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PAOLO TULIO DI NIZO

Effect of Implant length in stress concentration in the alveolar ridge in mandibular overdenture, through in finite element analyzes and photoelasticity

Efeito do comprimento dos implantes na concentração de tensões no rebordo alveolar em *overdenture* mandibular, por meio de análises por elementos finitos e fotoelasticidade

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Dissertação apresentada à Faculdade de Odontologia de Piracicaba da Universidade Estadual de Campinas como parte dos requisitos exigidos para o título de Mestre em Materiais Dentários

Dissertation presented to the Piracicaba Dental School of the University of Campinas in partial fulfillment of the requirements for the degree of Master in Dental Materials.

Orientador: Professor Doutor Lourenço Correr Sobrinho

Coorientador: Professor Doutor Mateus Bertolini Fernandes dos Santos

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RESUMO

O presente estudo avaliou o efeito de diferentes comprimentos de implantes (9, 11, 13 e 15 mm) nas tensões geradas próximas aos implantes e na região do corpo da mandíbula quando a prótese do tipo *overdenture* suportada por dois implantes foi submetida à carga unilateral de 170N. Quatro modelos fotoelásticos contemplando uma mandíbula com prótese total inferior do tipo *overdenture* retida por dois implantes do tipo hexágono externo com diferentes comprimentos e sistema barra-clipe foi confeccionada. As tensões geradas próximas aos implantes quando a prótese for submetida à carga unilateral de 170 N foram analisadas com auxílio de equipamento para análise de tensões por fotoelasticidade, para avaliação qualitativa e quantitativa das tensões. Para a análise de elementos finitos, modelos tridimensionais de uma mandíbula com prótese total inferior do tipo *overdenture* retida por dois implantes e sistema barra-clipe foram confeccionados e exportados para *software* de simulação mecânica Ansys Workbench – Academic Mechanical module v16. Da mesma maneira, a carga foi aplicada unilateralmente e com intensidade de 170 N e todas as estruturas do modelo 3-D foram avaliadas quanto à distribuição de tensões. As análises de elementos finitos avaliaram a Tensão Máxima Principal e de von Mises, em MPa. Usando a análise fotoelástica a análise quantitativa e qualitativa demonstraram um significativo aumento na concentração de tensões na área peri-implantar principalmente do lado afetado pela aplicação da carga a análise de elementos finitos apresentou resultados similares de aumento de tensão na área peri-implantar como observados na ánalise fotoelástica. A análise fotoelástica demonstrou que os implantes com menores comprimentos apresentaram tensão média maior que os maiores comprimentos de implantes. Os valores apresentados pela análise por elementos finitos demonstraram que a tensão aumentou na região periimplantar proporcionalmente ao aumento do tamanho do implante.

Palavra-chave: Implantes Dentários, *Overdenture*, Fotoelasticidade, Elementos Finitos.

ABSTRACT

This study evaluated the effect of different implant lengths (9, 11, 13 and 15 mm) in tensions near the implants and jaw area of the body when the prosthesis type overdenture supported by two implants was submitted to a unilateral load of 170N. Four photoelastic models contemplating a jaw denture lower overdenture retained by two implants type of external hexagon with different lengths (9, 11, 13, and 15 mm) and bar-clip system has been made. The tensions near the implants when the device was subjected to a unilateral load of 170 N were analyzed with the aid of equipment for a photoelastic stress analysis equipped with software for the qualitative and quantitative evaluation of stress. For the finite element analysis, three-dimensional models of a jaw denture lower overdenture type retained by two implants and bar-clip system were made and exported to mechanical simulation software Ansys Workbench - Academic Mechanical module v16. In the same way, the load was applied unilaterally and with an intensity of 170 N and all the 3-D model structures were evaluated for stress distribution. The finite element analysis evaluated the maximum principal Stress and von Mises in MPa. Using the photoelastic analysis of quantitative and qualitative analysis demonstrated a significant increase in stress concentration in the peri-implant mainly on the side affected by the load application area of finite element analysis, gave results similar voltage increase in peri-implant area as observed in photoelastic analysis.The photoelastic analysis showed that implants with smaller lengths had an average stress greater than the largest implant lengths. The values presented by the finite element analysis showed that the increased stress in the peri-implant region in proportion to the increase of the implant size.

Key words: Dental Implants, Overdenture, photoelasticity, finite element

SUMÁRIO

INTRODUÇÃO

Atualmente tem sido comum a utilização de implantes osseointegrados na reabilitação de pacientes desdentados totais. Dentre as possibilidades de tratamento, as próteses totais tipo *overdentures* se destacam por oferecer satisfação aos usuários(Thomason *et al*., 2010), custo relativamente menor do que as próteses totais tipo protocolo (Carlsson & Omar, 2010) e pelo fato de requerer menor número de implantes. Há também menor necessidade de realização de cirurgias de enxerto ósseo, que pode aumentar as despesas e o tempo necessário para a realização do tratamento. As próteses totais do tipo *overdenture* têm sido indicadas como a primeira opção de tratamento para mandíbula totalmente edêntula(Feine *et al*., 2002; Thomason *et al*., 2009; Thomason *et al*., 2010), por propiciar expressivo ganho de estabilidade e retenção comparadas às próteses totais convencionais.

Em muitos casos, a colocação de implantes não é viável devido às reabsorções ósseas severas. A realização do enxerto ósseo acarreta ganho na quantidade óssea, mas pode ser contraindicada para pacientes com problemas de saúde geral ou mesmo para pacientes que não possuam condição financeira. A opção para estes pacientes é a colocação de implantes com comprimento reduzido. Entretanto, os implantes com comprimento maior e mesmo diâmetro proporcionam maior área de contato com o tecido ósseo e oferecem melhor resposta às tensões. Outro fator importante é que próteses totais tipo *overdenture* também possuem suporte mucoso, sendo que os implantes osseointegrados atuam no aumento da retenção e estabilidade.

As *overdentures* podem apresentar diferentes sistemas de retenção, como magnetos, *O'rings* e barra-clipe. Encaixes *O'ring* proporcionam maior grau de liberdade para a prótese, permitindo rotação em todas as direções (Kimoto *et al*., 2009). Entretanto, este sistema de retenção apresenta grande sensibilidade com relação à inclinação dos implantes, sendo sugerida angulação máxima de 10 graus entre os implantes (Walton *et al*., 2001). Outro sistema de retenção relatado na literatura é o magneto; entretanto, este sistema é pouco utilizado por ser menos retentivo dentre todos utilizados em *overdentures* (Petropoulos *et al*., 1997). Além disso, apresenta corrosão e desgaste excessivo com consequente redução da retenção (Naert *et al*.,1991). O sistema de retenção barra-clipe é o sistema que proporciona maior retenção da prótese (Trakas *et al*., 2006). Este sistema proporciona distribuição favorável das tensões devido à esplintagem, permitindo rotação do clipe sobre a barra. Esta rotação permite que as forças provenientes da mastigação, consideradas as mais prejudiciais para os implantes, sejam melhores distribuídas nos implantes e na área de suporte mucoso da *overdenture* (Allen *et al*., 2003)

A avaliação clínica é, sem dúvida, o método mais seguro para analisar uma determinada situação. Entretanto, o estudo do comportamento biomecânico de estruturas intraósseas se torna inviável por aspectos éticos e/ou metodológicos (Abreu *et al*., 2010; Spazzin *et al*., 2011). Na tentativa de prever possíveis falhas decorrentes da excessiva concentração de tensões, diversas metodologias foram desenvolvidas, dentre elas pode-se ressaltar a Análise Fotoelástica e a Análise de Elementos Finitos (AEF). A Análise Fotoelástica é um método experimental baseado na propriedade óptica de certos materiais plásticos transparentes que, quando submetidos à tensão/deformação, apresentam alterações nos índices de refração possibilitando por meio da "Lei óptica das tensões" quantificar as tensões geradas nas regiões desejadas (Markarian *et al.,* 2007). Ainda o desenvolvimento de modelos tridimensionais (3-D) específicos por elementos finitos possibilita investigar de forma similar o que acontece *in vivo*, de maneira não destrutiva, oferecendo informações precisas e confiáveis a respeito da biomecânica envolvida em diversas situações(Bergendal *et al.,*1995; Taddei *et al*., 2006). Possibilita, ainda, prever e quantificar as tensões concentradas por todo o sistema (mucosa/implante/osso). A utilização de diferentes metodologias para avaliar uma mesma situação possibilita a diminuição de possíveis falhas referentes às interpretações inadequadas de resultados e/ou limitações inerentes de cada método. Desse modo, o clínico poderia melhor interpretar as situações clínicas referentes à indicação de diferentes comprimentos de implantes para serem utilizados na reabilitação com próteses totais tipo *overdentures* (Geng *et al*., 2001).

Entretanto, pouco se sabe também sobre o comportamento biomecânico de overdentures retidas por implantes com comprimentos de 9, 11, 13, e 15 mm. Dessa forma, seria importante avaliar o comportamento biomecânico de overdentures retidas por implantes com diferentes comprimentos, a hipótese do trabalho foi que os diferentes comprimentos de implantes utilizados na retenção de *overdentures* iriam promover o estresse diferente na região peri-implante.

