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| ORIGINAL

Biomechanical behavior of implants with prosthetic connection of the morse (Cone) type, with different angulations at the implant-abutment interface in multiple dental prostheses: a finite element study

Comportamento biomecânico de implantes com conexão protética tipo morse (cônica), com diferentes angulações na interface implante-pilar em próteses múltiplas: estudo de elementos finitos

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ABSTRACT

Objective: Evaluate the biomechanical behavior of the influence of different internal angles of conical prosthetic connections in fixed partial prostheses of three elements, through the tridimensional finite element method. **Methods**: Two different models of segment of the posterior portion of the mandible, with two implants with conical connections at angulations of 11.5 and 16 degrees. Afterwards, and occlusal load of 180N was used, and divided into 2 points of application on the premolar, and 400N divided into 5 points of application on the molar. Data were acquired as the tensile, compressive and shear stresses on cortical and medullary bone, and von Mises stresses on implants and prosthetic components of two implants in both in three-unit fixed partial prosthesis. In the quantitative analysis, both in cortical and medullary bone, the tension peaks in tensile, compression, and shear forces were higher for the CM16 group. **Results**: When analyzing qualitatively, the cortical and medullary bones presented a greater stress around the implant platform with a higher incidence in the implant in the molar region. In the von Misses analysis in both groups, the tensions were concentrated in the cervical region of the implants, in the first threads, in the premolar and molar regions. Regarding prosthetic pillars, the stress concentration was located in the region of contact with the implant. **Conclusion**: The increased angulation of conicity of the internal

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conical connections represents a determinant factor to increase in stress concentration in the implants, prosthetic components and adjacent structures, such as the cortical and medullary bone.

Indexing terms: Dental implantation. Finite element analysis. Prostheses and implant.

RESUMO

***Objetivo**: Avaliar a influência das diferentes angulações internas de conexões protéticas cônicas em próteses parciais fixas de três elementos, em relação a distribuição de tensões no osso cortical e medular adjacente, também como nos implantes e componentes protéticos através do método dos elementos finitos. **Métodos**: Foram analisados de forma quantitativa e qualitativa, através do método de elementos finitos, as tensões de tração, compressão e cisalhamento no osso cortical e medular, e tensões de von Misses nos implantes e componentes protéticos de dois implantes, um com conexão cônica de 11.5 graus e o outro de 16 graus. Ambos em prótese múltipla de três elementos. **Resultados**: Na análise quantitativa, tanto no osso cortical quanto no medular, os picos de tensão nas forças de tração, compressão, e de cisalhamento foram maiores para o grupo CM16, se comparado ao CM11,5, exceto a força de cisalhamento do osso cortical, que obteve valores muito próximos em ambos os grupos. Ao se analisar qualitativamente, os ossos corticais e medulares apresentaram um maior stress ao redor da plataforma dos implantes com incidência maior no implante na região do molar. Na análise von Misses em ambos os grupos, as tensões concentraram-se na região cervical dos implantes, nas primeiras roscas, nas regiões de pré-molar e molar. No que diz respeito aos pilares protéticos, a concentração de tensões foi localizada na região de contato com o implante. **Conclusão**: Podemos concluir que conforme o ângulo da interface implante-pilar aumenta, ocorre uma incidência maior de tensões em todas as áreas envolvidas nesse estudo.*

***Termos de indexação**: Implantação dentária. Análise de elementos finitos. Próteses e implantes.*

INTRODUCTION

Differently from natural teeth, dental implants are in direct contact with the bone, and the bone-implant interface has the lowest level of resistance, because the occlusal loads are transmitted directly onto the periphery of bone. When analyzing the dynamics of the occlusal load on the implant, it is possible to observe this difference, because the natural tooth has a periodontal ligament that allows the absorption of stresses, or even its movement within the alveolus [1]. This is directly associated with the type of loading, supporting bone tissue, implant geometry and mechanical properties of both the implant and prosthesis. If the occlusal force exceeds the capacity of stress absorption of the osseointegrated interface, the implant will be doomed to failure [2].

