MATEUS BERTOLINI FERNANDES DOS SANTOS

Cirurgião Dentista

AVALIAÇÃO POR ELEMENTOS FINITOS DE TENSÕES NO TECIDO ÓSSEO PERI-IMPLANTAR DURANTE A OSSEOINTEGRAÇÃO

Tese de doutorado apresentada à Faculdade de Odontologia de Piracicaba, da Universidade Estadual de Campinas, para obtenção do Título de Doutor em Clínica Odontológica – Área Prótese Dental.

Orientador: Prof. Dr. Rafael Leonardo Xediek Consani

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A Comissão Julgadora dos trabalhos de Defesa de Tese de Doutorado, em sessão pública realizada em 09 de Fevereiro de 2011, considerou o candidato MATEUS BERTOLINI FERNANDES DOS SANTOS aprovado.

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“A virtude, o estudo e a alegria são três irmãos

que não devem viver separados”

Voltaire

RESUMO

Forças aplicadas por próteses totais a implantes submersos durante o período de osseointegração podem, em alguns casos, levar ao insucesso clínico. Até o momento não existe trabalho na literatura que quantifique e/ou verifique a distribuição das forças mastigatórias em implantes submersos durante a ação mastigatória de próteses totais convencionais usadas provisoriamente durante o período de osseointegração. Dessa forma, neste trabalho foram avaliadas as tensões geradas no tecido ósseo subjacente a implantes recém-colocados, em diferentes situações, durante a ação mastigatória em próteses totais convencionais provisórias inferiores, por meio da metodologia dos elementos finitos. Com software de modelagem 3-D (SolidWorks 2010, SolidWorks Corp., Concord, Massachusetts, EUA) foram confeccionados modelos tridimensionais de mandíbula simulando diferentes situações clínicas: (1) implantes submersos, próteses totais convencionais e próteses reembasadas com diferentes materiais reembasadores macios; (2) diferentes níveis de altura de exposição dos cicatrizadores (submerso, nível gengival, 1,5 mm exposto no meio bucal); e (3) diferentes espessuras e comparação entre reembasamento na base da prótese inteira ou somente na região dos implantes. As análises foram realizadas em software específico (ANSYS Workbench 12, Ansys Inc., Canonsburg, Pennsylvania, EUA) e para cada modelo foram simuladas duas situações, com aplicação de carga mastigatória em canino inferior direito (35N) e primeiro molar inferior direito (50N). Todas as análises foram realizadas em tensão máxima principal, em MPa. Os resultados obtidos demonstraram que o reembasamento da prótese com material macio reduziu a concentração de tensões no tecido ósseo peri-implantar, sendo a concentração de tensão diretamente relacionada com a maciez do material. Os cicatrizadores submersos foram os que apresentaram menor valor de concentração de tensões. A espessura e área de reembasamento estão relacionadas à transmissão de tensões ao osso peri-implantar, quando o reembasamento da região dos implantes com espessura de 3 mm apresentou melhores resultados. Comparando-se os resultados mostrados nas diferentes simulações conclui-se que a situação que promoveu menor concentração de tensões no osso peri-implantar foi com implantes submersos, reembasamento realizado somente na região dos implantes, espessura de 3 mm e material macio.

Palavras-chave: Biomecânica, Implante dentário, Reembasadores de prótese dentária.

ABSTRACT

Forces applied to submerged implants from complete dentures during the osseointegration period can, in some cases, lead to clinical failure. To date there is no study in the literature that quantifies and/or verifies the stress distribution of occlusal forces in submerged implants during the masticatory function of conventional complete dentures used on an interim basis during the period of osseointegration. Thus, this study evaluated the stresses in the bone adjacent to newly placed implants during the masticatory function in conventional complete dentures through the finite element methodology. Using a 3-D modeling software (SolidWorks 2010, SolidWorks Corp., Concord, Massachussets, EUA) it were made tridimensional models of a mandible simulating different clinical situations: (1) submerged implants, conventional complete dentures and relined ones with different soft liner materials; (2) different height levels of exposure to the oral environment (submerged, gingival level and 1.5mm of exposure to the oral environment); and (3) different thickness and comparation between relining the entire base or only in the region near the implants. The analysis were made in a specific software (ANSYS Workbench 12, Ansys Inc., Canonsburg, Pennsylvania, EUA) and for each model it were simulated two situations with masticatory load in inferior right canine (35N) and inferior right first molar (50N). All the analysis were made in maximum principal stress, in MPa. The obtained results showed that relined dentures with soft liner material reduced the stress concentration in the peri-implant bone tissue, being the stress concentration directly related to the softness of the material. Submerged implants presented the lowest values of stress concentration in the peri-implant bone tissue. The thickness and the area of reline are related to the transmission of stress to the peri-implant bone tissue, when relining the denture only in the region of the implants with a 3-mm thick layer of soft liner material presented better results. Comparing the results obtained from the different simulations it is possible to conclude that the situation which promoted fewer stress concentration in the peri-implant bone was with submerged implants, relining made only in the implants region, thicker layer (3 mm) of reline and softer material.

Key words: Biomechanics, Dental implantation, Denture Liners.

SUMÁRIO

INTRODUÇÃO

Em meados dos anos 80, o desenvolvimento da odontologia preventiva acarretou mudança no comportamento dos pacientes no que diz respeito à higiene bucal e manutenção dos dentes. Entretanto, observa-se em todo o mundo alta prevalência de indivíduos desdentados totais (Atchison & Andersen 2000; Bourgeois & Doury 1999; Colussi *et al,*. 2004; Moreira *et al.*, 2009), existindo perspectiva de aumento do número de desdentados na população durante as duas próximas décadas (He *et al.*, 2005).

Até pouco tempo atrás, o único tratamento reabilitador para pacientes nessa condição eram as próteses totais mucossuportadas que, de modo geral, apresentam bons resultados clínicos (Bellini *et al.*, 2009), melhorando a capacidade mastigatória, restabelecendo a estética e inserindo novamente esses indivíduos no convívio social. Entretanto, a retenção e a estabilidade das próteses totais convencionais podem estar comprometidas devido ao remodelamento do osso alveolar, causando desconforto, insegurança e limitação estética (Redford *et al.*, 1996; Thomason, 2010).

O tratamento reabilitador com implantes osseointegrados torna-se a melhor opção nestes casos, pois soluciona parte dessas deficiências do tratamento convencional (Emami *et al.*, 2009), superando as expectativas prévias ao tratamento (Baracat *et al.*, 2009). Dentre as possibilidades de reabilitação com implantes osseointegrados, as overdentures destacam-se por apresentar custo relativamente menor (Carlsson & Omar, 2010), satisfação dos usuários (Thomason, 2010) e, segundo o consenso de alguns autores, tem sido proposta como primeira opção de tratamento para mandíbula totalmente edêntula (Feine *et al.*, 2002; Thomason *et al.*, 2009; Thomason, 2010).