Portanto, o objetivo neste estudo *in vitro* foi verificar:

1 - Por meio da análise fotoelástica e da análise por elementos finitos, o comportamento biomecânico de overdentures retidas por dois implantes com comprimentos de 9, 11, 13, e 15mm.

Este trabalho foi apresentado no formato alternativo de tese de acordo com as normas estabelecidas pela deliberação 002/06 da Comissão Central de Pós-Graduação da Universidade Estadual de Campinas. O artigo referente ao Capítulo 1 foi submetido à publicação no periódico Brazilian Dental Journal.

CAPÍTULO 1- Effect of Implant length in stress concentration in the alveolar ridge in mandibular overdenture, through in finite element analyzes and photoelasticity

Artigo submetido para publicação no periódico Brazilian Dental Journal.

ABSTRACT

This study evaluated the effect of different implants' length on stress distribution on peri-implant bone tissue and jaw body when overdentures supported by two implants were subjected to the unilateral load of 170N. Four photoelastic models of an edentulous mandible with an overdenture retained by two implants and a bar-clip system were be made. The stresses generated near the implants when the prosthesis were submitted to a unilateral load of 170 N were evaluated using photoelastic stress analysis equipment with software for qualitative and quantitative evaluation. For the finite element analysis, three-dimensional models of an edentulous mandible with an overdenture retained by two implants with different lengths (9, 11, 13 and 15 mm) and a bar-clip system were be made and exported to mechanical simulation software Ansys Workbench – Academic Mechanical module v16. Also, the load was applied unilaterally and with an intensity of 170 N and all the 3-D model structures were assessed on stress distribution. The finite element analyzes assess the maximum principal and von Mises stress, in MPa. Using the quantitative and qualitative photoelastic results it was observed a significant increase in the stress in the peri-implant area mostly on the side affected by the load application. Finite element analysis presented similar results. implants with smaller lengths have presented the highest stress concentrations in the peri-implant region.

Keywords: Dental Implants, Overdenture, photoelasticity, finite element

INTRODUCTION

Currently, the use osseointegrated implants in the rehabilitation of edentulous patients increasing. Among the possibilities of treatment, overdentures stands out by offering user satisfaction,[1] cost relatively lower than the full-arch implant retained dentures,[2] and the fact that it requires fewer implants which avoid the need for bone grafting procedures that increase the morbidity, costs, and time required for treatment. Overdentures have been indicated as the first treatment option for completely edentulous jaw,[1,3,4] by providing a significant improvement in stability and retention compared to conventional dentures.

In many cases, placement of implants is not feasible due to severe bone resorption. A possible option for these patients is the placement of implants with reduced length. However, it is known that implants with larger area have a greater contact area with bone tissue, and have a better biomechanical response. Another important factor is that overdentures are also supported by mucosa, and the osseointegrated implants act in increasing retention and stability.

Overdentures may show different retention systems, such as magnets, O-rings and bar-clip. O-ring attachments provides a higher degree of freedom to the prosthesis, permitting rotation in all directions.[5] However, this attachment system is highly sensitive with respect to the inclination of implants, being suggested a maximum angle of 10 degrees between the implants.[6] Another retention system reported in the literature is the magnet; however, this system is not generally used to be the least among all retentive system used in overdentures.[7] In addition, it presents corrosion and excessive wear with consequent reduction of retention.[8] The bar-clip attachment system is the one which provides the highest retention for the prosthesis.[9] This system provides favorable distribution of stresses due to splinting, allowing the clip rotation over the bar. This rotation allows the forces from chewing, to be better distributed in the implants and mucosa support area of the overdenture. [10]

Clinical evaluation is undoubtedly the safest method for evaluation of a given situation. However, the study of the biomechanical behavior intra-bony structures it becomes unviable for ethical and / or methodological aspects.[11, 12] In trying to predict possible failures resulting from excessive concentration strains, different methodologies have been developed, among which we can highlight the Photoelastic Analysis and Finite Element Analysis (FEA). The Photoelastic Analysis is an experimental method based on the optical property certain transparent plastic materials, when subjected to stress show changes in the refractive indices, enabling by "Law of optical strains" quantify the tensions generated in the desired regions.[13] The development of three-dimensional models (3D) specific finite element enables to investigate similarly to what happens in the in vivo bone, of non-destructive way, providing accurate and reliable information about the biomechanics involved in many situations.[14, 15] It also allows to predict and quantify the stresses induced by the system (prosthesis / mucosa / implant / bone).

The use of different methods to evaluate the same situation allows decreasing possible failures related to misinterpretation of results and / or limitations inherent of each Photoelastic Analysis and Finite Element Analysis. Thus, the clinician would be better prepared to interpret the clinical situations relating to the appointment of different total overdenture types.[16]

Then, aim of this study was to determine by photoelastic and finite element analyses, the biomechanical behavior of overdentures retained by two implants with different lengths (9, 11, 13, and 15 mm).The hypothesis was that different implants lengths retaining overdenture would promote different stress in the peri-implant region.

MATERIALS AND METHODS

Photoelastic Analysis

A master model representing a jaw with two implants external hexagon positioned in the anterior region, with a distance of 20 mm between them were made of dental stone type III (Herodent – Soli Rock, Vigodente, RJ, Brazil). An overdenture bar was waxed with section cylindrical cross-section of 2 mm diameter on casting cylinder. The bars were casted in CoCr alloy (Wirobond 280, Bego, Bremen, Germany) by the conventional lost-wax method. The bars received proper finishing and polishing until they were considered clinically acceptable. An inferior overdenture was made on the master model.

Photoelastic models

Open tray transfers were screwed on the implants of the master model and then splinted with dental floss and acrylic resin (Pattern Resin, GC America Inc, EUA). After the splinting of the transfers impressions were made with dense silicone (Silibor – Clássico). The silicone was handled according to the manufacturer's instructions (ratio of 5% catalyst for 100 g silicone). After curing, the impression was removed from the master model and implants with different lengths were attached to the transfers according to each experimental group. The impression was then filled with photoelastic resin (Araldite, Araltec Guarulhos, SP- Brazil). The resin was manipulated in the proportion of 37 g of hardener for each 100 g of the resin for ten minutes. After the manipulation, the resin was placed in a vacuum chamber with 70 kgf/cm^2 pressure for 5 min to remove bubbles, and then poured in the impression.

The setting times of photoelastic resin was 72 hours. After this period, the models were removed from the mold and divided into four experimental models, according to the length of the implants: G1 – 9 mm; G2 – 11 mm; G3 – 13 mm; and, G4 – 15 mm.

Photoelastic analysis

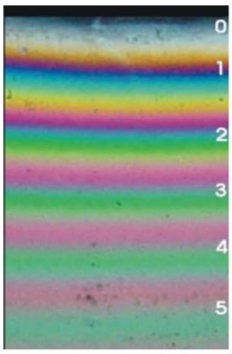
The photoelastic analysis was performed using the equipment for stress analysis by photoelasticity Fringes® (em Ambiente MatLab®) the Prosthesis Laboratory of FOP-UNICAMP (developed by Mechanical Design Laboratory, Federal University of Uberlândia, MG -Brazil). This equipment enables the evaluation of direction and distribution of stresses transmitted to structures on the photoelastic resin. Initially, the analyses were performed when photoelastic models were only with the bars positioned in order to verify the absence of stress, which can affect results. Calibration of the resin respected the optical constant of the photoelastic material, the value used (k=0.38 N/mm) is supported by previous study.[17]

An initial photo was carried out only with bars and positioned prosthesis with the assistance of equipment for stress analysis Fringes® (at room temperature MatLab®) in order to check the absence of residual stresses induced in the specimens that may interfere in the results. Then, the coupled test machine with a metal tip incidence was programmed to perform a constant displacement of 1 mm/min until the 170 N load in the region of mandibular first molar, in order to simulate maximum force unilaterally bite with overdentures prostheses.[18] When loading was over, other image was acquired and used in the software to evaluate the stress at predetermined points near the implants.

Points were be mapped by the images obtained by the equipment and transmitted to specific software Fringes® (Ambiente MatLab®), in order to calculate the average shear stress at each point. All analysis were performed by one operator.

The analysis of fringe patterns were performed by means of color scale (Figure 1) considering that the isochromatic fringes are defined in the program, depending on the stress levels at some point of the model.

Figure 1- Fringe orders



Finite Element Analysis

Geometric Model

Three-dimensional model were obtained from the clinical situation considered prevalent in prosthetic rehabilitation on implants. The considered model was a resorbed jaw with two implants in the anterior region, arranged in a distance of 20 mm between them and an overdenture retained by bar-clip system.

The geometry of the jaw, implants, bar and denture were modeled from data obtained by CT scan. The implants presented external hexagon conection and were 4.1 mm diameter platform. According to each group, different lengths were modeled (9, 11, 13 or 15 mm) (Titamax Ti Cortical, Neodent, Curitiba, Brasil). To manipulate images obtained by the CT scans, it was used a software (Mimics®, Materialise, Belgium). In this software 2D images obtained by CT scans can be transformed through grayscale into 3D model that could be exported in STL format.