Dental implant systems differ in the macrogeometry of the implant, and in the geometry of the implant-abutment interface. Basically, we could distinguish between external connections, an external hexagon pattern on the implant platform; internal connections that have a variety of morphologies (internal hexagon, internal octagon, internal Trigon); and internal conical connections, with different angles at the implant-abutment interface [3], which must be considered a category apart, because they have particular properties, and have previously been investigated separately [4].The different angles at the implant-abutment interface could be leads to differences in the mechanical resistance and biomechanical behavior, due to the difference in the contact surface between the interface of the implant and the prosthetic abutment.

The implant-abutment connection has been considered a strategic area for the long-term success of a rehabilitation with dental implants because it is profoundly involved in all the biological and technical complications. The implant-abutment interface represents the weak link of the dental implant system. This is because it must resist the maximum and permanent masticatory forces, and be resistant to bacterial penetration, which could lead to increased marginal bone loss [5].

Therefore, the aim of this study was to evaluate the different internal angulations of conic prosthetic connections in three-element implant -supported fixed, partial dentures, by means of the finite element method, by qualitatively and quantitatively evaluating the stresses on and deformation of bone, implants and prosthetic components.

METHODS

In this study, the methodology used for evaluating the distribution of stresses was by means of computation tools for numerical analysis, Method of Finite Elements (FEM) in three dimensions.

To conduct the study, the three-dimensional modeling software SolidWorks 2018 (SolidWorks Corp., Concord, Massachusetts, U.S.A.) and software for analysis by the finite element method Ansys (ANSYS Workbench 17, Ansys Inc., Canonsburg, Pennsylvania, USA), were used in a Gateway NV53 computer with an AMD Athlon II X2 M300 processor, 15.6” monitor 16:9 HD LED LCD, 500 GB HDD and 16 GB of RAM memory.

Making the three-dimensional models

A specific software for modeling three-dimensional structures (SolidWorks 2013, SolidWorks Corp., Concord, Massachusetts, U.S.A.) was used for modeling a segment of the posterior portion of the mandible on the basis of cross-sectional images of the posterior human mandible obtained by cone beam computer tomography. Two virtual model consisted 2 implants with conical connections at angulations of 11.5 (group CM 11.5) and 16 degrees (group CM16); prosthetic components for three-unit screw-retained fixed partial dentures were composed.

Each model of the mandibular segment received two cone morse implants of 3.75 x11 mm in parallel with different angulations of the prosthetic connections. For Group CM11 the implants used had an angulation of 11.5 degrees without index and for Group CM16 the implants used had an angulation of 16 degrees (Titamax Grand Morse, Neodent, Curitiba, PR Brazil) (figure 1). For positioning the implants, the presence of two anatomic accidents was considered - the mandibular canal and mental foramen. In the two groups, the implants were specifically allocated to the same positions along the mandibula.

The partial denture was constructed with the aid of a CAD drawing software program, Exocad, in which a three-element fixed partial prosthesis was designed, having the right second premolar, tooth 35, and right second molar, tooth 37, as abutments, with the right first molar, tooth 36 as pontic. After creating the prosthesis, it was exported to the Solidworks 2018 software in STL Format. The CAD files of the implants and prosthetic components were provided by the company Neodent Implants (Neodent, Curitiba, Brazil).

