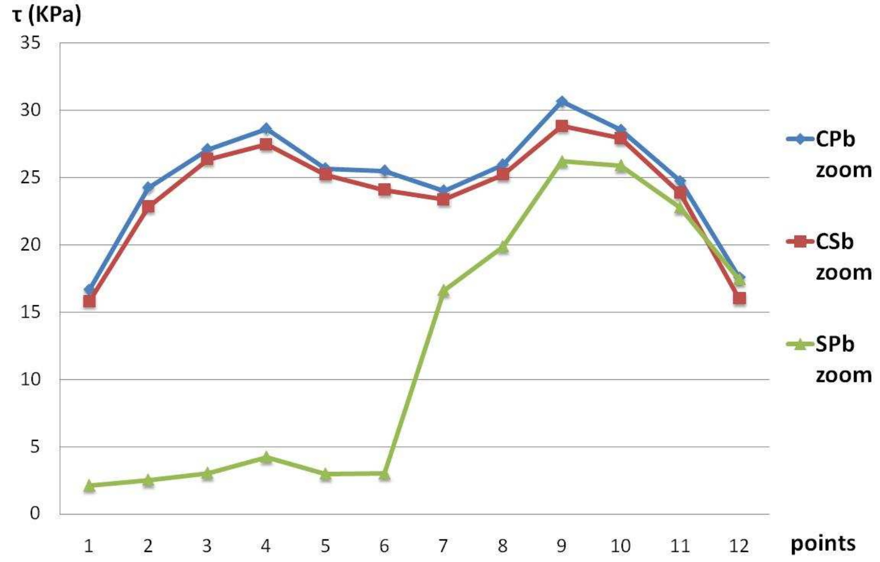

Figure 8: Means values of shear stress (τ) of the bone crest region of 1M implant for “b” loading.

Table 3 shows the results of the graphs’ areas under the curve of stress for the groups analyzed in the loading type "b" in 12 points in the area of the 1M implant’s bone crest. The values shown in table 3 are normalized by the group that obtained lower value of the graph area (SPb zoom = 136.91). It is observed that the CSb zoom group presented levels 98%higher than the SPb group zoom and the CPb group 106% higher.

Table 3: Graph’s area – b zoom; Normalized areas – b zoom.

Comparative areas grupo “b” zoom			Normalized areas grupo “b” zoom		
CPb zoom	**CSb zoom**	**SPb zoom**	**CPb zoom**	**CSb zoom**	**SPb zoom**
282,15	271,19	136,91	2,06 (106%)	1,98 (98%)	1,00 (0%)

For “c” loading, the distribution of stress in the implant of groups CP, CS and SP can be seen in Figure 9. A higher stress concentration around the 2PM implant could be observed for groups CP and CS. Although the stress distribution around the tooth is higher in the SPc group, this group showed a reduction in the stress level around the implants, followed by the CSc group. Many points (1-19 and 23) of the CSc group showed lower levels of stress when compared to the CPc. All the analyzed points between groups CPc x SPc were statistically different. The 2PM implant in SPc group presented the lowest stress levels (point 18 = 10,8 KPa) (Fig. 10). Table 4 shows the normalized values determined by the group that received lower value of the graph area (SPc= 201,3).

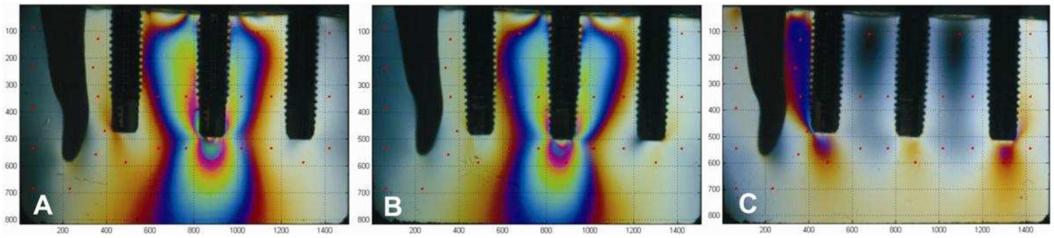

Figure 9: representative images of stress distribution on groups CPc (A), CSc (B) and SPc (C).