Estudo clássico defende que após a colocação, os implantes devem permanecer sem procedimentos técnicos de 3 a 6 meses para permitir a osseointegração sem complicações (Adell *et al.*, 1981). Segundo esses autores, a micro movimentação do implante, causada pela força funcional na interface osso-implante durante o período de osseointegração, pode induzir formação de tecido fibroso ao invés de neoformação óssea, levando ao fracasso do implante (Adell *et al.*, 1981). Entretanto, existe outra tendência na literatura defendendo a colocação imediata dos implantes em função, reportando taxas de sucesso similares quando comparadas à técnica cirúrgica de dois estágios (Chiapasco *et al.*, 1997; Randow *et al.*, 1999; Gatti *et al.*, 2000; Horiuchi *et al.*, 2000; Malo *et al.*, 2000). Todavia, essa tendência não implica no entendimento que o protocolo cirúrgico de dois estágios não seja mais necessário (Gapski *et al.*, 2003), considerando que a literatura relata que este sucesso estaria na dependência de diversos outros fatores, tais como estabilidade primária, quantidade e qualidade óssea, higiene, hábitos do paciente e doenças sistêmicas.

Assim, a estabilidade primária é o fator mais importante dentre todos que podem causar influência no sucesso de implantes sob carga imediata. Por outro lado, a colocação de implantes em tecido esponjoso com pouca estabilidade primária muitas vezes resulta no encapsulamento por tecido conjuntivo (Albrektsson & Sennerby, 1991). Micro movimentações maiores que 100 μm são suficientes para colocar em risco o processo de reparação, dificultando a deposição de matriz óssea diretamente ao redor do implante (Brunski, 1993). Deste modo, fica indicada a opção do protocolo de dois estágios com período de osseointegração de 3 a 6 meses, sempre que durante o procedimento de colocação do implante não se vislumbre a possibilidade de obter estabilidade primária adequada de 30 N/cm^2 (Misch, 2004).

Durante o período de osseointegração são provisoriamente utilizadas próteses totais convencionais com o objetivo de estabelecer função e estética adequadas até a colocação das próteses implantossuportadas. Com o uso das próteses provisórias, os implantes mesmo que submersos recebem transmissão de forças provenientes tanto da mastigação como de possíveis hábitos parafuncionais, o que pode também afetar a qualidade da osseointegração. Durante este período, os profissionais utilizam empiricamente os materiais reembasadores macios para evitar sobrecarga aos implantes. Entretanto, mesmo próteses reembasadas em uso durante o período de osseointegração podem causar carga sobre os implantes, causando exposição dos mesmos, perda óssea marginal e/ou falha na osseointegração (Misch, 2004). Até o presente momento não existem estudos na literatura que verifiquem se essas transmissões de força ao implante são realmente nocivas à osseointegração e se a utilização de materiais reembasadores macios reduz a intensidade dessas forças, contribuindo para que os implantes mantenham-se imperturbáveis pelo período necessário.

O método mais seguro para avaliar a resposta biomecânica é a avaliação clínica. Entretanto, o estudo do comportamento biomecânico de estruturas *in vivo* fica inviabilizado por aspectos éticos e/ou metodológicos (Abreu *et al.*, 2010). O desenvolvimento de modelos tridimensionais (3-D) específicos com elementos finitos é ferramenta poderosa para investigar forças que ocorrem no osso de forma semelhante ao que acontece *in vivo* sem danificar estruturas, pois oferecem informações precisas e confiáveis a respeito da biomecânica envolvida em diversas situações (Bergendal & Palmqvist, 1995; Taddei *et al.*, 2006). Essa metodologia possibilita prever e quantificar as tensões induzidas em todo o sistema (prótese/mucosa/implante/osso) e determinar a capacidade de cada estrutura em suportar determinadas cargas dentro de dada situação clínica. Dessa forma, baseado nos resultados obtidos por meio dessa metodologia, o clínico estará melhor preparado para interpretar as situações clínicas (Geng *et al.*, 2001), podendo indicar ou não a utilização de reembasadores macios em caso de próteses provisórias durante o período de osseointegração.

A apresentação do trabalho foi no formato alternativo de tese de doutorado, de acordo com as normas estabelecidas pela deliberação 002/06 da Comissão Central de Pós-Graduação da Universidade Estadual de Campinas.

O artigo correspondente ao Capítulo 1 foi submetido para publicação no periódico *Clinical Implant Dentistry & Related Research*, conforme documento relacionado em Anexos. Os artigos correspondentes aos Capítulos 2 e 3 foram redigidos nas normas dos periódicos *Journal of Oral Rehabilitation* e *Journal of Prosthodontics* Implants, respectivamente.

CAPÍTULO 1

Should soft liners be used in complete lower dentures after implants placement? A 3-D finite element analysis.

Running title: Stresses in peri-implant bone of submerged implants.

Key words: Biomechanics, Finite element analysis, Bone implant interactions, Prosthodontics.

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Abstract

Purpose: This paper aims to evaluate the stress distribution in the bone adjacent to submerged implants during masticatory function in conventional complete dentures through finite element analysis.

Material and methods: Three-dimensional models of a severely resorbed mandible with two and four submerged implants in the anterior region were created and divided into the following situations: (1) conventional complete denture; and conventional complete denture with different soft liner materials: (2) Coe-comfort ®, (3) Softliner ® and (4) Molteno Hard ®. The models were exported to mechanical simulation software; two simulations were done, with load in inferior right canine (35N) and inferior right first molar (50N). Data were qualitatively evaluated using Maximum Principal Stress given by the software.

Results: The models showed stress concentration in cortical bone corresponding to the cervical part of the implant. When the load was applied directly over the implant (canine) the softer the material, the lower stress was observed, since the conventional denture without a soft liner presented the highest values of stress. However, when the load was applied in a molar, the harder the material the lower stress was observed in the peri-implant bone, but in this case all values were very low.

Conclusions: The use of soft liners provides decreased levels of stress in peri-implant bones when the load was applied in canine teeth and increased levels when applied to molar teeth. Considering all values obtained in this study, the use of soft liners becomes the most suitable for use during the period of osseointegration.

Introduction

Since its introduction, dental implants have become a successful restorative modality in clinical dentistry, with a report of over 90% success rate[1]. Nowadays, oral rehabilitations with dental implants becomes the best choice for treatment because solves many problems that treatment with conventional dentures has[2], exceeding the pre-treatment expectations for both, esthetic and function[3].

