http://dx.doi.org/10.1590/1981-86372023005520230038

| ORIGINAL

The importance of properly distributing the occlusal load for the correct biomechanics of implant-supported fixed partial dentures: stress analysis in implants, prosthetic components and infrastructures

A importância da distribuição da carga oclusal de forma adequada para a correta biomecânica de prótese parcial fixa implantosuportada: análise das tensões em implantes, componentes protéticos e infraestruturas

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ABSTRACT

Objetcive: The present study analyzed the biomechanical behavior of the generated stress on the external surface of the rehabilitation elements (implants, components and infrastructures) according to different occlusion patterns on a fixed partial denture on osseointegrated implants. **Methods**: The experimental groups varied according to the location of the occlusal load applied to the Fixed partial denture, with a total occlusal load of 750N in all groups, opting for greater loads on the occlusal table of the molar in relation to the premolar. This evaluation was performed by the finite element method with simulations by the AnsysWorkbench 16.0 Software program. **Results**: The results analyzed for implants and their components showed that the more posterior the occlusal loading, the greater the stress developed (group 4), always in the connection area between the prosthetic component and the implant, as this location can induce greater screw loosening. The results analyzed for the infrastructures showed that the most distributed occlusal loading possible (group 1) is the best situation for generating less stress. However, even in group 3 which obtained the highest stresses in the critical area of the prosthetic connection, the zirconia flexural strength values generated were not worrisome. **Conclusion**: It can be concluded that the occlusal adjustment of Fixed partial dentures are preponderant and decisive factors for correct biomechanics and preservation of the system in the long term in order to avoid possible damage and/or failures, and exert significant and notorious differences in the behavior of all structures studied herein.

Indexing terms: Finite element analysis. Fixed partial denture. Occlusal adjustment.

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How to cite this article

Sakamoto SPS, Souza DHV, Terada ASSD, Borges ALS, Toniollo MB. The importance of properly distributing the occlusal load for the correct biomechanics of implant-supported fixed partial dentures: Stress analysis in implants, prosthetic components and infrastructures. RGO, Rev Gaúch Odontol. 2023;71:e20230055. http://dx.doi.org/10.1590/1981-86372023005520230038

RESUMO

***Objetivo**: O presente estudo analisou o comportamento biomecânico do estresse gerado na superfície externa dos elementos reabilitadores (implantes, componentes e infraestruturas) de acordo com diferentes padrões de oclusão em uma prótese parcial fixa sobre implantes osseointegrados. **Métodos**: Os grupos experimentais variaram de acordo com a localização da carga oclusal aplicada na Prótese Parcial Fixa, com carga oclusal total de 750N em todos os grupos, optando por cargas maiores na mesa oclusal do molar em relação ao pré-molar. Esta avaliação foi realizada pelo método dos elementos finitos com simulações pelo programa AnsysWorkbench 16.0 Software. **Resultados**: Os resultados analisados para os implantes e seus componentes mostraram que quanto mais posterior a carga oclusal, maior a tensão desenvolvida (grupo 4), sempre na área de conexão entre o componente protético e o implante, pois este local pode induzir maior soltura do parafuso. Os resultados analisados para as infraestruturas mostraram que a carga oclusal mais distribuída possível (grupo 1) é a melhor situação para gerar menos estresse. No entanto, mesmo no grupo 3 que obteve as maiores tensões na área crítica da conexão protética, os valores de resistência à flexão da zircônia gerados não foram preocupantes. **Conclusão**: Pode-se concluir que o ajuste oclusal das Próteses Parciais Fixas são fatores preponderantes e decisivos para correta biomecânica e preservação do sistema a longo prazo a fim de evitar possíveis danos e/ou falhas, e exercem diferenças significativas e notórias no comportamento de todas as estruturas aqui estudadas.*

***Termos de indexação**: Análise de elementos finitos. Ajuste oclusal. Prótese parcial fixa.*

INTRODUCTION

Osseointegration emerged in the 1950s with the action of Per-Ingvar Branemark and collaborators through a study of bones, who conceptualized that osseointegration would be the intimate connection of an implant with the surrounding bone [1].