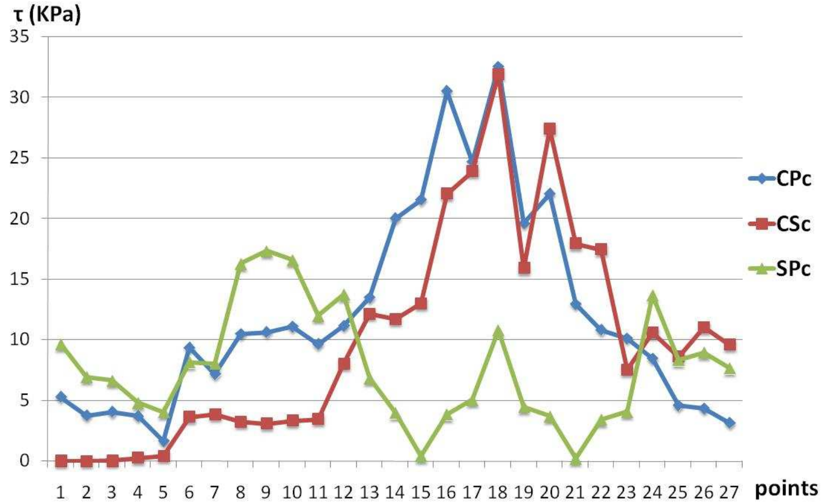

Figure 10: Means values of shear stress (τ) for "c" loading.

Table 4: Graph's area - c; Normalized areas - c.

Comparative areas - "c" load			Normalized areas - "c" load		
CPc	**CSc**	**SPc**	**CPc**	**CSc**	**SPc**
323,25	265,56	201,33	1,60 (60,55%)	1,31 (31,89%)	1,00 (0%)

For the bone crest area of the 2PM implant, at the central loading (c), it is noticed that the CSc zoom group showed a lower stress concentration on all 12 points as compared to CPc. The higher levels of stress were in the more superior and closest area of the implant, both at the mesial as the distal (point 9), with the highest value of the PC group (25.8 kPa) (Fig. 11). Table 5 shows the results of the graph areas under the curve of stress for the groups analyzed in the loading type "c" in 12 points of the bond crest area of the 2PM implant. The SPc group was not analyzed in the area of bone crest due to low stress values in the 2PM implant, discarding the need for comparison between other groups. The values shown in Table 5 are normalized by the group that received lower value of the graph area (CSc zoom = 196.2). It can be seen that the CPc zoom group showed levels 15.3% higher than the CSc group zoom.

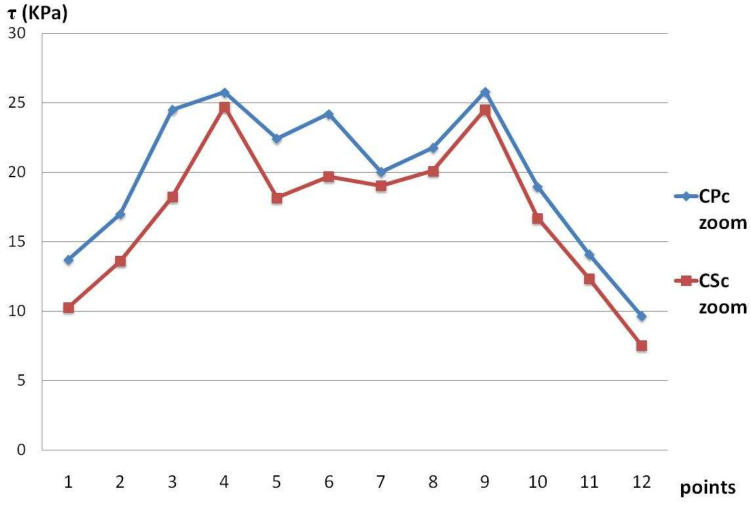

Figure 11: Means values of shear stress (τ) of the bone crest region of 2PM implant for "c" loading.

Table 5: Graph's area – c zoom; Normalized areas – c zoom.

Comparative areas grupo "c" zoom		**Normalized areas grupo "c "zoom**	
CPc zoom	**CSc zoom**	**CPc zoom**	**CSc zoom**
226,48	196,29	1,15 (15,3%)	1,00 (0%)

4. DISCUSSION

In rehabilitation of posterior edentulous areas, some authors recommend the placement of one implant for each missing tooth (Rangert *et al.,*1995). However, the number of implants required to support a fixed partial prosthesis depends on several factors such as available bone volume and its density, the nature of antagonist teeth and location of implants. The implants were positioned in a straight line in the photoelastic model because it is very difficult to achieve a significant misalignment of implants due to restrictions normally imposed by bone resorption (Itoh *et al.,* 2004). Some authors defend the alignment in tripod for better balance of mechanical implants (Rangert *et al.,*1995).