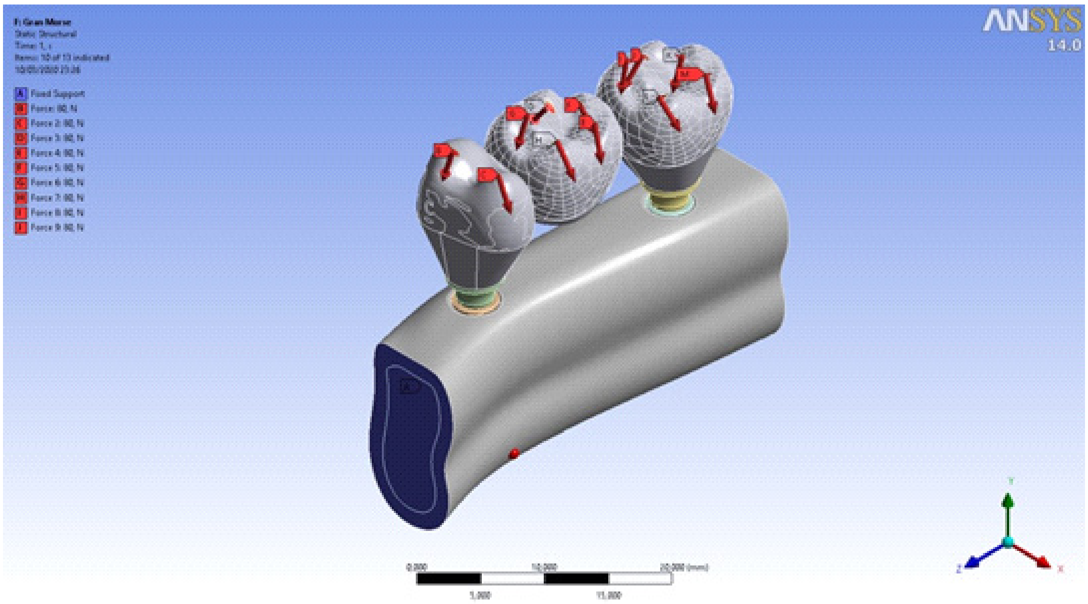

Figure 1. Occlusal loading applied on molars and premolars.

Finite element analysis

The models were exported to the finite element mathematical analysis program Ansys Workbench; version 18 (Swanson Analysis Inc., Houston, PA, USA) for biomechanical analysis. The biomechanical properties of the prosthesis, prosthetic abutments, screws and implants were considered to be isotropic, homogeneous and linearly elastic; and the cortical and medullary bone were considered anisotropic (table 1). In the analysis, a discrete finite element mesh was generated, using 10-knot quadratic tetrahedral elements with 3 degrees of freedom per knot.

Table 1. Mechanical properties.

Material	Young's Modulus (E) (MPa)		Shear Modulus (G) (MPa)		Poisson Coefficient	
Cortical Bone	E_x	12600	G_{xy}	4850	δ_{xy}	0.30
	E_y	12600	G_{yz}	5700	δ_{yz}	0.39
	E_z	19400	G_{xz}	5700	δ_{xz}	0.39
Medullary Bone	E_x	1150	G_{xy}	6800	δ_{xy}	0.010
	E_y	2100	G_{yz}	4340	δ_{yz}	0.32
	E_z	1150	G_{xz}	6800	δ_{xz}	0.05
Titanium	104000		38800		0.34	
Zirconium	210000		33000		0.31	

To improve accuracy and ensure the comparability of results, the analysis was accomplished by mesh refinement at a 5% level. The mesh was generated with 0.5-mm quadratic tetrahedral elements of 10 nodes (ANSYS solid187), enabling the simulation of irregular structures. Group CM11 had 221463 knots and 128277 elements (figure 2) and Group CM16, 194009 knots and 113818 elements. The contour conditions were defined by means of fixating the distance at the upper surfaces of the bone segment in all the directions of the Cartesian axes (x, y and z).