However, considerable differences exist between natural teeth and implant prosthesis functioning. Mechanoreceptors located in the peri-implant bone are approximately 8 times less sensitive in perceiving sensitivity when compared to mechanoreceptors in the periodontal ligament, which makes occlusal adjustment and the intensity of force applied to artificial teeth difficult and essential in care [2].

When it comes to rehabilitation on implants in the posterior region in which the masticatory loads become more accentuated, it is necessary to pay attention to its correct control and inquiry. This is even more exacerbated when there is no implant for each rehabilitated element, as in the case of fixed partial dentures (FPD) containing suspended or pontic elements. Cases such as this in which there is a tendency for greater requirement of rehabilitation and of all components that involve the system require extreme caution and maximum possible control of various factors, including occlusion.

According to Flanagan [3], failures can be avoided by following predetermined precepts in the literature, including carefully adjusted occlusal load. Thus, implant-supported prostheses not receiving excessive loads tend to have good stress distribution, generating treatment success and patient satisfaction, and this will favor the biomechanics of FPD.

In order for the implants to perform their functions without failure, it is necessary to have correct biomechanical load distribution to all the components which compose the rehabilitation [4]. In addition, this fact is directly linked to how the occlusal factor is adjusted on the implant prosthesis surface. The distribution of occlusal loads can be altered to enable better stress dissipation to the system to avoid exacerbated stresses, since a FPD with pontic can generate greater stresses and biomechanical demands [5-7].

In addition to this force intensity, the position and distribution of the masticatory load is a fundamental point to be analyzed [8,9], which can be more or less distributed to different places in the occlusal table of the dental elements [10]. According to Costa et al. [11], all occlusal contacts must be established and fully distributed throughout the arch for an adequate balanced occlusion. This will ensure that there is better distribution of forces. However, despite its importance, the representation and occlusal scheme are not always clear in the minds of professionals.

Osseointegrated implants can result in unwanted failures, and one of the factors which increases their incidence is excessive occlusal load on the prosthesis [12,13]. It is known that there will be a biomechanical reflex of stresses in both bone and implants according to the application of occlusal loads during mastication [14]. Therefore, occlusal loads must be within a tolerated physiological threshold, which is difficult to measure and control, but of fundamental importance for the correct biomechanical behavior of the system [3].

In this context, it is important that professionals pay attention and are careful regarding this issue. They must base their decision regarding occlusal adjustment of prostheses on implants on scientific and safe evidence, since it can lead to rehabilitation failure if not respected [15].

Therefore, the objective of this study was to analyze and compare the biomechanical behavior of the implant-supported FPD elements (implants, components and infrastructures) according to the variation in the applied occlusal load distribution.

METHODS

The present study used FEM to evaluate which occlusal load distributions presented the best aspects in an oral environment with an implant-supported FPD with an intermediate pontic, installed and well-adapted. Cylindrical implants inserted 2mm below the bone were used with transmucosal prosthetic abutments of 3.5mm. The cortical bone and mucosa thickness was set at 2mm.

All drawings of the structures (CADs) used in the experimental models had a finite element mesh generated and were assigned each respective mechanical characteristic. The models were considered isotropic, homogeneous, and linearly elastic. The contact between the different structures was considered "bonded", meaning without sliding. All FPD infrastructures were metal-free with a zirconia infrastructure (modulus of elasticity 269,000 MPa and Poisson's ratio 0.25 – reference by Arinc [16] and Gungor & Yilmaz [17]), with feldspathic ceramic coating (modulus of elasticity 80,000 MPa and Poisson's ratio 0.30 - reference by Arinc [16] and Erkmen et al. [18]), and closure of the screw holes with composite resin. The bones were type I, considered to be of good quality. The assigned modulus of elasticity and Poisson's ratio were based on a bibliographic reference by Toniollo et al. [19].

The total occlusal load applied in all experimental groups was exactly the same in order to standardize the simulation of the same bite with identical intensity and in the same oblique direction (approximately 30 degrees in the lingual-vestibular direction), and at the same occlusal points (cusp tip and groove bottom, predetermined).