The first studies related to implantology advocated that after the placement of an implant it has to be maintained undisturbed for 3 to 6 months of healing to obtain osseointegration without major problems[4], it is because the micro motion, caused by loading it earlier, may induce fibrous encapsulation instead of a direct bone–implant interface[5, 6]. At this time, it is safe to say that completely undisturbed healing of the implant–bone interface is not necessary for successful osseointegration to occur[7], and according to an experimental work, healing of peri-implant bone under load seems to be beneficial[8]. However, these findings do not imply that the protocol of delayed loading is no longer needed[9], since the literature reports that the success of immediate loaded implants is dependent on several factors. Among them, primary stability is the key factor, once micromotions at the bone-implant interface beyond 150 µm may result in fibrous encapsulation instead of osseointegration[10]. In these way, when primary stability cannot be achieved (30 N/cm^2)[11] it is recommended to opt for an adequate healing time before loading[9].

During the healing time, the patient needs to wear a conventional prosthesis on a provisional basis, in order to maintain proper function and aesthetics until the placement of the implant-supported prostheses. Using this temporary prosthesis, implants even submerged receive transmission of forces from both chewing and parafunctional habits, which may affect osseointegration. Relining this prosthesis with soft liners is usually recommended to avoid overloading the implants, but on an empirical basis. Even when relined, it is possible that occur excessive load on the implants, leading to implant exposure, marginal bone loss and/or failure in osseointegration[11].

To date, there is no study in the literature which verifies if these transmissions of forces are really harmful, and if relined prostheses with soft materials are able to reduce these forces, helping to keep the implants without disturbances during the healing period. The most reliable method to evaluate the biomechanical response of a given situation is the clinical evaluation, however, the study of intraosseous structures are impracticable by ethical and methodological aspects[12-14]. Thus, the finite element analysis becomes a powerful tool to investigate the forces that occur in the bone similarly to what happens in vivo, giving accurate and reliable information about the biomechanics involved in a given situation[15-19].

The purpose of the present study was to verify, through a three-dimensional (3-D) finite element analysis (FEA), the stress concentration in the bone near submerged implants in fully edentulous mandible when forces were applied in posterior or anterior teeth of conventional complete dentures relined, or not, with soft liners materials. The following null hypotheses were set: (1) the use of soft liners in complete lower dentures during the healing time does not affect the stress concentration in the bone adjacent to the implants, and (2) there is no difference in the stress concentration in the bone near implants when it is used liners with different hardness properties.

Material and Methods

Three-dimensional finite element models reproducing a severely resorbed jaw with two and four submerged titanium implants (4.0-mm diameter x 10-mm length) in the anterior region and a conventional complete denture seated on the mucosa were modeled, as standard models, using specific 3-D modeling software (SolidWorks 2010, SolidWorks Corp., Concord, Massachusetts, USA). The implant thread was removed, because after convergence tests, they were found to be not relevant to the analysis and provided a relevant reduction in elements.

Finite element models were obtained by importing the solid model into mechanical simulation software (ANSYS Workbench 11, Ansys Inc., Canonsburg, Pennsylvania, USA). The models were divided into two groups according to the number of implants and within them in four subgroups each, varying among a control (with the denture base formed only by acrylic resin) and the others presenting a 3-mm thick layer of different soft liner materials, as shown in Table 1.

All materials used in the models were considered to be isotropic, homogeneous, and linearly elastic. The elastic properties used were taken from literature (Table 2)[20-22].

The model stability was carried out to obtain a reliable model, which was regarded as relevant to engineering and clinical aspects[13]. The total numbers of elements generated in the FE models were 354,417 for the control group with two implants and 376,115 for the control group with four implants; 355,140 and 371,666 to relined dentures models with two and four implants, respectively. The shape of the element was tetrahedral with 10 nodes. The investigated models showed the configurations presented in Figure 1. Stability of the model was checked, and particular attention was paid to the refinement of the mesh resulting from the convergence tests at the bone/implant interface.

The base of the mandible was set to be the fixed support and loads were applied separately in the right inferior canine (35 N) and inferior right first molar (50 N), as observed in a clinical study that evaluated the bite force of complete denture wearers[23]. Data for Maximum Principal Stresses were produced numerically, color coded, and compared among the models.

Results

Maximum Principal Stresses that occurred in the different groups in the mandible with two when the load was applied to canine and molar are presented in Figure 2 and 3, respectively. The highest value of stress for each situation in the mandible with two implants is presented in Table 3.

Figures 4 and 5 shows the Maximum Principal Stresses occurred in the different groups in the mandible with four implants when the load was applied to canine and molar, respectively. The highest value of stress for each group in the mandible with four implants is also presented in the Table 4.

All the models and situations showed stress concentration in the cortical bone corresponding to the cervical part of the implant. Different stiffness of the materials showed to be relevant in the stress distribution bone adjacent to the implants.

Discussion

Our first hypothesis was that the use of soft liners in complete lower dentures during the healing time does not affect the stress concentration in the bone adjacent to submerged implants. However, complete dentures relined with soft materials showed lower stress concentration compared to the control groups when the load was applied to the inferior right canine (above the implant) (Figures 2 and 4). When the load was applied to the inferior right molar this situation was inverted (Figures 3 and 5), but in a smaller proportion of values, being that conventional complete denture (Control) showed the lowest values of stress. This hypothesis was rejected because the values of stresses when the load was applied in the molar seem to be not relevant in all materials, and when applied to canine the value of stress in the control group was more than double of all the other groups (Tables 3 and 4).

Our second hypothesis, that there is no difference in the stress concentration in the bone adjacent to submerged implants when it is used liners with different hardness properties, was also rejected by our findings (Tables 3 and 4). Once in molar all the values seem to be not relevant too, and in canine the values of stresses were influenced by the stiffness's of the materials. The softest material showed less stress concentration in the peri-implant bone, being 4.82 times lower than the control group; and the hardest material only 2.44 times (Tables 3 and 4). Our results also did not found substantial differences among mandibles with two or four implants, being that the stresses values in the mandible with four implants showed an average of 0.85 MPa more than the mandible with 2 implants when the load was applied to canine and 0.038 MPa for molar.

The stresses in all groups were concentrated in the cortical bone around the implant neck, a possible explanation about this finding is that the elastic modulus of cortical bone is higher than cancellous bone and that cortical bone is much strong and more resistant to deformation[15, 19]. Usually the stress levels that actually cause biological response, such as resorption and remodeling of the bone, are not comprehensively known. Therefore, the data of stress provided from the FEA need substantiation by clinical research[7, 14].

To the best of our knowledge, there are no published studies about the influence of relined dentures on the stress distribution on peri-implant bone, as previously stated here. It was reported that prostheses used during healing time can cause uncontrolled implant loading, which may lead, in some cases, to failed integration[5, 11].

Well done oral rehabilitations, even conventional ones[24], can bring back the self steem to patients, improving esthetics and function[2, 3]. Although the success rates of immediately loaded implants are comparable to a staged healing protocol, there are greater risks with this approach[8, 9, 11]. Screw loosening, prosthesis breakage, overloading, and/or parafunction can lead to significant micromovement of the implant resulting in failure[6, 10, 11]. Thus, if unfavorable conditions are present or discovered at the time of surgery, the patient should be treated with the traditional submerged healing approach.