Finite Element model

The geometric models were then imported into the CAE environment (Computer Aided Engineering) of CAE (Computer Aided Engineering) of Ansys Workbench – Academic Mechanical module v16.

The models used in this study were made according to the international metric system. All materials were considered elastically linear, homogeneous and isotropic. Table 1 shows the values of the elastic properties of the different materials used in the study, obtained from the literature.[11]

Table 1 - Properties of elastic materials used in the study.

Material	Modulus of elasticity (MPa)	Poisson's ratio
Ti (implant)	110.000	0.35
Alloy Cr-Co	218.000	0.33
Prosthetic screw	110.000	0.28
Plastic clip	3.000	0.28
Acrylic resin	1.960	0.30
Artificial tooth	2.940	0.30

The finite element mesh was generated using tetrahedral elements, characterized by a triangular base pyramid with a node at each vertex and one in the center of each edge, resulting in a total of 10 nodes per element. The mesh was refined until the results was not significantly affected by, which was verified by means of convergence test. The contacts between the interfaces were considered bonded in all parts.

Finite Element Analysis (FEA)

The analyzis were performed using the mechanical simulation software Ansys Workbench – Academic Mechanical module v16. (Canonsburg, Pensilvania, EUA).Through this tool it can perform static, linear and nonlinear analysis with applications in bioengineering. For configuration of the analysis, the base of the jaw was considered a fixed point, the application of unilateral load was applied in the lower right first molar region with an intensity of 170 N in order to simulate the maximum bite force with prostheses type overdentures.[18]

Analysis of Data Obtained

The data analysis was conducted as follows: (1) qualitative analysis by means of figures and colors, gradients according to the concentration of stresses in each region; and (2) Quantitative analysis by numerical reading of the stresses at certain nodes of the mesh model, by software. All analyzes were carried out considering the Maximum Principal and von Mises stress, both in MPa.

RESULTS

Quantitative Analysis

For quantitative analysis two positions have been selected, a right implant and the other on the left side of the implant, evaluate with and without the application of load 170 N in the lower right first molar in a prosthesis type overdenture with a bar-clip system. For each group we calculated the average of the mandibular body and an average of the peri-implant region, fringe order of the values (N) and shear stress (T) were obtained in Fringes® program.

Table 2- The results of the fringe order (N) of the right and left side.

	9mm	**11mm**	**13mm**	**15mm**
Right side with load				
Mean body of the jaw	1.85	3.06	2.01	2.04
Mean peri-implant	2.52	3.18	2.48	2.39
Right side without load				
Mean body of the jaw	0.54	0.55	0.53	0.59
Mean peri-implan	0.60	0.55	0.52	0.58
Left side with a load				
Mean body of the jaw	0.56	0.58	0.62	0.66
Mean peri-implant	0.60	0.67	0.77	0.83
Left side without load				
Mean body of the jaw	0.57	0.66	0.69	0.67
Mean peri-implan	0.60	0.72	0.92	0.76

Table 3- The results of the shear stress (T) of the right and left side.

	9mm	**11mm**	**13mm**	**15mm**
Right side with load				
Mean body of the jaw	745.14	1232.53	807.90	819.21
Mean peri-implant	1013.27	1281.33	999.18	962.41
Right side without load				
Mean body of the jaw	217.44	220.98	212.49	238.66
Mean peri-implan	241.49	220.98	210.73	235.48
Left side with a load				
Mean body of the jaw	225.53	234.77	251.39	264.29
Mean peri-implant	276.66	268.71	311.49	334.92
Left side without load				
Mean body of the jaw	229.29	264.29	278.08	269.92
Mean peri-implan	240.07	290.93	370.54	304.69

Qualitative analysis

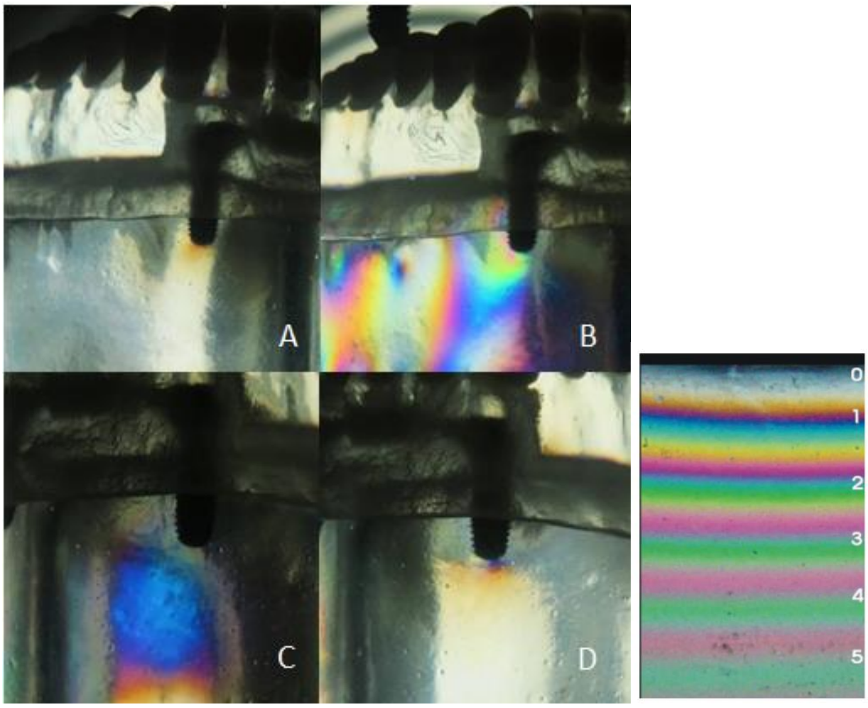
Photoelastic Analysis

For qualitative analysis, two locations were selected, one on the right and another on the left, evaluating with and without the application of a load on the lower right first molar in the overdenture with the bar-clip system.

Figure 2 shows the photoelastic model 9mm implants group, 2A and 2C show the right and left implants respectively without the application of load, Figure 2B shows the stress concentration at the implant apex after charging but the left side of figure 2D showed virtually unchanged.

Group 1 - Analysis of samples with and without application of load for Group 1 at right and left sides.

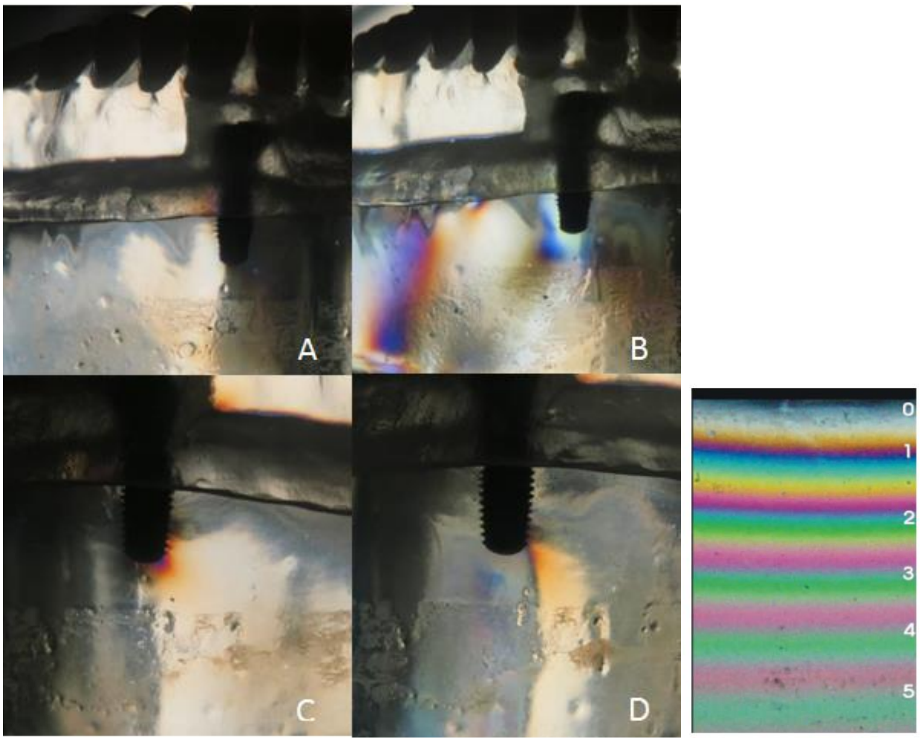
Figure 2 - Distribution of isochromatic fringes in the photoelastic analysis for 9 mm implant: A) Implant right side without exerting any load; B) Implant with load application; C) Left without exerting any load; D) Implant with load application.



Compared to Group 2 shows the photoelastic models behavior similar to Group 1, however, the fringe order had the highest values of all groups. In the 11mm implant is a remarkable change of the fringes at the apex of the implant caused by the convergence of stress and is even more remarkable the difference of the right side of the implant with the implant on the left side (Figure 3 - A, B, C and D).