The total occlusal load applied to the FPD was 750N, opting for greater loads on the occlusal table of the molar in relation to the premolar. The variation between the experimental groups (figure 1) was in the location of the occlusal load in the FPD, with the 4 situations explained below:

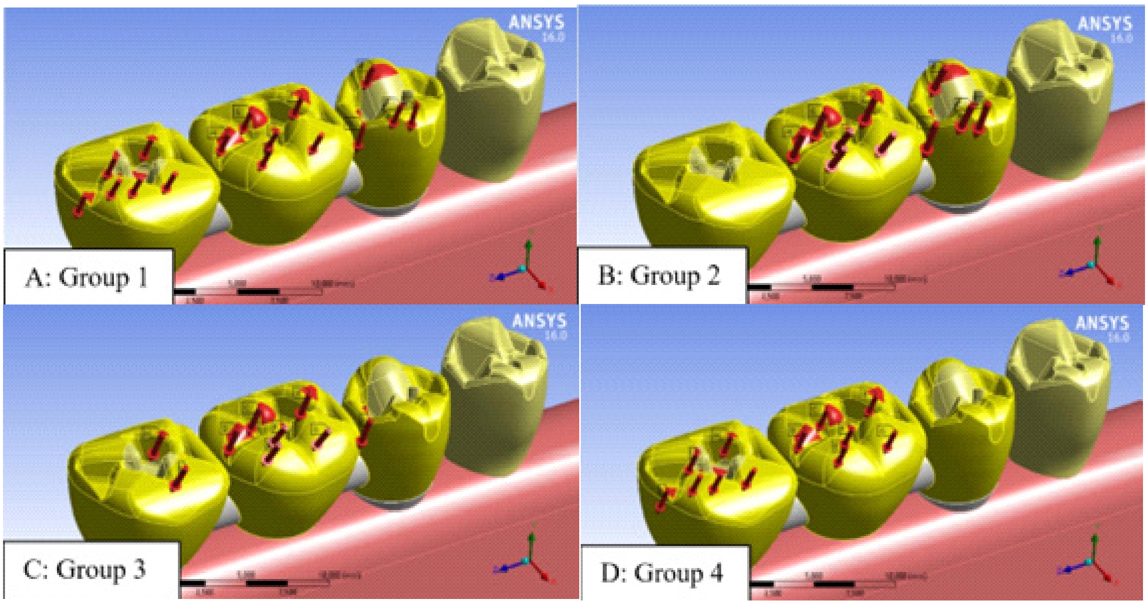

Figure 1. Experimental groups, A: Group 1 (control) - homogeneous and distributed occlusal loading throughout the FPD; B: Group 2 - occlusal loading on the most anterior and intermediate element of the FPD; C: Group 3 - occlusal loading on the intermediate element and part of the anterior and posterior elements of the FPD; D: Group 4 - occlusal loading on the most posterior and intermediate element of the FPD.

- Group 1 (control): homogeneous occlusal loading and distributed over the occlusal table of the entire implant-supported FPD, being 150N in the premolar and 300N in each molar; total occlusal load of 750N across the FPD.

- Group 2: occlusal loading located only on the most anterior and intermediate elements (pontic) of the implant-supported FPD, being 200N in the premolar and 550N in the 1st molar (pontic); total occlusal load of 750N across the FPD.

- Group 3: main occlusal loading located in the intermediate element (pontic) and in part of the anterior and posterior elements of the implant-supported FPD, being 550N in the 1st molar, 100N in the mesial of the 2nd molar and 100N in the distal of the premolar; total occlusal load of 750N across the FPD.

- Group 4: occlusal loading located only on the most posterior and intermediate (pontic) elements of the implant-supported FPD, with 375N in the 1st molar and 375N in the 2nd molar; total occlusal load of 750N across the FPD.

The master model used in creating all experimental groups had 172,800 nodes and 103,536 elements (figures 2 and 3). The stresses developed in the implants, components, and infrastructures were analyzed using von Mises Equivalent Stress (VMES).

This evaluation was performed by the finite element method (FEM) with simulations by the AnsysWorkbench 16.0 Software program. The results were analyzed quantitatively (absolute values of stress developed in the proposed experimental groups) and qualitatively (location, intensity and dispersion of the generated stress).