FEA has been widely used in the field of oral implantology to estimate peri-implant stresses and strains[16], it is numerical method of analysis for stresses and deformations in structures of any given geometry, for this, the structures are broken down into many small simple blocks or elements that can be described with a relatively simple set of equations[7]. This method allows researchers to overcome some ethical and methodological limitations and thus enables them to verify how the stresses are transferred to the studied structures, but like any methodology, it has pros and cons, a common limitation is that the analyses are based on a specific set of input values, assumed to be average or representative values; such as specific occlusal loading directions, bone material properties and bone dimensions[12]. The materials were assumed to be homogeneous isotropic and to possess linear elasticity, however, it is known that some materials, such as cortical bone of the mandible, are isotropic and inhomogeneous[18]. Also, the type, arrangement, and total number of elements may affect the accuracy of the results[7, 14].

In this study, the contact bone-implant was set to be 100%, although this is not what happens in reality, a previous study found that the results based on complete osseointegration and non-linear frictional contacts among bone-implant are very similar[7].

Conclusion

This study furthers our understanding on the stress distribution of mastication on submerged implants during the healing period. In conclusion, this study suggests that the use of conventional complete dentures during the healing period may introduce more risk of loss of implants compared with dentures which are relined with soft materials. With respect to the soft liners materials, the use of harder materials is more critical in reducing peri-implant stresses than softer ones.

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Tables

Table 1 – Distribution of the studied groups.

Two implants	Conventional complete denture (Control)
	Coe-comfort ®
	Softliner ®
	Molteno Hard ®
Four implants	Conventional complete denture (Control)
	Coe-comfort ®
	Softliner ®
	Molteno Hard ®

Table 2 – Materials properties adopted in the study.

Material	Young's modulus (MPa)	Poisson's ratio	References
Artificial teeth	2,940	0.30	†
Acrylic resin	1,960	0.30	†
Mucosa	340	0.45	†
Cortical bone	13,700	0.30	*
Cancellous bone	1,370	0.30	*
Implant	110,000	0.33	*
Molteno Hard ®	27.94	0.30	§
Softliner ®	11.79	0.30	§
Coe-Comfort ®	7.32	0.30	§

*Rubo & Capello Souza, 2010; † Kawasaki *et al.*, 2001; § Sato *et al.*, 2000.

Table 3 - Maximum principal stress values (MPa) in the bone in the models with two implants.

Canine	Conventional denture	0.786
	Coe-Comfort ®	0.163
	Softliner ®	0.206
	Molteno Hard ®	0.322
Molar	Conventional Denture	0.074×10^{-2}
	Coe-Comfort ®	2.858×10^{-2}
	Softliner ®	2.893×10^{-2}
	Molteno Hard ®	2.395×10^{-2}

Table 4 – Maximum principal stress values (MPa) in the bone in the models with four implants.

Canine	Conventional denture	0.981
	Coe-Comfort ®	0.197
	Softliner ®	0.253
	Molteno Hard ®	0.389
Molar	Conventional Denture	0.110×10^{-2}
	Coe-Comfort ®	2.994×10^{-2}
	Softliner ®	2.897×10^{-2}
	Molteno Hard ®	2.373×10^{-2}

Figures

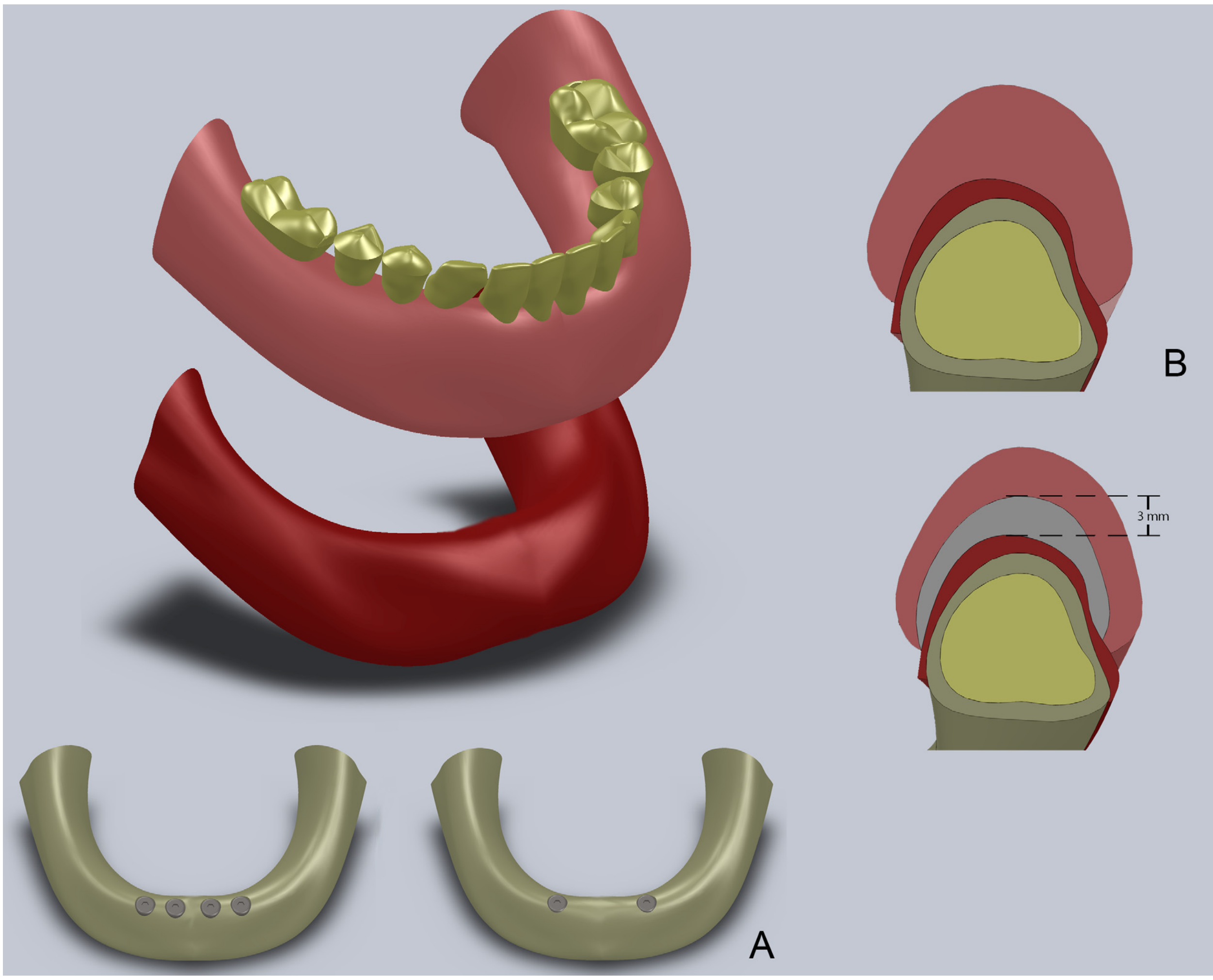

Figure 1 – Three-dimensional solid models: (A) Mandible with two and four implants; (B) Differences on the models among control group and relined dentures.