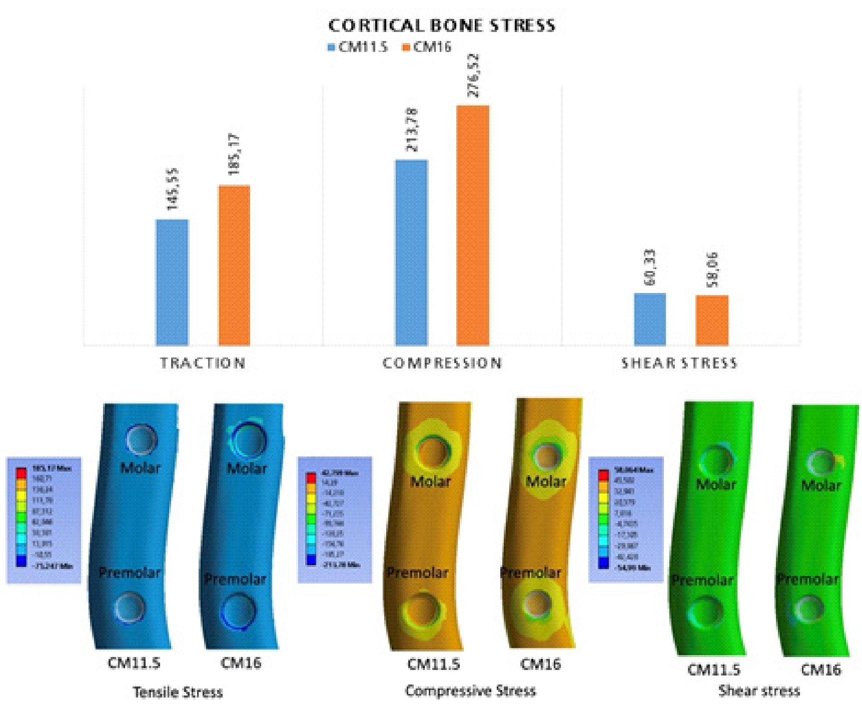

Figure 2. Tensile, compressive and shear stresses on cortical bone for Groups CM11.5 and CM16, and Cortical bone stress maps for Groups CM11.5 and CM16.

The contacts between the implant and cortical bone, between implant and medullary bone, between cortical bone and medullary bone and between denture retainer screws were assumed to be bonded, while the contact between the structure/implant were assumed to be juxtaposed. The contour conditions were established as being fixed on the three axes (x, y and z) on the lateral surfaces of the cortical and medullary bone, with the remainder of the set being free of restrictions.

Afterwards, and occlusal load of 180N was used, and divided into 2 points of application on the premolar, and 400N divided into 5 points of application on the molars (figure 3), simulating a normal masticatory force on the modality of nodal force.

The tensile stress values (σmax), compression (σmin) and shear (τ) for the cortical and medullary bone tissue and the equivalent von Mises stress (σvM) and maximum deformation (εmax) for the implants were obtained for numerical comparison and coded by colors between the groups of all the models.

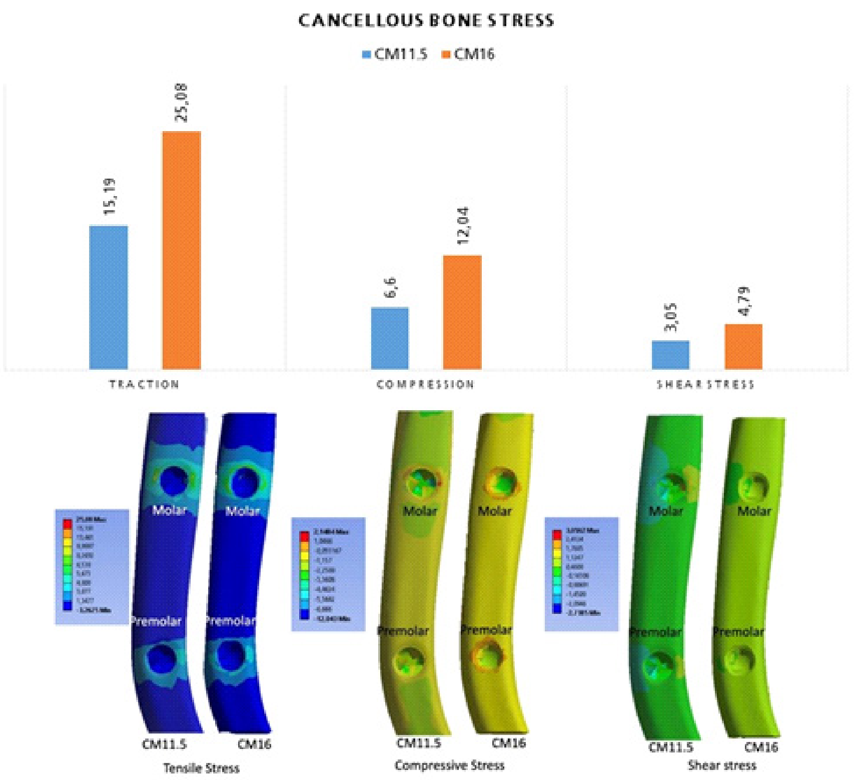

Figure 3. Tensile, compressive and shear stresses on medullary bone for Groups CM11.5 and CM16 and Medullary bone stress maps for Groups CM11.5 and CM16.