Group 2 - Analysis of samples with and without the application of load Group 2 right and left sides.

Figure 3 - Distribution of isochromatic fringes in the photoelastic analysis for 11 mm implant: A) Implant right side without exerting any load; B) Implant with load application; C) Left without exerting any load; D) Implant with load application.



The results evaluated in both groups eventually following a pattern with values in an increasing order fringe. Group 3 implants 13mm shows changes in fringe order but such changes are not comparable to those presented in Groups 1 and 2 showing a lower concentration of this stress groups mainly seen in Figure 4B.

Group 3 - Analysis of samples with and without the application of load Group 3 at right and left sides.

Figure 4 - Distribution of isochromatic fringes in the photoelastic analysis for 13 mm implant: A) Implant right side without exerting any load; B) Implant with load application; C) Left without exerting any load; D) Implant with load application.

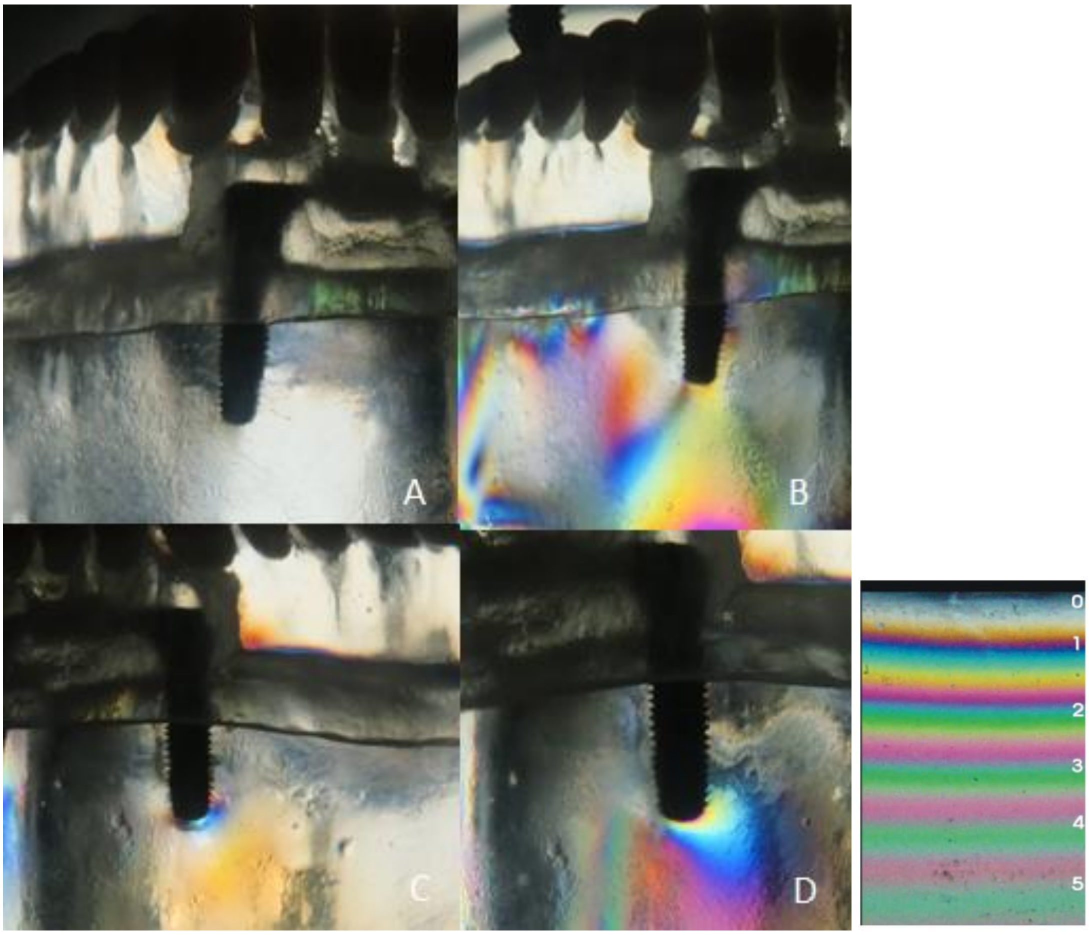


Figure 5 shows the longest implant of four groups, the group eventually present the stress concentration along the loading side of the implant (Figure 4 C) and the implant left side shows a stress concentration in the apex region of the implant which is the most common region of stress concentration (Figure 4 D).

Group 4 - Analysis of samples with and without the application of load Group 4 at right and left sides

Figure 5 - Distribution of isochromatic fringes in the photoelastic analysis for 15 mm implant: A) Implant right side without exerting any load; B) Implant with load application; C) Left without exerting any load; D) Implant with load application.

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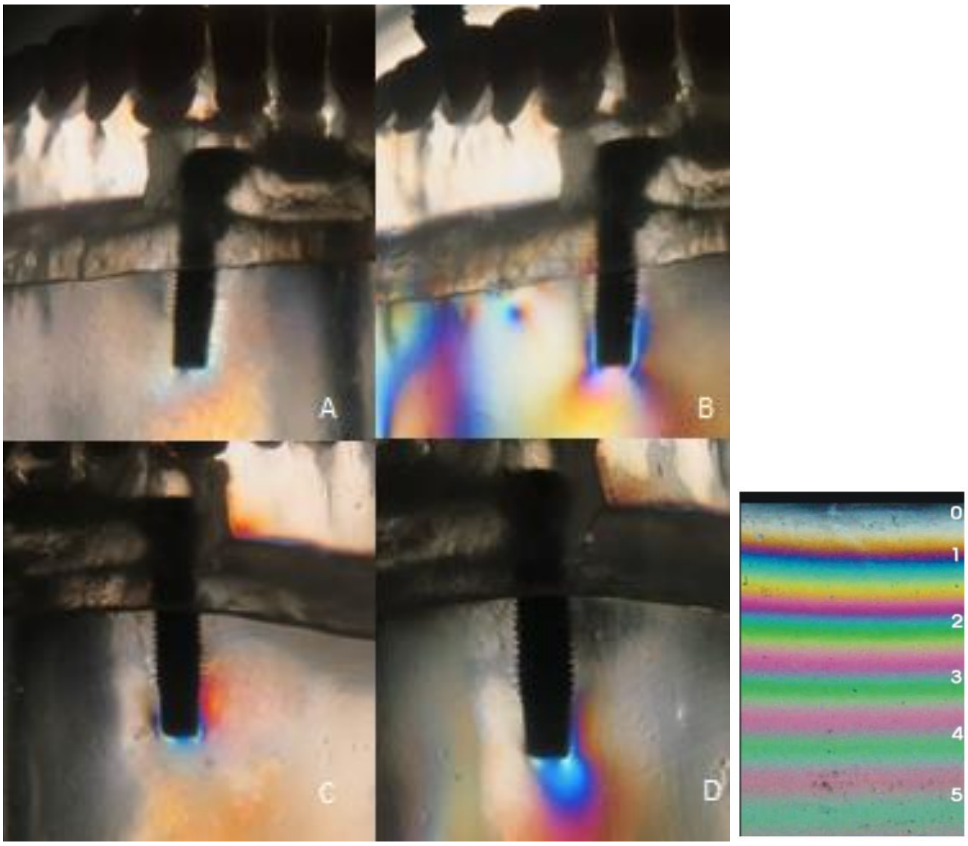
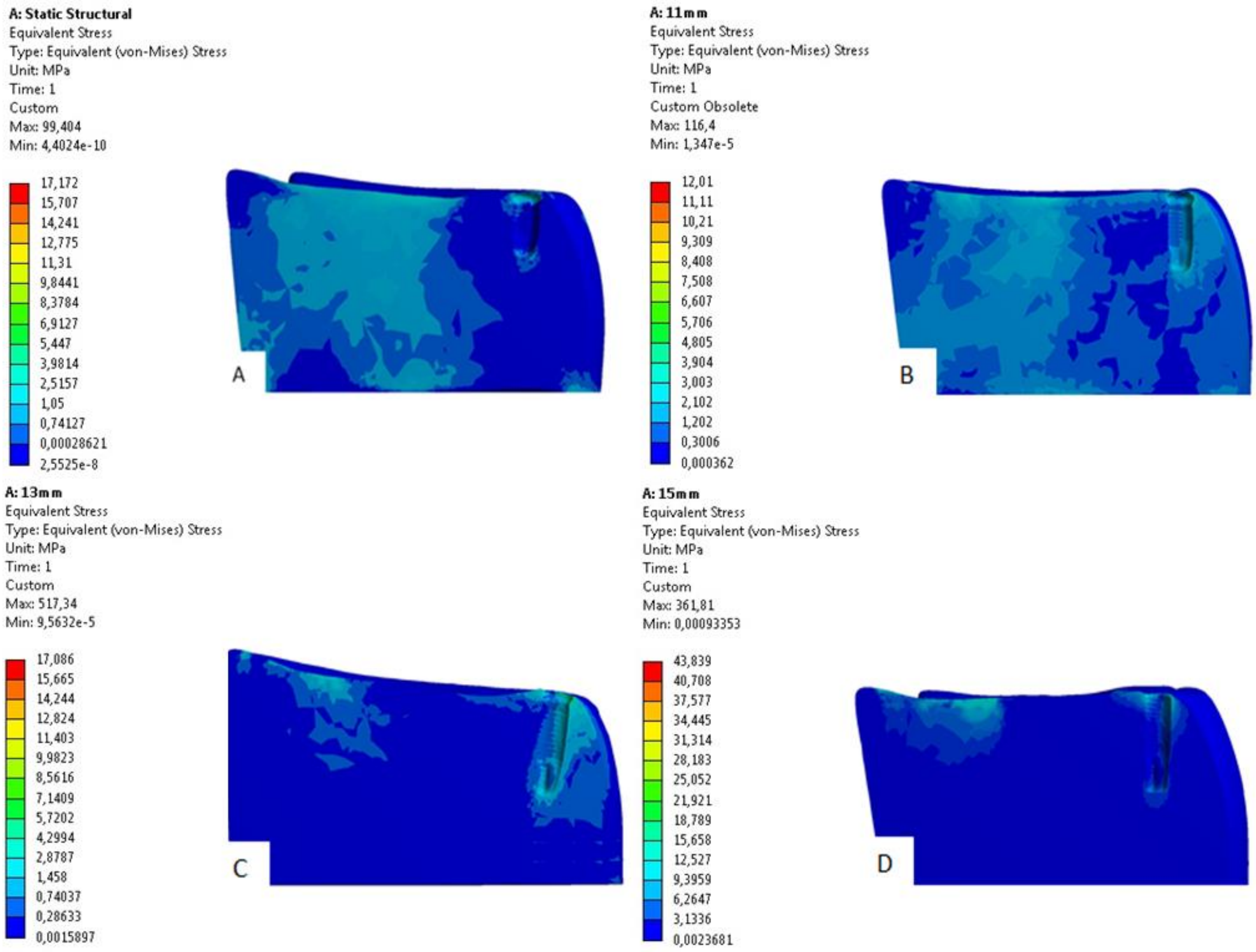