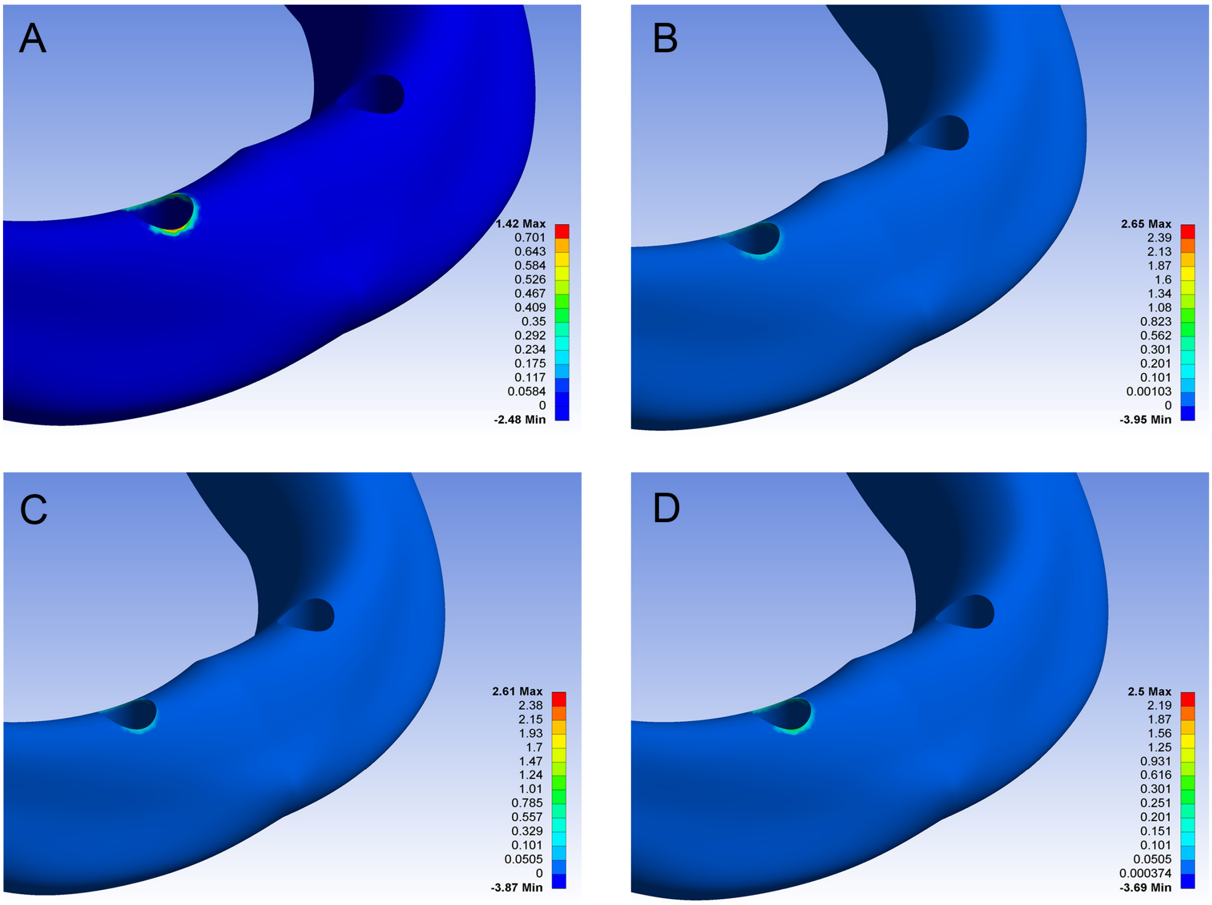

Figure 2 – Maximum Principal stress (MPa) distribution in the peri-implant bone tissue for the different materials with two implants when load was applied to canine (35 N): (A) control group; (B) Coe-Comfort ®; (C) Softliner ®; (D) Molteno Hard ®.