Manner of analyzing the results

The results were recorded, evaluated and compared both graphically and numerically for qualitative and quantitative analysis, in order to gain a better understanding of the situation analyzed. The different materials were analyzed by different criteria due to the inherent characteristics of each material and its behavior.

The Mohr-Coulomb criterion was used to quantify the structural level and risk of damage. This criterion was selected because it considers the difference in the impact of tensile and compressive stresses on a friable material such as bone, and its impact on generating bone damage.

The theory of the Mohr Coulomb criterion defines that a material fractures when the combination of the principle stresses are equal to or exceed the limits of resistance. The classical criterion could be defined by the formula:

$$\frac{\sigma 1}{\sigma \textit{ tensile strength}} + \frac{\sigma 3}{\sigma \textit{ compressive strength}} < 1$$

Where:

σ1 is the Maximum Principle Stress,

σ3 is the Minimum Principle Stress and

σ resistance The maximum stress at fracture under compressive and tensile load

Therefore, the criterion analyzes the impact of the tensile stresses and their relations with the resistance to traction, as well as the compressive stresses and their relations with the resistance to compression. To facilitate the comparative analyses, an adaptation was made, and could be defined by the formula:

$$\frac{\sigma 1}{\sigma \textit{ limit of flow stress}} + \frac{\sigma 3}{\sigma \textit{ limit of flow compression}} \quad \sigma R$$

Where:

σR is the result,

σ1 is the Maximum Principle Stress,

σ3 is the Minimum Principle Stress

σ limit The maximum flow stress under compressive and tensile load

As reference for the calculation by the criterion the limit of flow stress to traction is 82.8 MPa and the of limit flow stress to compression is 133.6 MPa. These values are based on medullary bone because no reference values were found within one and the same study for the cortical bone indices. However, because they are similar materials, the values would probably have a similar proportion.

The titanium components were analyzed according to the von Mises criterion, due to the ductile characteristics of titanium, and because this criterion is indicated for the analysis of ductile metals. As reference of analysis for implants, the flow limit of 550 MPa of Grade 54 titanium was used.

RESULTS

The results of the stress and deformation analyses were quantitatively and qualitatively evaluated. For quantitative evaluation, the maximum values of the stress criterion chosen for each structure, in Megapascal (MPa) and µstrain for deformation were used. In the qualitative evaluation, the authors sought to understand how these stresses were dissipated and where the sites of maximum stress accumulation were. The images generated in the finite element analysis software were acquired for each structure of each group (cortical bone, medullary bone, implants and components) according to the criteria of analysis (von Mises, tensile, compressive and shear stress). With the purpose of being able to compare the study groups, the gradient and color scales were standardized in the images for comparison of each structure.

Biomechanical analysis for cortical bone tissue

The results obtained of the analyses of stress on cortical bone based on the quantitative and qualitative evaluation are presented in figure 1. The maps of stresses on cortical bone and the prevalence of stress may be observed around the implant platform; this was more evident on the implant in the region of the molar.

From the tensile stresses, 145.55 and 185.17 Mpa, and compressive stresses, 213.78 and 276.52 Mpa, it was observed that Group CM11.5 showed lower stress concentration values when compared with Group CM16. However, for shear stress the two groups showed similar behaviors.

Biomechanical analysis for medullary bone tissue

The results obtained of the analyses of stress on medullary bone based on the quantitative and qualitative evaluation are presented in figure 2.

The concentration of tensile, compressive and shear stresses occurred at higher magnitude in Group CM16 with values of 25.08; 12.04 and 4.79 MPa, respectively, when compared with Group CM11.5, 15.19; 6.60 and 3.05 MPa, respectively. Figure 5 demonstrates the map of stresses found on medullary bone.

Biomechanical analysis of Implants and Prosthetic Abutments

The quantitative results of the biomechanical analysis of the implants and prosthetic abutments are presented in figure 4.

The stresses were concentrated on the implants in the cervical region, on the first threads; on the implants in the molar and premolar regions in both groups. As regards the prosthetic abutments, the stress concentration was localized on the region of contact with the implant, narrowing the prosthetic abutment.