Finite Element Analysis

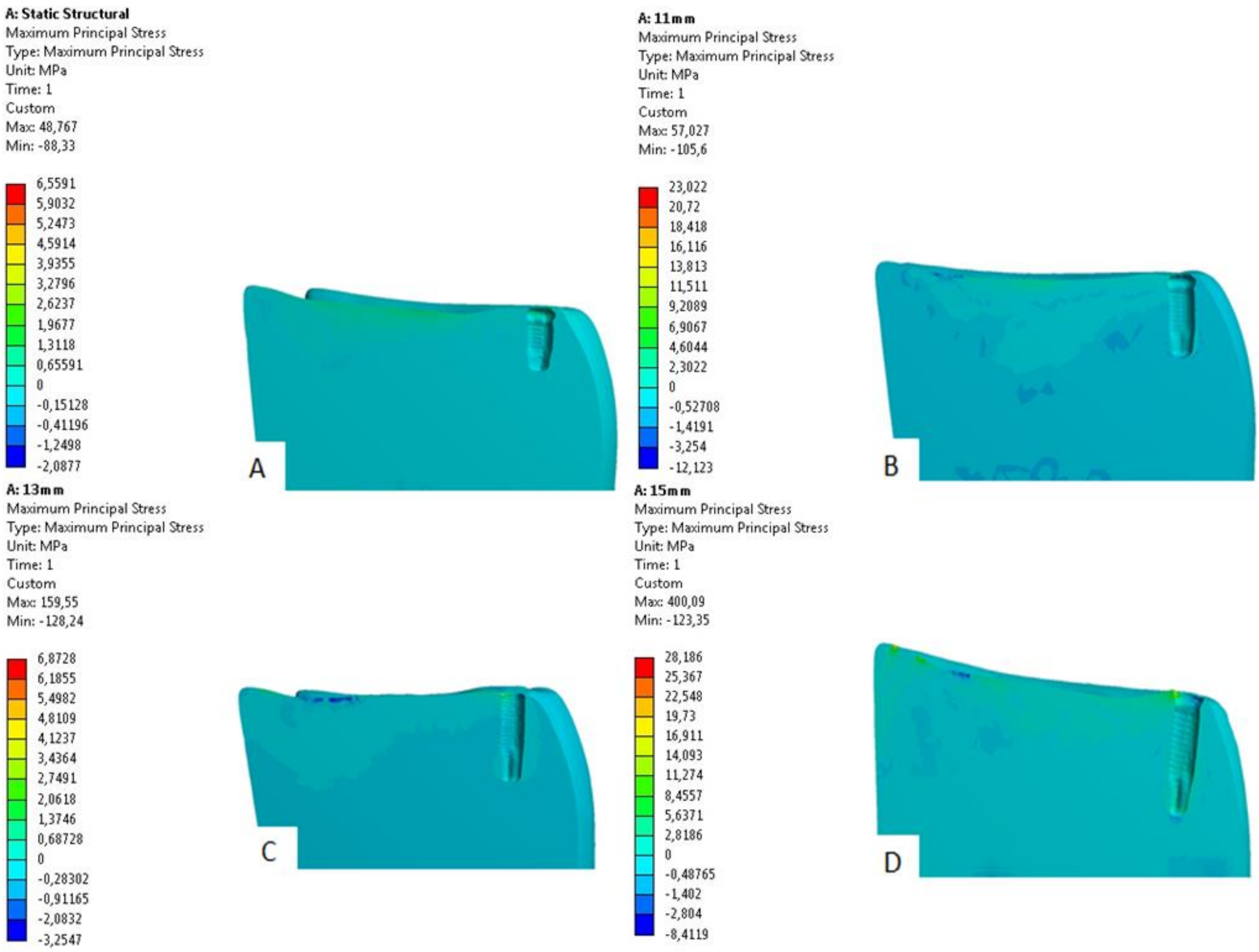
The Von Mises stresses occurring on the right side of the mandibular body and peri-implant region shown in Figure 6.

Figure 6 - Von Mises stresses right side: A) Implant 9mm; B) Implant 11mm C) Implant 13mm; D) Implant 15mm.



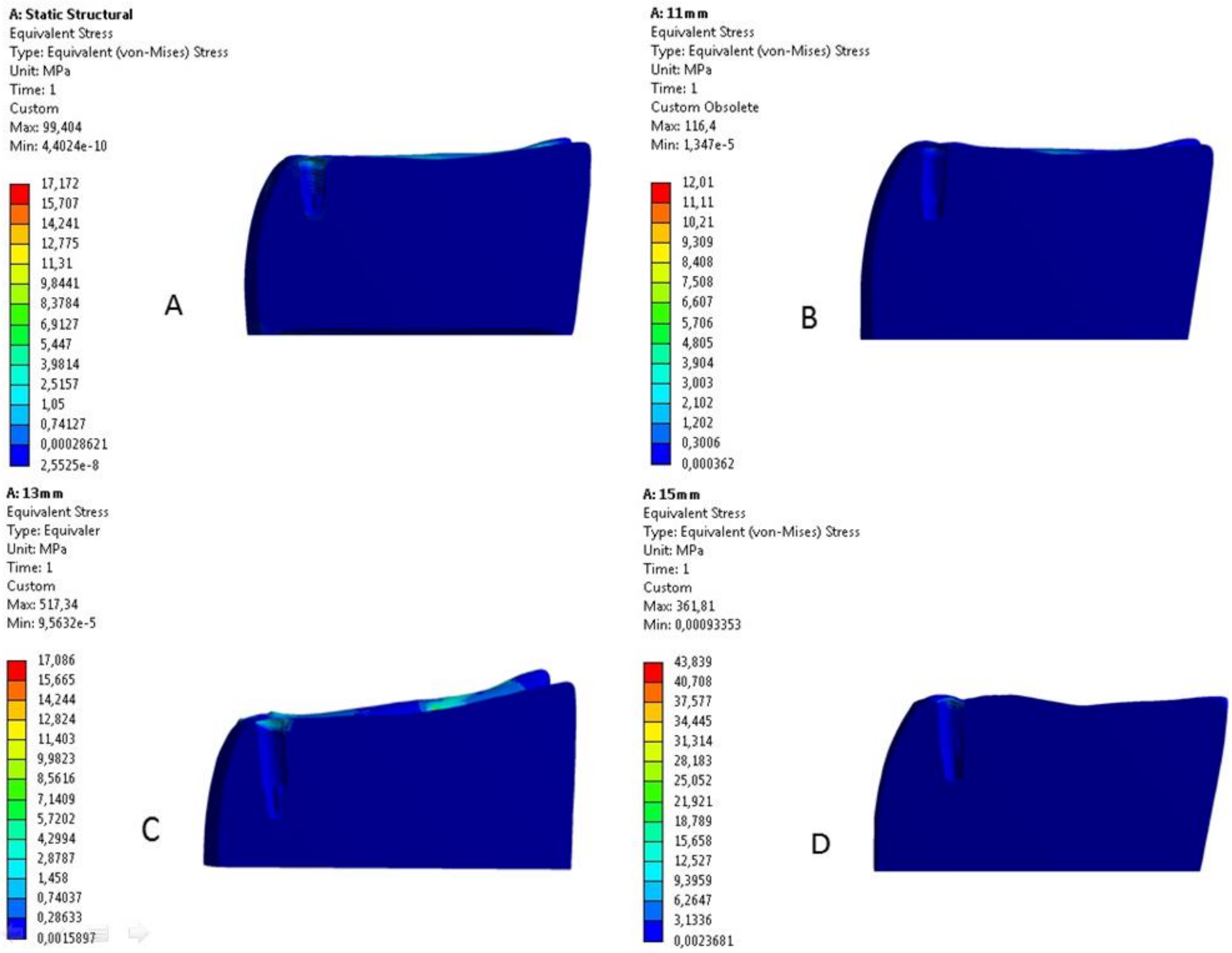
The maximum principal stresses occurring on the right side of the mandibular body and peri-implant region shown in Figure 7.