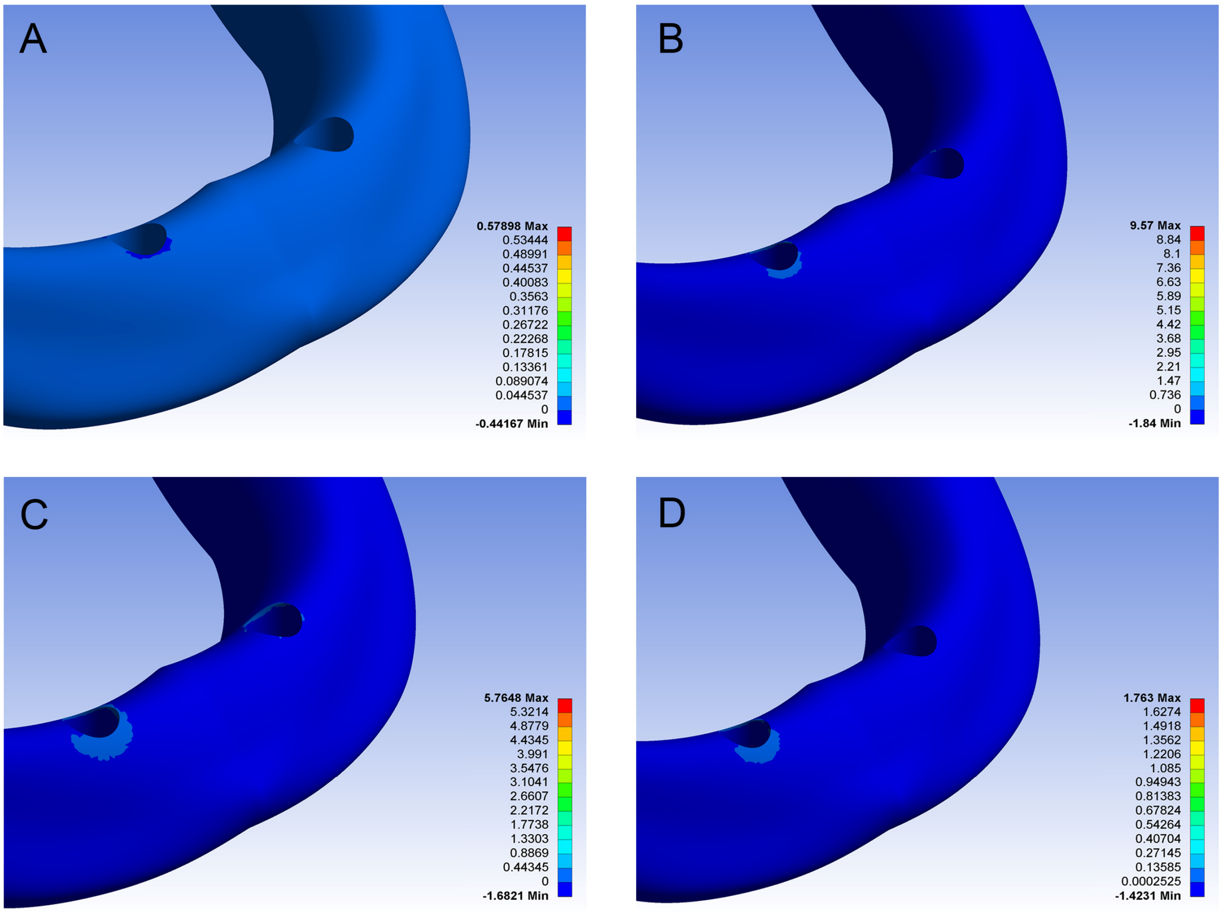

Figure 3 – Maximum Principal stress (MPa) distribution in the peri-implant bone tissue for the different materials with two implants when load was applied to molar (50 N): (A) control group; (B) Coe-Comfort ®; (C) Softliner ®; (D) Molteno Hard ®.

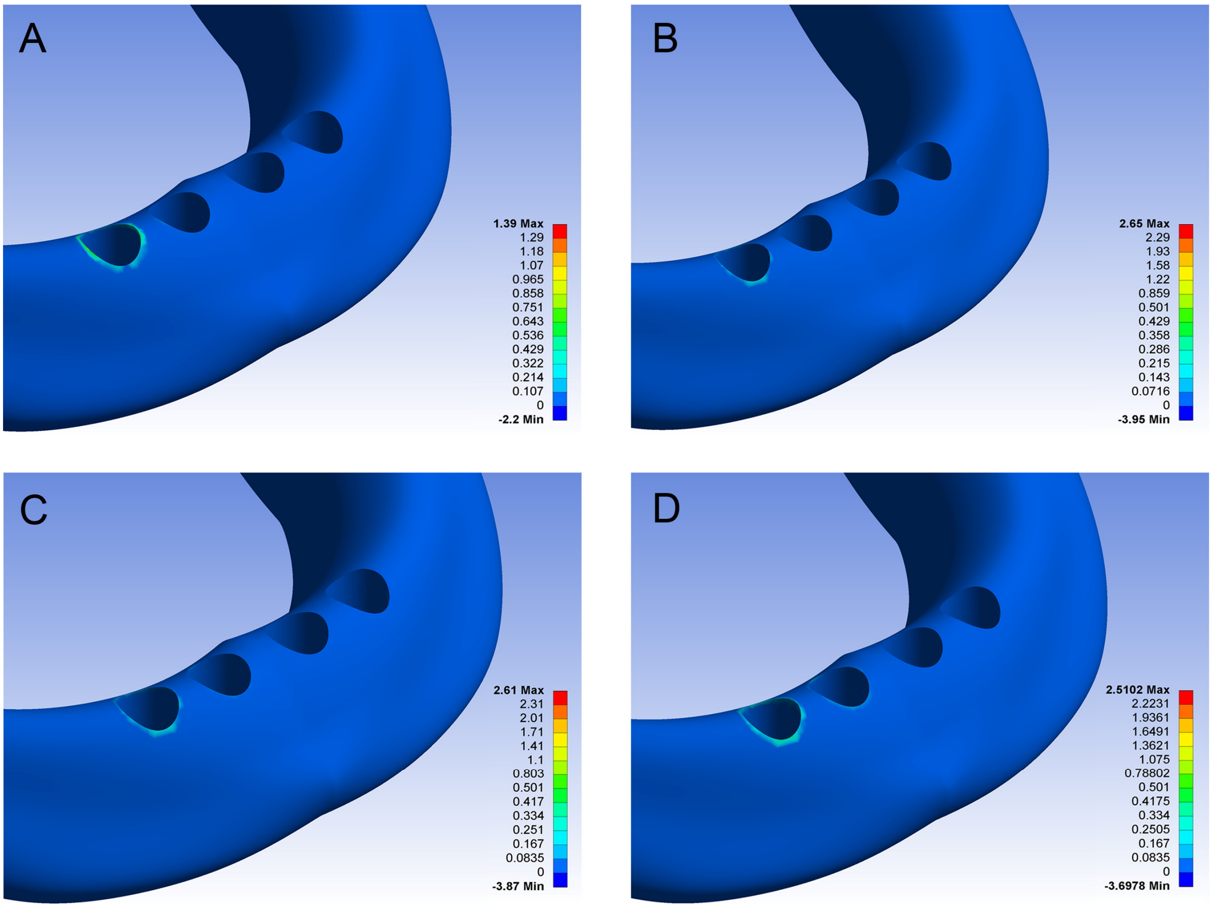

Figure 4 – Maximum Principal stress (MPa) distribution in the peri-implant bone tissue for the different materials with four implants when load was applied to canine (35 N): (A) control group; (B) Coe-Comfort ®; (C) Softliner ®; (D) Molteno Hard ®.