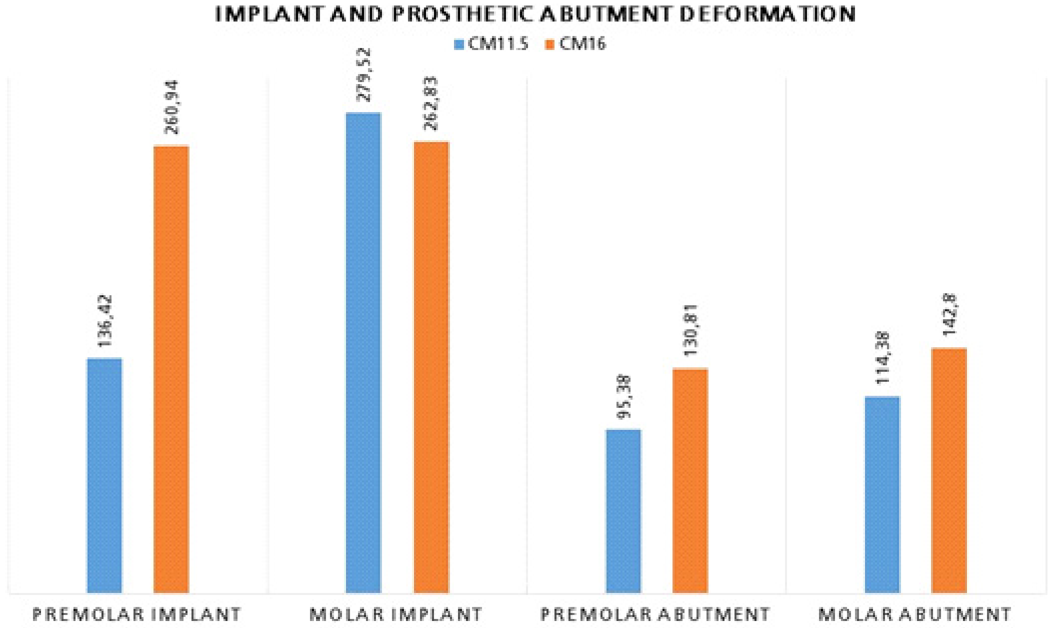

Figure 4. The von Mises stresses on implants and prosthetic abutments for Groups CM11.5 and CM16.

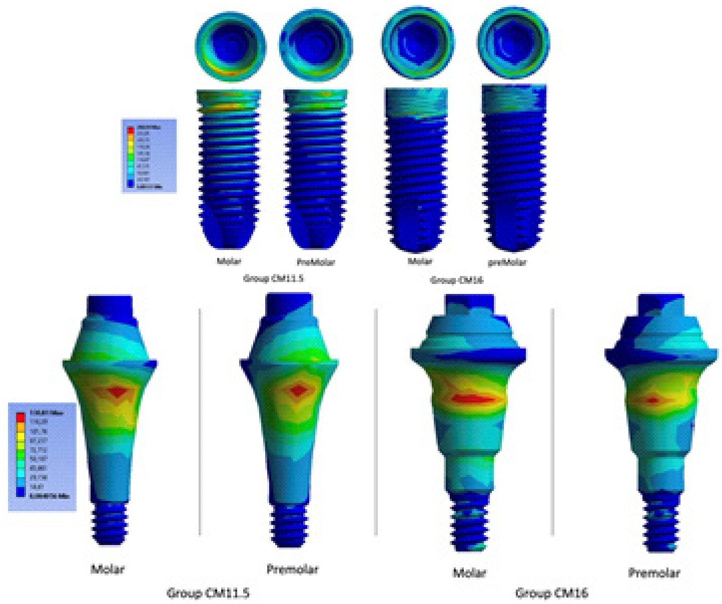

Figure 5. Implant stress maps and Abutment stress maps for Groups CM11.5 and CM16.

DISCUSSION

The internal conical connection has demonstrated better biomechanical behavior when compared to hexagonal connections, mainly the external hexagonal connection. However, the internal conical connections have different configurations regarding the conicity of the connection angle, with in this study showed the increased angulation of conicity of the internal conical connections influence negative in the stress distribution.