Figure 7 - Maximum Principal Stress right side: A) Implant 9mm; B) Implant 11mm C) Implant 13mm; D) Implant 15mm.



The Von Mises stresses occurring on the left side of the mandibular body and peri-implant region shown in Figure 8.

Figure 8- Von Mises stresses left side: A) Implant 9mm; B) Implant 11mm C) Implant 13mm; D) Implant 15mm.



The maximum principal stresses occurring on the left side of the mandibular body and peri-implant region shown in Figure 9.

Figure 9 - Maximum Principal Stress left side: A) Implant 9mm; B) Implant 11mm C) Implant 13mm; D) Implant 15mm.

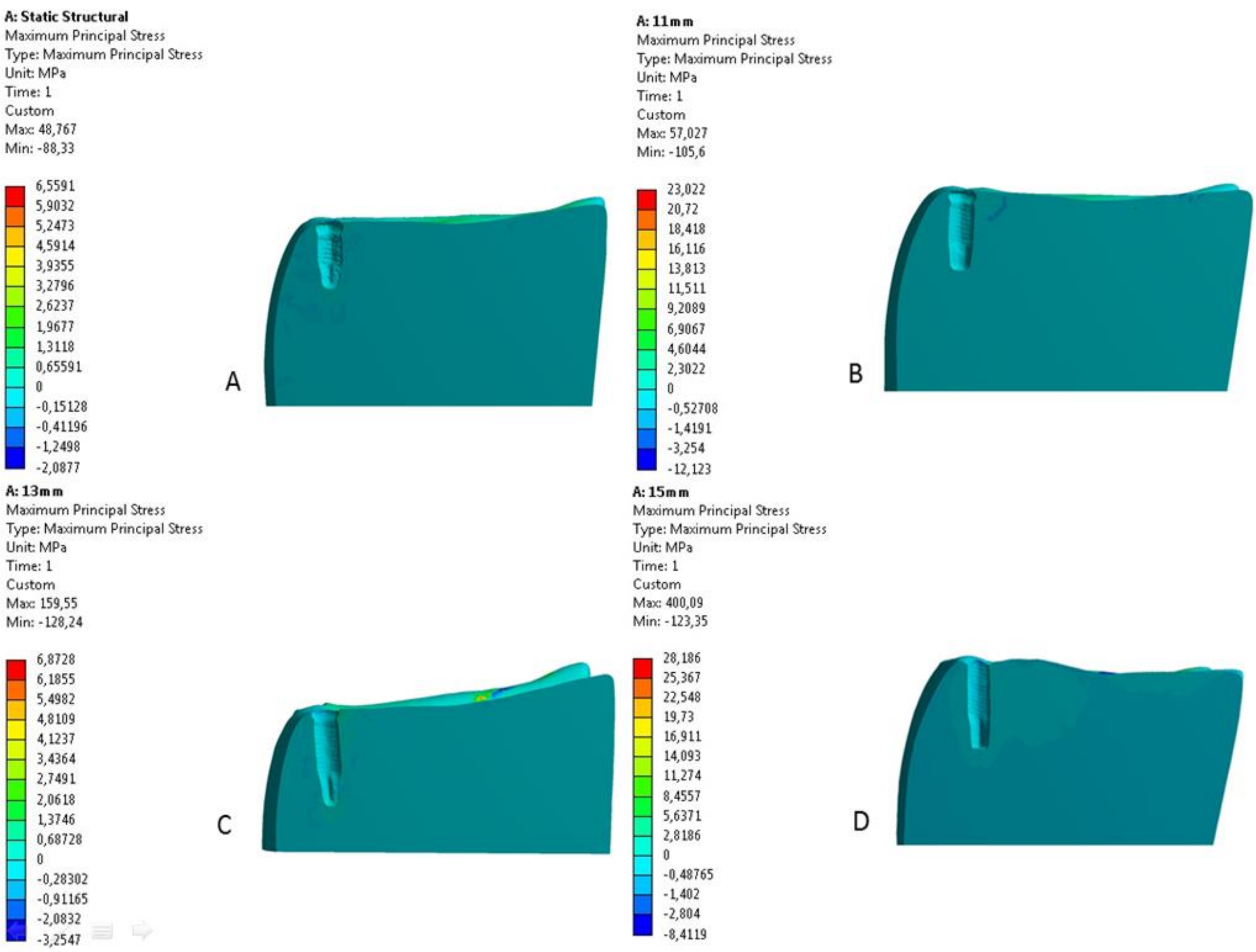


Table 4 - The results of the peri-implant stress right and left sides in MPa.

	9mm	11mm	13mm	15mm
Right side				
Von Mises	0.173	0.250	0.415	0.466
Maximum Principal	-0.004	0.030	0.037	0.043
Left side				
Von Mises	0.020	0.025	0.019	0.132
Maximum Principal	0.074	0.006	0.017	0.109

Table 5 - The results of the body of the jaw stress of the right and left sides in MPa.

	9mm	11mm	13mm	15mm
Right side				
Von Mises	0.410	0.315	0.612	0.627
Maximum Principal	0.065	0.054	0.118	0.082
Left side				
Von Mises	0.013	0.009	0.015	0.066
Maximum Principal	0.007	0.022	0.005	0.035

DISCUSSION

The results allow analyzing the tension stress of load application and its transmission by the prosthesis and its components in the model photoelastic. The study involved four different implant lengths causing different results occurred in the concetration of force on the model.

The effect of the loads applied to implants presents great interest and can be found in others studies involving different methodologies. In this study, by the analysis of the images, it was observed that the qualitative values of the fringes were different among the groups. This fact emphasizes the importance of quantitative and qualitative analysis for photoelastic methodology compare the stress at the bone-implant region.[19]

The shear stress values and fringe order were distinct and superior on the right side were the load was applied due application of the load only on the right. With respect to the length of the implants, it can observe a significant difference in the values of both fringe order and shear stress, amond thus the shorter implants as 9 and 11 mm showed the highest results (Tables 2 and 3). Based on this results, the work hypothesis that different implant lengths retaining overdenture would promote different stress in the peri-implant region was accept. Thus decrease in shear stress between the groups with larger implants corroborates other studies that evaluated short implants and they demonstrated that the major stresses generated in the peri-implant region are recorded in the short implants compared with long implants and lower bone density present.[20,21]

The qualitative analysis of models reflect which ultimately demonstrated when 9mm implant (Figures 2 A, B, C and D) is subjected to load and observing the fringes gradient is much greater than when compared to implant 15 mm (Figures 5 A, B, C and D).

The fact that larger implants lengths show the lowest strains, whether the stress distribution throughout the body.[22,23] The values showed in the right peri-implant region were higher due to application of force and the convergence of tension to the apex of the nearest implant side loading on the comparison with the left side that even the loading presence the values presented if lower (Table 3 to 4)

However, this method has limitations, for example, the resin used to simulate bone structure differs when compared to human bone tissue.[24,25] Especially the photoelastic resin assume an isotropic and not orthotropic characteristic as the characteristic of bone tissue is known.

With regard to finite element analysis, the evaluated models are represented by color gradients. The von Mises stress was used to evaluate stress distribution in the four different implant lengths. Although most studies of finite element analysis using Von Mises, this criterion is only valid for ductile materials[26] thus the maximum principal stress was also used to evaluate the materials in this study.

The von Mises stresses are a representation of the effective stress caused by energy flow over the material that ultimately receives the load. Their magnitudes reflect the mechanical behavior of the structure. [27]

Figure 6 shows the stress concentration evaluated for von Mises stress for all implants (9,11,13 and 15 mm). Around the implant neck there was concentration of stress stating the same occurred in photoelastic analysis. Typically, the stress levels to actually cause a biological response such as bone resorption and remodeling are not widely known. Therefore, the data for the stress provided by FEA need evidence for clinical research. [28-31]

Figure 8 shows the results of left side to evaluate the Von Mises stress for the implants (9,11,13 and15mm) in the peri-implant region is notable that the concentration of stress is practically inexpressive in comparison with the right side (Figure 6) which turned out to receive the load. Among the implants had a growing number of values for both Von Mises, and for maximum principal stress (Table 4) the implant had no noticeable effect.[32] In another study using the same methodology concluded that increasing the implant reduces the stress generated in peri-implant spongy bone region. [33]

These reported facts corroborate the results obtained in Photoelastic Analysis; however, enter and disagreement with the results obtained in Finite Element Analysis, despite the different values of photoelastic analysis data are average values obtained through the points of transparency and the finite element analysis data are absolute values at an exact point.