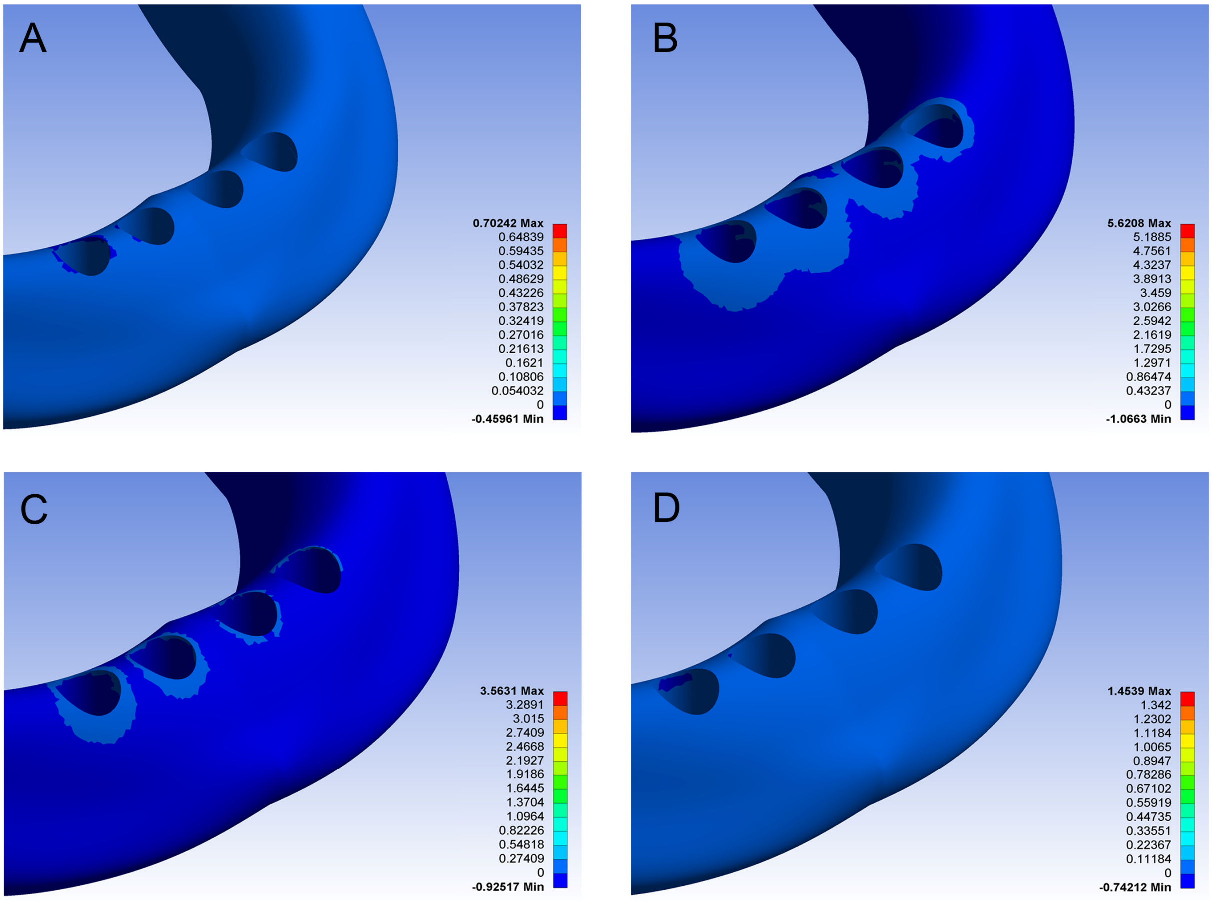

Figure 5 – Maximum Principal stress (MPa) distribution in the peri-implant bone tissue for the different materials with four implants when load was applied to molar (50 N): (A) control group; (B) Coe-Comfort ®; (C) Softliner ®; (D) Molteno Hard ®.

CAPÍTULO 2

3-D FEA of stress distribution in peri-implant bone with relined dentures and different heights of healing caps

Running title: Stresses in peri-implant bone of non-submerged implants

Key words: Finite element analysis, healing period, osseointegration, dental implant, soft liners.

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* This manuscript is in accordance with author guidelines of the *Journal of Oral Rehabilitation*.

Abstract

The purpose of this study was to evaluate the influence of height of healing caps and the use of soft liner materials on the stress distribution in peri-implant bone during masticatory function in conventional complete dentures during the healing period by using finite element analysis. Three-dimensional models of a severely resorbed mandible with two recently placed implants in the anterior region were created and divided into the following situations: (1) submerged implants; (2) healing cap at gingival level; and (3) 1.5-mm supragingival. All these situations were also analyzed for a conventional complete denture and a denture relined with a 3-mm thick layer of soft liner material. The models were exported to mechanical simulation software that presented two simulations, one with load in the inferior right canine (35N) and the other in the inferior right first molar (50N). Data were evaluated using Maximum Principal Stress provided by the software. All models showed a stress concentration in the cortical bone corresponding to the cervical part of the implant. The simulations with non-submerged implants showed higher values of stress concentration than those that were submerged. Likewise, soft liner materials presented better results than when the denture base was not relined. The height of the healing caps seems to have a direct influence on the stress distribution in the peri-implant bone during the healing period. Considering the values obtained in this study, the use of soft liners with submerged implants seems to be the most suitable method to use during the period of osseointegration.

Introduction

Occlusal forces affect the bone surrounding an oral implant. Mechanical stress can have both positive and negative consequences for bone tissue (1) and for maintaining osseointegration of an oral implant (2). Loading protocols for the dental implant treatment of edentulous jaws have been widely discussed in the dental literature. Initial implant stability (30 N/cm2 or 55 ISQ) (3, 4), implant surface characteristics, bone quality, bone healing, interim prosthesis design, and occlusion pattern during the healing phase have been identified as factors that influence achieving osseointegration with modified loading protocols (5). When primary stability is not achieved, research indicates that dentists should follow the delayed loading protocol (4 to 6 months) to ensure a satisfactory process of bone healing and apposition of bone to implant (6-8). However, longitudinal studies showed that maintaining the implants submerged and the two stage protocol are not mandatory to achieve successful osseointegration (9).

Overloading the implants in addition to the microbiota and the absence of primary stability during the healing period can cause micro-movement (higher than 150 μm) of the implant, inducing the emergence of fibrous tissue around the implant and interposing the bone-implant interface, which results in failures of the osseointegration process (5, 10-13).

During the healing period, patients need to wear a conventional prosthesis on a provisional basis, in order to maintain proper function and aesthetics until the placement of the implant-supported prostheses. When using this temporary prosthesis, submerged and non-submerged implants absorb forces caused by chewing and parafunctional habits, which may affect osseointegration. Relining this prosthesis with a soft liner is usually recommended to avoid overloading the implants, but on an empirical basis. In order to allow better stress distribution the soft liner materials should have a minimal thickness (2-3mm) and should be periodically changed due to the significant increases of hardness over time (14).

The peri-implant gingival level is unpredictable, so it is difficult to select the healing caps to use during the surgical procedures. The combination of the height of supragingival healing caps and increased hardness or inappropriate use of resilient materials can potentially generate excessive load on the implants, marginal bone loss and/or failure in osseointegration (4).

To date, no research has been done that explains the influence of submersion of the implants during the healing period or the influence of the height of the healing caps on stress distribution to the peri-implant bone tissue. Finite element analysis is a powerful tool to aid an investigation of the forces that occur in the bone, similar to what happens in vivo, giving accurate and reliable information about the biomechanics involved in a given situation (15-19). The purpose of this study was to verify, through a three-dimensional (3-D) finite element analysis (FEA), the stress concentration in the bone near implants with different heights of healing caps in a fully edentulous mandible when forces were applied to the posterior or anterior teeth of conventional complete dentures with or without soft liner material. The following null hypotheses were set: (1) there is no difference in the stress concentration in the bone near implants whether submerged or non-submerged implants are used, and (2) the use of a soft liner in complete dentures during the healing time does not affect the stress concentration in the bone adjacent to the implants.

Materials and Methods

Using 3-D modeling software (SolidWorks 2010, SolidWorks Corp., Concord, Massachusetts, USA), a three-dimensional, finite element model was built of a severely resorbed jaw with two titanium implants (4.0-mm diameter x 10-mm length) in the anterior region with a conventional complete denture seated on the mucosa. The implant thread was removed because convergence tests found it was not relevant to the analysis, and it provided a relevant reduction in elements.

Finite element models were obtained by importing the solid model into mechanical simulation software (ANSYS Workbench 11, Ansys Inc., Canonsburg, Pennsylvania, USA). The models were divided into three groups according to the height of the healing caps (submerged, at gingival level, and 1.5mm supragingival), and there were two controls, one with the denture base made of acrylic resin and the other with a 3-mm thick layer of soft liner.