In the present study, two systems of the implant prosthetic connection conical internal were used, however, with different angles of conicity at the implant-abutment interface; one of 11.5 degrees and the other of 16 degrees. The change in angulation of the implant-abutment interface leads to differences in the mechanical resistance and biomechanical behavior, due to the difference in the contact surface between the interface of the implant and the prosthetic abutment. However, the increase in angulation reduces the morse effect at the implant connection-abutment interface [10]. It is noteworthy that the internal conical connections to be considered connections morses must respect an angle of 1.5° in each wall, totaling a taper of 3°. Thus, connections with these characteristics would have self-locking by pure friction. Therefore, the two studied angles cannot be considered with Morse effect.

The results of this study showed that although the two implants had conic connections, with the only difference between them being the angle of the interface, their biomechanical behavior exhibited differences in practically all the stresses tested. This may suggest that the conicity of the prosthetic connection could influence the biomechanical behavior of the implant-abutment system.

From a quantitative aspect, in the cortical bone the conicity of 16 degrees showed higher tensile and compressive stresses than those shown for the conicity of 11.5 degrees. Under shear stress, however, both showed the same behavior. From the qualitative aspect, we saw that there was higher prevalence of these stresses around the implants inserted in the region of the molars, in both models.

On medullary bone, the concentration of tensile, compressive and shear stresses occurred with higher magnitudes at the conicity of 16 degrees, than at that of 11.5 degrees. Qualitatively, as was the case with cortical bone, there was a higher prevalence of these stresses on the implants inserted in the molar region in both models, which may be explained by the higher level of masticatory force exerted on the molars in comparison with premolars [6]. In addition, we saw that the cortical bone was subjected to a great deal more stress than the medullary bone, due to its mechanical properties and greater difficulty with dissipating stresses [5].

With regard to implants, the stresses were concentrated on the first threads (of the screws) in the cervical region in both groups, in agreement with various published studies [7,8]. However, there was higher incidence of stress on the first molars in the Group of 16 degrees, and in the region of the molars in the Group of 11.5 degrees. As regards the prosthetic components, the stress was concentrated on the region of contact with the interface of the implants, and was higher in the Group of 16 degrees, both in the region of the premolars and molars [6].

For this study, we elected the finite element method because it was the method that would best represent the complex geometries, in addition to allowing the insertion of distinct properties into the same system and identification of the results localized. Nevertheless, this method has some limitations, such as premises that live tissues are homogeneous and linearly elastic, and that the contacts between the structures are connected, which could influence the results obtained [9].

The models were submitted to occlusal loads, simulating the masticatory forces, as follows: 2 points of application on the premolar, and 5 points of application on the molars, simulating the clinical conditions based on masticatory forces of a healthy patient of the male sex [10]. In the present study the torque applied for tightening the screws of the prosthetic components was included, which is a factor that has been overlooked in various other studies using the same methodology [11-15]. Moreover, different stresses such as tensile, compressive and shear types were evaluated for the cortical and medullary bone tissues, and the equivalent von Mises stress for the titanium elements (implants and prosthetic components). These factors were evaluated both quantitatively and qualitatively, using different criteria, because each element has its own characteristics and behaves in a different way.

Although the values for the internal distribution of stresses found by the finite element study provided us with important data, which together with the numerical values of maximum stresses (smax, smin, svM) and mechanical test values of resistance to fracture, could lead to improvements in the project of implant-supported restorations, the in vivo stress values that really cause biological changes, such as bone resorption and remodeling, are not yet known at present [16].

CONCLUSION

Within the limitations of this study, the increased angulation of conicity of the internal conical connections represents a determinant factor to increase in stress concentration in the implants, prosthetic components and adjacent structures, such as the cortical and medullary bone.

Collaborators

MFA Serpa and BS Sotto-Maior, these authors contributed to conception and design to the study, acquisition of data, analysis, and interpretation of data. Additionally, this author was important in drafting the article and revising it critically for important intellectual content. CE Francischone, this author contributed to conception and design to the study and interpretation of data. Additionally, this author was important in drafting the article and revising it critically for important intellectual content. MA Ribeiro and W Lima, these authors contributed to conception and design to the study and interpretation of data. Additionally, this author was important in drafting the article and revising it critically for important intellectual content.

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