CONCLUSION

Based on the methodology, the following conclusions can draw:

Photoelastic analysis showed that implants with smaller lengths promosted greater strain than largest lengths implant. The finite element analysis showed that the stresses at peri-implant region increased proportionally according to the lenghts of implant.

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CONCLUSÃO

Baseado na metodologia utilizada conclui-se que:

A análise fotoelastica demonstrou que os implantes com menores comprimentos apresentaram tensão média maior que os maiores comprimentos de implantes. Os valores apresentados pela análise por elementos finitos demonstraram que a tensão aumentou na região periimplantar proporcionalmente ao aumento do tamanho do implante.

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APÊNDICE

APÊNDICE 1

METODOLOGIA

Análise Fotoelástica

Confecção do Modelo Mestre

Um modelo mestre representando uma mandíbula com dois implantes posicionados na região anterior, com distância de 20 mm entre eles, foi confeccionado em gesso pedra tipo III (Herodent – Soli Rock, Vigodente, RJ, Brasil). Sobre este modelo foram realizados enceramentos de barras para *overdentures* com secção transversal cilíndrica de 2 mm de diâmetro sobre pilares UCLA calcináveis. As barras foram fundidas em liga de Co-Cr (Wirobond 280, Bego, Bremen, Alemanha) pelo método convencional da cera perdida. A barra recebeu acabamento e polimento adequados até que fosse considerada clinicamente aceitável (Figura 1).

Uma prótese total inferior do tipo *overdenture* foi confeccionada sobre o modelo mestre (Figura 2) onde foi realizada posteriormente a captura do clipe

Figura 1- Modelo de Gesso com a barra fundida.

Figura 2 – Confecção da prótese total inferior sobre o modelo mestre.

Confecção dos Modelos Fotoelásticos

Transferentes para moldeira aberta foram parafusados sobre os implantes do modelo mestre e posteriormente unidos entre si com fio dental e resina acrílica com menor contração (Pattern Resin, GC America Inc, EUA). Após a união dos transferentes foi realizada a moldagem de transferência com silicone denso (Silibor – Clássico Artigos Odontológicos). Este molde abrangeu todo o modelo mestre de modo a replicá-lo inteiramente. O silicone foi manipulado de acordo com as recomendações do fabricante (proporção de 5% de catalisador para 100g de silicone - Figura 3). Depois de adequada polimerização, o molde obtido foi removido do modelo mestre e implantes com comprimentos variados de 9, 11, 13 e 15 mm (Figura 4), de acordo com cada grupo experimental foram posicionados cuidadosamente nos transferentes dentro do molde e fixados com parafusos. O molde foi então preenchido com resina fotoelástica (Araldite, Araltec Produtos Químicos Guarulhos, SP). A resina foi manipulada na proporção de 37g de endurecedor para cada 100g da resina por dez minutos (Figura 5). Após a manipulação, a resina foi colocada em câmara de vácuo com 70 kgf/cm^2 por 5 minutos para a remoção de bolhas, e posteriormente preenchimento do molde.(Figura 6)

A polimerização da resina fotoelástica é de 72 horas. Após este período, os modelos são removidos do molde e deram origem a quatro modelos experimentais, de acordo com o comprimento dos implantes.

Figura 3- Silicone denso (Silibor-Clássico Artigos Odontológicos) utilizado na moldagem de transferência.

Figura 4- Implantes com variados comprimentos (9,11,12,13 e 15mm) hexágono externo.

Figura 5- Resina fotoelástica (Araldite, Araltec Produtos Químicos Guarulhos, SP)

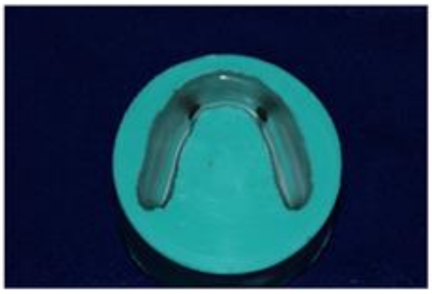


Figura 6 – Molde preenchido com resina fotoelástica.

Análise da Fotoelasticidade

A análise de fotoelasticidade foi realizada com auxílio do equipamento para análise de tensões pelo programa Fringes® (em ambiente MatLab®) do Laboratório de Prótese da FOP-UNICAMP (desenvolvido pelo Laboratório de Projetos Mecânicos, Universidade Federal de Uberlândia, MG - Figuras 7 e 8) Este equipamento possibilita a avaliação da direção e distribuição das tensões transmitidas às estruturas de resina fotoelástica em uma determinada situação. Inicialmente foi realizada a análise dos modelos fotoelásticos somente com as barras posicionados de modo a verificar a ausência da indução de tensões que pudessem interferir nos resultados. A análise fotoelástica foi realizada a partir de imagens que o próprio equipamento captou durante a análise.

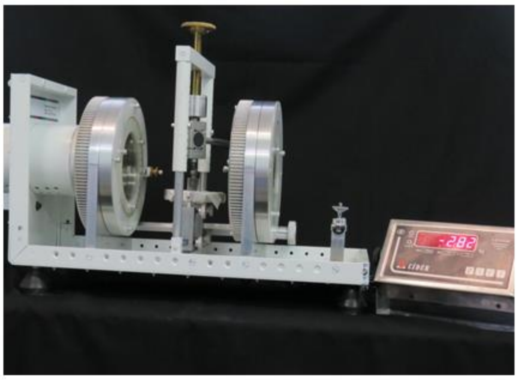


Figura 7- Friges® polarisocópio máquina de carregamento universal.

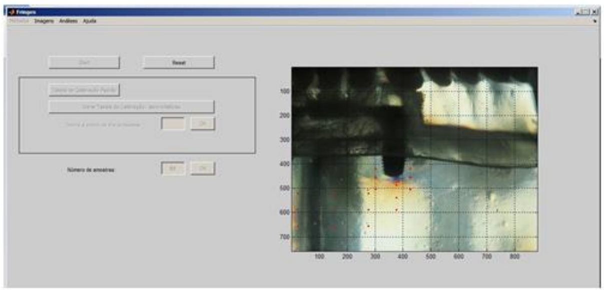
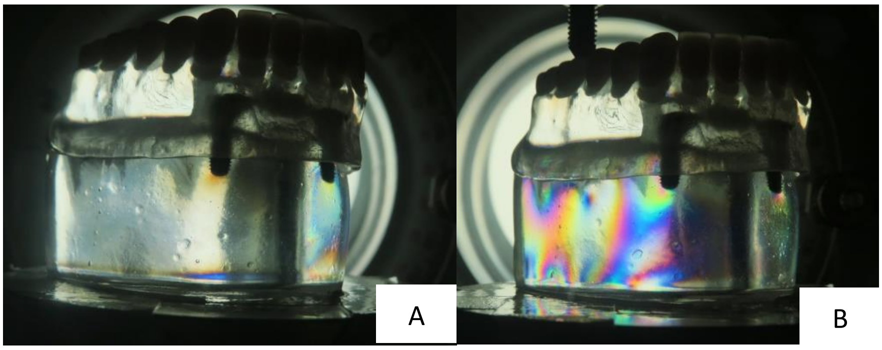


Figura 8 - Ilustração do programa Fringes® em plataforma MATLAB.

A calibração da resina respeitou a constante óptica do material fotoelástico, o valor utilizado (k=0,38 N/mm) está amparado por estudo prévio.[17]

Inicialmente foi realizado uma tomada fotográfica inicial, somente com as barras e a prótese posicionadas com auxílio do equipamento para análise de tensões Fringes® (em ambiente MatLab®) a fim de verificar a ausência de indução de tensões residuais nas amostras que pudessem interferir nos resultados. Em seguida, a máquina de ensaio acoplada com uma ponta de incidência metálica foi programada para realizar um deslocamento constante de 1 mm/min. até atingir a carga de 170N na região de primeiro molar inferior direito, com a finalidade de simular força máxima de mordida unilateral com próteses *overdentures*. Quando o carregamento cessou, outra tomada fotográfica foi realizada e a leitura das franjas foi realizada em pontos pré-determinados próximos aos implantes (Figura 9).

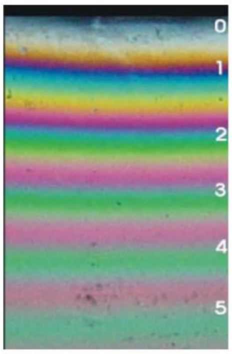
Figura 9 - Inicialmente foi realizada uma tomada fotográfica inicial(Figura 9 A) e outra com o carregamento oclusal (Figura 9 B).