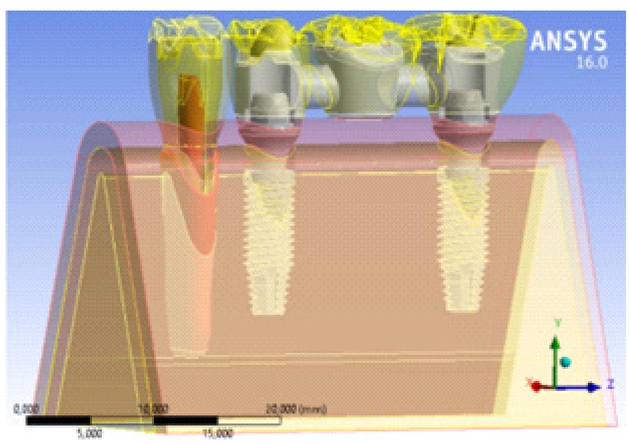

Figure 2. Three-dimensional transparency view of the master model used for the experimental groups.

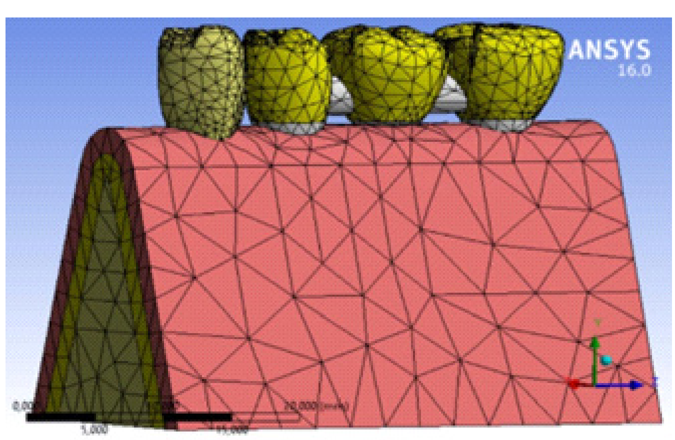

Figure 3. Finite element mesh generated over the master model.

The value scales obtained in the simulations varied according to the stress obtained in each group, and therefore the scales were standardized in their values and color references to enable better comparison between the experimental groups; more specifically, for the analysis of implant and component stresses, a scale of unique values was adequate for the 4 experimental groups; and for the analysis of infrastructure stresses, a scale of unique values was adequate for the 4 experimental groups.

RESULTS

The simulations performed obtained results of the stresses generated (VMES) on the external surface of the implants and their respective prosthetic components (figure 4), as well as the prosthetic infrastructure (figure 5), according to the experimental groups simulated in the different occlusal loads.

The results of stresses in implants and components are presented below from the vestibular view (the area of greatest significance for analysis). The results in Figure 4 show that the most significant stresses always occur in the connection area between the implant and the prosthetic component (abutment). Figure 4B reveals that group 2 presented the lowest stress among the analyzed experimental groups (721 Mpa). Figure 4D shows that group 4 presented the highest stresses among the experimental groups analyzed (882 Mpa), especially in the most posterior implant/component. Thus, a difference of 18% is observed in the stress values obtained between such groups.

The results in figure 5 show that the most significant infrastructure stresses always occur in the area of the most anterior prosthetic connector between the most anterior element and the intermediate prosthetic element (pontic). In the case of infrastructure, the maximum stress values obtained will be disregarded due to the fact that they are located in areas on the occlusal edge of the FPDs with low thickness, which is why they increased such records. Figure 5A reveals that group 1 presented the lowest stresses among the analyzed experimental groups (around 150 Mpa). Figure 5C shows that group 3 presented the highest stresses among the analyzed experimental groups (around 200 Mpa), especially in the abovementioned area of the prosthetic connector.