The higher success rates for partial fixed prostheses are reported in the literature in the posterior area of mandible (Lekholm *et al.,* 1999). In rehabilitation with adjacent implants in areas with multiple dental absences, it is recommended in most cases, the splitting of fixed prosthetic restorations, which is necessary if there is not one implant for each tooth, also applied in adjacent unit crowns to achieve a better biomechanical behavior of the prosthesis (Weinberg, 1993). In this study, it was observed that the splitting of adjacent implants leads to a lower stress concentration around the implants, especially in eccentric loads. There is a smooth transfer of stress to the tooth in contact with 1PM implant in the "a" loading group. On "b" loading, the stress levels in SP group were smaller regarding the other groups. It is observed that the CSa group showed values 11.23% higher than the SPa group and the CPa group showed values 16.32% higher. It should be taken into consideration that functional deformations of mandible occur, such as torsion and bending, leading on higher stress values on posterior implants with splinted crowns (Chen, 2000). Moreover, splinted crowns in a structure that does not present a passive framework fit may cause overload in the implants and, consequently, in the surrounding bone (McGlumphy *et al.,* 1998). One way to avoid this problem that jeopardizes the bone integrity is the crowns separation, individualizing the restorations over the implants, since the use of implant-supported restorations alone can reduce the cost and simplify laboratory procedures, facilitating the collection of structures that can provide a passive fit on the prosthetic connections (Guichet *et al.,* 2002).

The restorations separated by points or surfaces of contact in this study showed, in a qualitative approach, great similarity in the stress distribution around the implants in loading "a" when compared to the splinted crowns. Grossmann, et al. (2005) complement the fact that when anterior healthy teeth and periodontal healthy canines are present, the canines immediately disocclude the posterior implants in lateral movements and the patient has vertical occlusal stability, the splitting of posterior implants may be unnecessary. The separation of the crowns can be beneficial to avoid periimplant diseases, improving interproximal contour and avoiding concentration of stress during jaw flexure (van Steenberghe *et al.,* 1990) , as well as the patient satisfaction. However, in eccentric loadings the crowns separation can lead to a higher overload in the implants suffering premature contact. The contacts out of the long axis of the implant may reduce the strength of the bone (Misch and Bidez, 1994). The results of groups CPb and CSb showed a higher stress concentration on 1M implants compared to the SP group. On all loading types in this study, the CS group presented lower stress values compared to CP group. Considering the critical area around the implant (zoom), the implants of groups CSb and CSc showed a reduction in the concentration of stress at all points in the crest bone area, 8% and 15.3% respectively, when compared to the group CPb and CPc. These results contradict the idea that the thicker is the interproximal contact the higher is the stress concentration along the implants with separated crowns (Guichet *et al.,* 2002). Although it simplifies laboratory procedures, it should be kept in mind that adjusting interproximal contacts in individual crowns is difficult. The installation of individual implants in the posterior jaw has high success rates (Naert *et al.,* (2002). As the groups CSc and CPc have similar behavior compared to individual implants and the highest stress levels in this study are within the range of strength of the cortical bone to shear forces. It is suggested that the separation of crowns may not cause damage in bone support.

The real importance of this discussion is that the bone loss remains within the limits suggested by Albrektsson *et al.* (1986) of 0.2 mm per year following the installation of the prosthesis, because they are clinically viable values with which the Implantodontics has lived with for forty years. However, two other possible causes for bone crest loss beyond these limits observed around the bone integrated implants are reported: local tissue infection caused by bacteria of the oral cavity, colonizing the interface pillar/implant and/or biomechanical stress acting on the bone crest around the implants causing local micro fractures and subsequent resorption of the surrounding bone (Adell *et al*., 1981).

Considering the levels of stress obtained in the CP and CS groups, it is suggested that non-splinted crowns may not be harmful to the resistance of the bone's physiological limit, as the range of resistance of the cortical bone to shear forces is 68 MPa (Reilly and Burstein, 1975). According to the results and limitations of this study, crowns separated by a larger contact surface have advantages with respect to the crowns separated by point of contact, because the distribution of stress in the system is smaller and more homogeneous. Under ideal conditions of occlusion, there is qualitative similarity between the groups (PCa x SCa x ESa) suggesting that the separation of crowns on implants can be performed with no pathological bone resorption.

To allow the development of the analysis, the models used in this study considered some simplifying conditions such as the adaptation of clinical conditions to minimize the errors inherent of the loading procedure and preparation of the photoelastic model. However, the method used in this study was correctly indicated due to the complex geometry and loading in the models. And according to Dally and Rilley (2005), the photoelastic technique has advantages over other methods because it allows an optical analysis of continuous field. It is suggested the accomplishment of a clinical study to validate the study, which is in development.

5. CONCLUSIONS

Based on the stress gradient found in this study, it is observed that splinted crowns have better biomechanical behavior. It is suggested that it is possible to use a fixed partial denture on posterior implants with crowns separated by contact surfaces in ideal conditions of occlusion, aiming at improving the patient's hygiene and satisfaction. Another analysis including in vivo tests are necessary to approve that results.

6. ACKNOWLEDGMENTS

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