Os pontos foram mapeados pelas imagens obtidas pelo equipamento e transmitidas para *software* específico Fringes® (em ambiente MatLab®), com a finalidade de calcular as médias de tensão cisalhante em cada ponto. Todas as análises foram realizadas por um operador, previamente calibrado.

As análises dos padrões de franjas foram realizadas por meio de escala de cores considerando que as franjas isocromáticas (Figura 10) são definidas no programa, dependendo dos níveis de tensão num determinado ponto do modelo.

Figura 10 - Ordens de franjas isocromáticas inteiras.



Análise de Elementos Finitos

Obtenção do Modelo Geométrico

O modelo tridimensional foi obtido a partir da situação clínica considerada prevalente em reabilitação protética sobre implantes. O modelo considerado foi uma mandíbula reabsorvida com dois implantes na região anterior, dispostos numa distância de 20 mm entre eles e uma prótese total do tipo *overdenture* retida pelo sistema barra-clipe, utilizando *software* de modelagem (Mimics®, Materialise, Belgium). Esse software transforma imagens 2-D obtidas em tomografias computadorizadas através dos diferentes tons de cinza em imagens 3-D no formato STL (Figura 11).

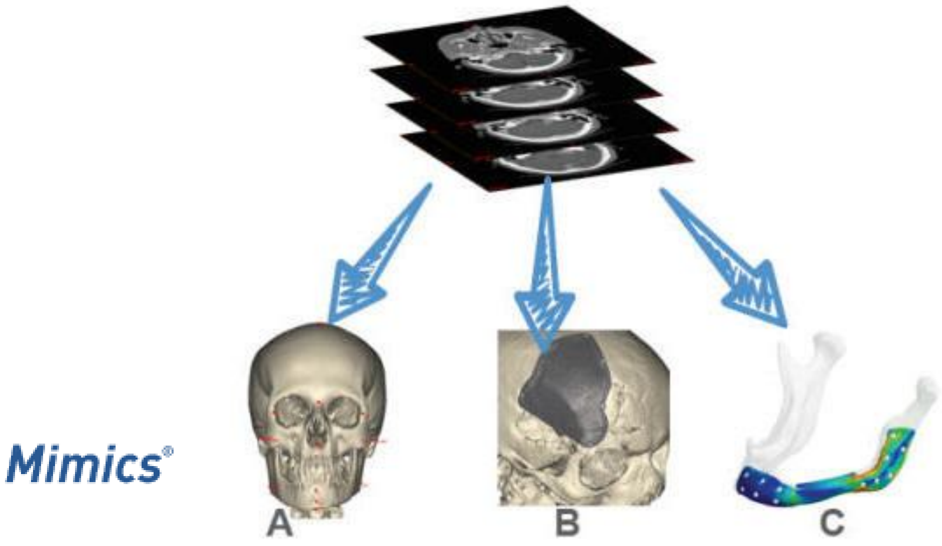
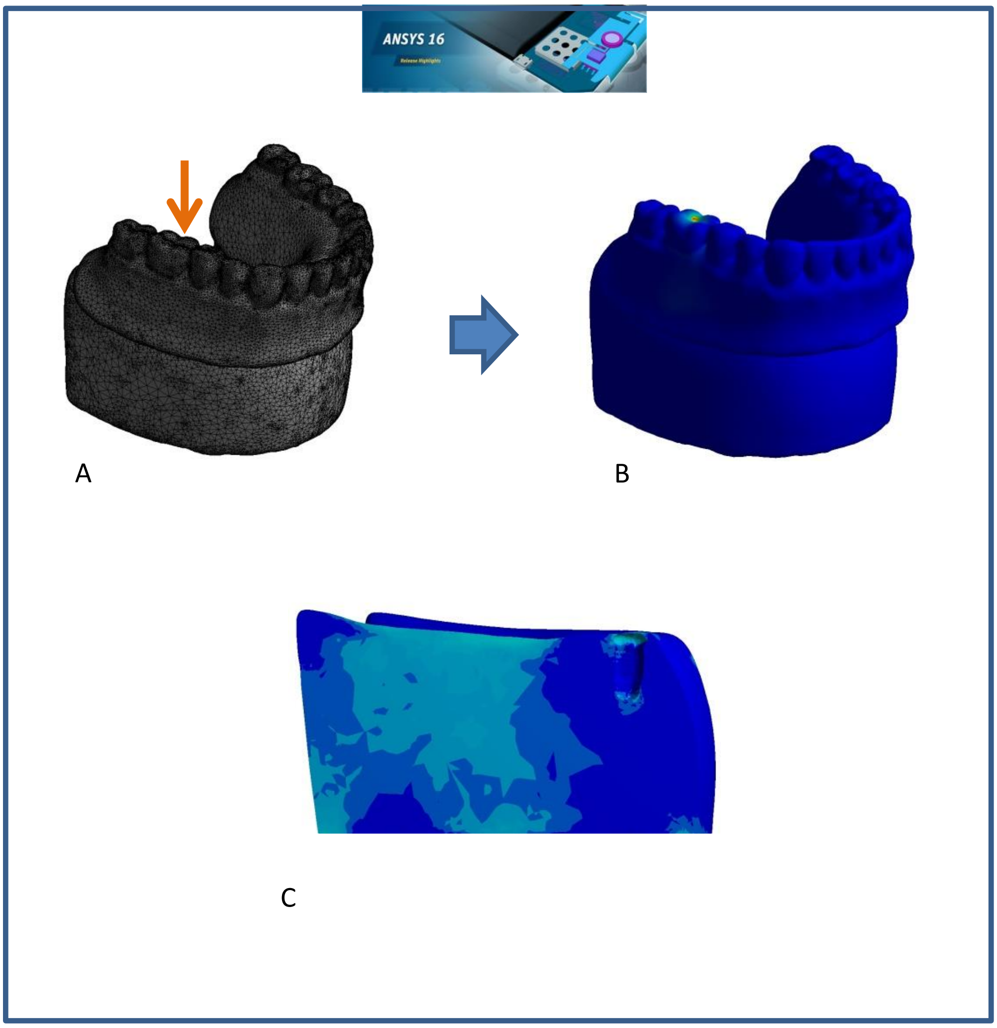


Figura 11- Esquema do *software* de modelagem (Mimics®, Materialise, Belgium).

Análise de Elementos Finitos (AEF)

As análises foram realizadas com auxílio do *software* de simulação mecânica ANSYS Workbench 16. Para configuração das análises, à base da mandíbula foi considerada como um ponto fixo, sendo realizada a aplicação da carga unilateral na região de primeiro molar inferior direito na intensidade de 170 N, de modo a simular a força máxima de mordida com próteses tipo *overdentures* (Figura 12)

Figura 12 - Esquema da análise de elementos finitos através do software ANSYS 16. A -Modelo de elementos finitos com representação a carga B- Análsie de elementos finitos C - Corte sagital para avaliação da região peri-implantar



ANEXOS

ANEXO I – NORMAS 002/06

Este trabalho foi apresentado no formato alternativo de tese de acordo com as normas estabelecidas pela deliberação 002/06 da Comissão Central de Pós-Graduação da Universidade Estadual de Campinas. O artigo referente ao Capítulo 1 será submetido à publicação em periódico internacional.

ANEXO II – CARTA DE SUBMISSÃO

23-Feb-2016

Dear Mr. di Nizo:

Thank you for submitting your manuscript entitled Effect of Implant in stress concentration in the alveolar ridge,in finite element analyzes and photoelasticity" to the Brazilian Dental Journal. Your manuscript ID is BDJ-2016-0848.

Please mention the above manuscript ID in all future correspondence or when calling the office for questions. If there are any changes in your street address or e-mail address, please log in to ScholarOne Manuscripts at http://mc04.manuscriptcentral.com/bdj-scielo and edit your user information as appropriate.

You can also view the status of your manuscript at any time by checking your Author Center after logging in to http://mc04.manuscriptcentral.com/bdj-scielo.

In accordance with the Brazilian Dental Journal's policies referring to the review process that precedes publication, all manuscripts accepted for publication undergo a Technical Review, which includes revision of language and scientific writing style, formatting corrections and technical editing to fit the manuscript into Journal's standards, and preparation of galley proofs.

The Technical Review Fee ranges from R$450,00 to R$ 550,00 Reais Brasileiros (for Brazilian authors) or U$200 to 300 American dollars (for foreign authors) and will be charged to the corresponding author, even if only minor corrections to the manuscript are needed.

For foreign authors, the Technical Review Fee should be paid upon acceptance of the manuscript for publication, using the PAYPAL ONLINE MONEY TRANSFER SYSTEM (www.paypal.com).

For both Brazilian and foreign authors, more detailed explanation will be provided if the manuscript is accepted.

If you DO NOT agree with these conditions, please inform your decision to withdraw the manuscript from the review process immediately.

Sincerely,
Brazilian Dental Journal Editorial Office