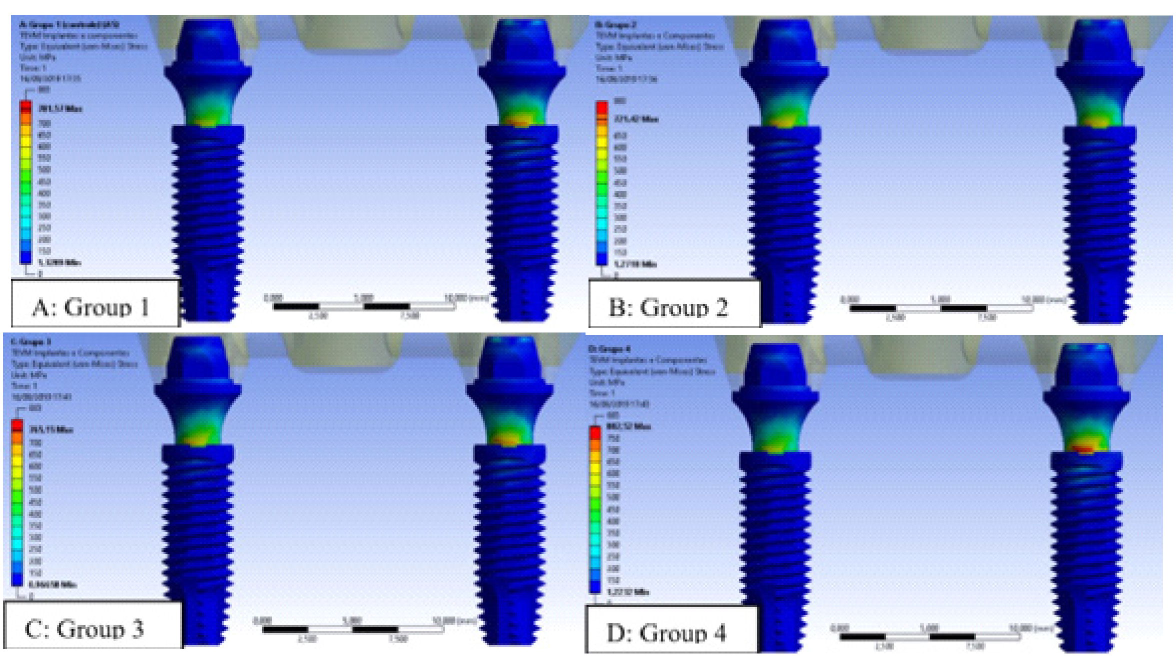

Figure 4. Results of the experimental groups for the stresses on the implants and their components (vestibular view); A: Group 1 (control) - homogeneous and distributed occlusal loading throughout the FPD; B: Group 2 - occlusal loading on the most anterior and intermediate element of the FPD; C: Group 3 - occlusal loading on the intermediate element and part of the anterior and posterior elements of the FPD; D: Group 4 - occlusal loading on the most posterior and intermediate element of the FPD.

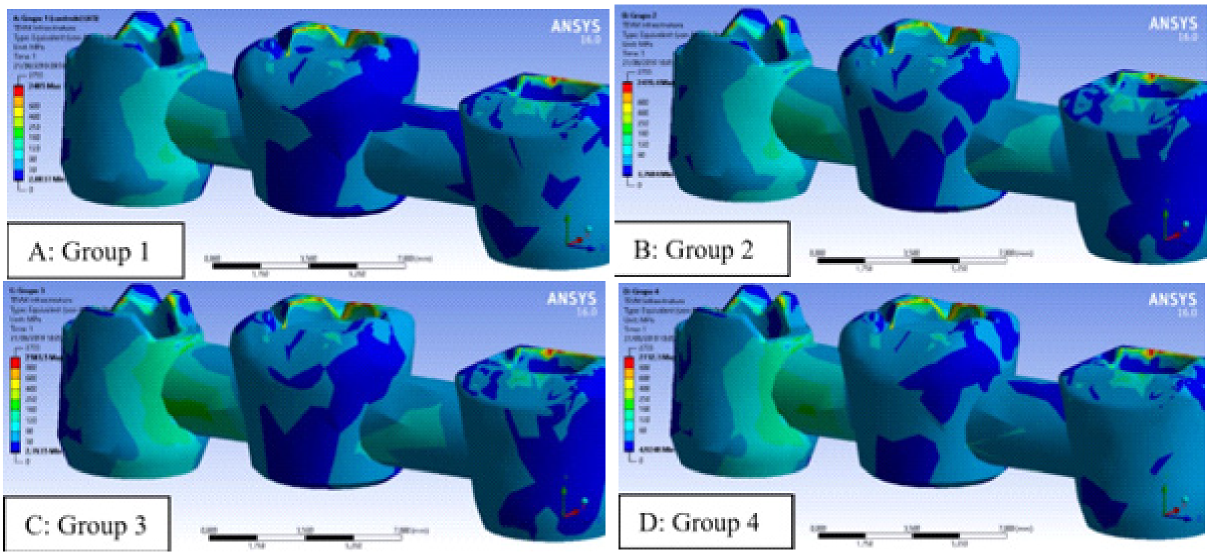

Figure 5. Results of experimental groups for stresses on zirconia prosthetic infrastructure (vestibular perspective view); A: Group 1 (control) - homogeneous and distributed occlusal loading throughout the FPD; B: Group 2 - occlusal loading on the most anterior and intermediate element of the FPD; C: Group 3 - occlusal loading on the intermediate element and part of the anterior and posterior elements of the FPD; D: Group 4 - occlusal loading on the most posterior and intermediate element of the FPD.

DISCUSSION

The literature still reveals some doubts and questions about the masticatory load tolerated by the jaws. Occlusal forces are variable, and the intensity, frequency and direction of these loads can alternate irregularly [20].

According to Flanagan [3], the intensity of the bite force in the human species can reach an average of 800N, and in these cases attention should be paid to the need for greater bone structure in order to withstand the generated stress. Therefore, the loads applied to the simulated posterior segment in the present study were 150N for the premolar and 300N for each molar, which totaled a load of 750N on the FPDs.

The same author mentions that priority should be given in these high masticatory intensity cases to having a greater number of implants in the rehabilitation support, and also to splinting the prosthesis with a flat and narrow occlusal table [3].

However, as in the present simulated study, it is often not possible to use the maximum number of implants in the area due to anatomical and/or financial limitations, thus requiring prostheses with the presence of a cantilever or pontic, for example.

In addition to the intensity of the masticatory loads, another important fact that often cannot be controlled is their direction. Occlusal loads in the axial direction are generally better tolerated by implant-supported prosthetic rehabilitations. The opposite is contraindicated, as loads in a distal, mesial, vestibular or lingual direction are not always well tolerated [10]. This means loads with an oblique characteristic are the most harmful, but at the same time those which appear most in the masticatory movement [21-23].

In the same context, Stegaroiu et al. [23] simulated axial loads and observed that prostheses with two implants and a central pontic obtained similar results to those of the prosthesis with three elements joined to three implants. However, under non-axial loads, only crowns joined with three implants were able to minimize the harmful effects of the occlusal loading performed. Therefore, it can be seen that the type of occlusal loading is also of paramount importance in the biomechanical behavior of the prostheses and its consequences for the supporting structures.

According to Tanasić et al. [24], there is also a correlation with the length and diameter of the implants, since they state that the greater the patient's occlusal force, the greater the need to increase the measurements of this implant.

There is a relationship cited by Davies et al. [25] correlating occlusal table size with implant size, in which the first measurement should not be greater than the second, because if this happens there will be excess lateral occlusal forces and possible failure in osseointegration. Thus, the implant should have a proportion of twice the length of the crown for an implant-supported prosthesis to support occlusal loads well [26].

However, when there is a limitation of bone structure, it is not possible to use as many implants as possible, or it is not possible to fully control the size relationship of the crown to the implant, or furthermore it is not possible to fully direct the forces to the long axis of implants, and therefore alternatives must be analyzed to determine the best biomechanical behavior of this FPD, for example different types of occlusal adjustments [5-7].

There is an ideal type of occlusion to be used for each type and size of implant-supported prosthesis [11]. Unilateral balanced occlusion has a higher occlusal pressure on its working side compared to bilateral balanced occlusion [14]. The fixed implant-supported complete dentures must be installed in mutually protected occlusion, seeking to perform the canine guide to avoid contact of the posterior teeth during mandibular excursive movements [27]. In cases where there is an antagonist arc with conventional mobile prostheses, bilateral balanced occlusion can be used to achieve prosthetic occlusal stability [27].

Such concepts are mainly more suitable when considering mandibular excursive movements which are dynamic. But there is also the relationship of static occlusal contacts regarding the relationship between working cusps and antagonistic elements. Such a relationship, conventionally known as occlusal contacts in maximum intercuspation, is also a delicate factor that can generate premature contacts and occlusal injuries when poorly adjusted.

In the present study, it was possible to simulate and predict the stress generated with occlusal loads similar to maximum intercuspation, and therefore the option to use contacts at the tip of cusps and the bottom of predetermined grooves was chosen.

Therefore, in varying the experimental groups in the present study, it can be seen that their variation according to the proposals of the groups exerted biomechanical reflexes on the supporting structures, even when using the same pre-established occlusal points. Varying the occlusal load in all the elements of the FPD in a more balanced way, or in the most anterior, middle or posterior direction of the FPD, and always keeping the total occlusal load equal to 750N, generated disparate behaviors of the stress in the implants, prosthetic abutments and infrastructures.

Specifically regarding the biomechanical behavior of the implants and their respective prosthetic components (figure 4), which in this case were 3.5 mm transmucosal abutments, a worse situation can be seen for the experimental group 4 (figure 4D). This finding was expected, since it has occlusal loads on the teeth of greater magnitude (molars), one of which is the pontic, and additionally in the most posterior region of the FPD, which overloaded the system. Furthermore, as there was no adjacent tooth in the posterior region, this may have further affected the stress in the region.

The comparison between groups 1 and 2 (figures 4A and 4B) reveals something interesting; it was expected that group 1 (control) would have the lowest possible stresses as it had the most distributed occlusal load. However, it was noticed that group 2 had the lowest stress peaks. From this, and added to the results of groups 3 and 4, it can be concluded that the preponderant factor and the greatest damage, at least regarding the biomechanics of implants and prosthetic components, are the occlusal loads on the most posterior elements of the FPD, since group 2 (which does not have occlusal loading on the posterior molar) obtained the best results, around 18% less than group 4 with the highest stress.

Taking into account the results obtained for the infrastructures (figure 5), a worse situation is observed for experimental groups 3 and 4, with group 3 still showing higher stress in the connection area of the FPD in the more posterior region. This reveals that occlusal loading exclusively concentrated in the intermediate pontic region and/or more posterior region of the FPD would not be the best situation for good stress distribution in infrastructure. Despite this, the obtained stresses ranging from approximately 120 to 200 MPa would not cause damage or risk of failure to the material used (in this case zirconia), which has flexural strength above 1000 MPa according to some authors [17,28,29].

In analyzing Group 1 (control) (figure 5A), it can be affirmed that there was less stress in the critical areas of the infrastructure, including better stress dissipation, which leads us to believe that the occlusal adjustment well distributed over the entire occlusal surface of the FPD is really beneficial for its biomechanical behavior.

Therefore, with correct occlusal adjustment, and mainly in search of preserving more posterior areas of the FPD (where there are less adjacent structures to contain the proximal movement, and which may have been one of the factors causing greater stress in the more distal areas associated with the greater occlusal table of the molars), is of great importance and attention to control the patient's occlusion in implant-supported prostheses.

CONCLUSION

According to the results obtained in the present study, and correlating them with the literature data, the following conclusions can be drawn: the biomechanical behavior and the external stresses of the analyzed structures vary according to the occlusal loading, with the control of such occlusal loads therefore being of important relevance. Implants and their respective prosthetic components are more affected when loads are positioned to more posterior regions of the FPD occlusal table, which is evident in the connection area between abutment and implant. The infrastructures are better preserved when there is good and balanced occlusal adjustment, which notably reduces the stresses in their external surface area.

Acknowledgment

The researchers involved in this study are grateful for the incentives provided by the University of Rio Verde (UniRV) and the National Council for Scientific and Technological Development (CNPq).

Collaborators

SPS Sakamoto and DHV Souza, writing - proofreading and editing. ASSD Terada, supervision. ALSB Borges, methodology. MB Toniollo, project administration.

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Received on: 16/6/2023
Approved on: 5/7/2023

Assistant editor: Luciana Butini Oliveira