All materials used in the models were considered to be isotropic, homogeneous, and linearly elastic. The elastic properties used were taken from literature (Table 1) (20-23).

The model stability was carried out to obtain a reliable model, which was regarded as relevant to engineering and clinical aspects (24). A total 354,417 elements were generated in the FE models for the control group and 347,388 in the relined dentures models with two and four implants, respectively. The elements were tetrahedral with 10 nodes. The investigated models had the configurations presented in Figure 1. The stability of the model was checked, paying particular attention to the refinement of the mesh resulting from the convergence tests at the bone/implant interface.

The base of the mandible was set to be the fixed support, and loads were applied separately in the right inferior canine (35 N) and inferior right first molar (50 N), as observed in a clinical study that evaluated the bite force of complete denture wearers (25). Data for Maximum Principal Stresses were produced numerically, color coded, and compared among the models.

Results

Maximum Principal Stresses that occurred in peri-implant bone in the groups with different heights of healing caps with and without a 3-mm layer of soft liner material when the load was applied to the canine are presented in Figure 2. The quantitative values of stress in the peri-implant bone are presented in Table 2.

In all the models and situations there was stress concentrated in the cortical bone corresponding to the cervical part of the implant. Different heights and the use of soft liners were relevant in the stress distribution to the bone adjacent to the implants.

Discussion

The first hypothesis of this study that there is no difference in the stress concentration in the bone near implants, whether they are submerged or not was rejected. When observing the stresses in the models, the submerged implants in both the control and the test group, showed lower values of stress concentration compared to the implants at the gingival level and at 1.5 mm supragingival level. The mucosa resiliency probably contributed by providing absorption of the stresses, minimizing the stress values in the bone/implant interface. Although there were higher values of stress in non-submerged implants, it did not generate failures in osseointegration itself, as shown in an earlier longitudinal study (9). Indeed, the exposure of the healing caps during the healing period may be considered a potential risk, mainly when the prosthesis is not relined with soft liner materials. In clinical situations of low primary stability, the submersion of the implants suggests greater protection when they are submitted to stress, and can lead to a safer healing period, as suggested in the initial implant studies (6-8).

The groups with supragingival healing caps showed the highest values of stress concentration in all the analyzed situations, which may be due to the formation of a lever and consequent action of it on the stress distribution during the effort. Micro-movements superior to 150 µm in the bone/implant interface proved to be harmful to osseointegration, while micro-movement up to 50 µm are well tolerated (5, 13). This control is clinically difficult to achieve, especially in individuals with parafunctional habits. However, better distribution of the stresses will provide a more predictable osseointegration. Based on this assumption, healing caps at the gingival level should be used after one-stage implant surgery or reopening the implants. Our findings support a previous study (26) that evaluated the bone formation in submerged and non-submerged implants in dogs through micro CT image analysis. The authors concluded that both the amount of osseointegration and the bone height around the implants were significantly greater in submerged implants than in non-submerged implants.

The second hypothesis that the use of a soft liner in complete dentures during the healing time does not affect the stress concentration in the bone adjacent to the implants was also rejected. The use of relining materials considerably minimized the values of stress in all the analyses. Moreover, when the load was applied to canines, the stress distribution in the relined groups was more homogeneous, differing from that found in the control groups in which the denture base was formed only of acrylic resin However, for satisfactory results, the soft liner material must have a minimum thickness, which was assumed to be 3-mm in this study, and specific hardness properties (22, 27). Over time, resilient materials in contact with oral fluids deteriorate, and their properties are modified, significantly raising it hardness (14), which may result in stress levels similar to those found with the non-relined dentures. Therefore, the soft liner material should be replaced each month (14).

FEA has been widely used in the field of oral implantology to estimate peri-implant stresses and strains (15).It is a numerical method of analyzing stresses and deformations in structures of any given geometry. To do this, the structures are broken down into many small simple blocks or elements that can be described with a relatively simple set of equations (28). This method allows researchers to overcome some ethical and methodological limitations and enables them to verify how the stresses are transferred to the studied structures. However, like any methodology, it has pros and cons.A common limitation is that the analyses are based on a specific set of input values that are assumed to be average or representative; such as specific occlusal loading directions, bone material properties, and bone dimensions (29). The materials were assumed to be homogeneous isotropically and to possess linear elasticity; however, it is known that some materials, such as cortical bone of the mandible, are isotropic and inhomogeneous (17). Furthermore, the type, arrangement, and total number of elements may affect the accuracy of the results (28, 30).

In this study, the contact bone-implant was set to be 100%, although this is not what happens in reality. A previous study found that the results based on complete osseointegration and non-linear frictional contacts among bone-implants are very similar (28).

In Table 2, it is possible to verify that when the load was applied to the molar, the control group showed lower stress values in the peri-implant bone than occurred with the relined dentures. This can be attributed to the fact that the base of only acrylic resin promotes less distribution of the functional forces (31, 32), so much of the stress is distributed in the region of the load.

FEA is a powerful tool that can help to overcome some ethical and traditional experimental methodological limitations by offering accurate and reliable information about the biomechanics of a determined situation (24). However, further investigations are necessary in order to clarify the real effects of functional forces on the risk of failure during a healing period following implant surgery.

Within the limitations of the adopted methodology, it is possible to conclude that: (1) non-submerged implants showed higher stress values in the peri-implant bone than submerged ones; and (2) the use of soft liner materials considerably reduces the stress levels in the peri-implant bone interface when the load was applied to canines.

Acknowledgments

The authors thank the Department of Products Development of the Renato Archer's Center of Information Technology, Campinas – SP, Brazil, in the person of Pedro Yoshito Noritomi, for its generous help with the finite element analysis. The authors also thank the National Counsel of Technological and Scientific Development (CNPq) for the support to PhD Programme at Piracicaba Dental School, State University of Campinas, SP, Brazil.

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Material	Young's modulus (MPa)	Poisson's ratio	References
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Acrylic resin	1,960	0.30	†
Mucosa	340	0.45	¥
Cortical bone	13,700	0.30	*,¥
Cancellous bone	1,370	0.30	¥
Implant	110,000	0.35	*
Coe-Comfort ®	7.32	0.30	§

¥ Barão *et al.*, 2008; *Rubo & Capello Souza, 2010; † Kawasaki *et al.*, 2001; § Sato *et al.*, 2000.

Table 2 – Maximum principal stress values (MPa) in the bone in the different models evaluated.

		Submerged	Gingival level	Supra gingival
Canine	Control	0.786	3.334	5.061
	Liner	0.163	0.308	0.785
Molar	Control	$0.746\ x10^{-3}$	$4.404x10^{-3}$	$7.519x10^{-3}$
	Liner	$0.285\ x10^{-1}$	$0.963x10^{-1}$	$2.029x10^{-1}$

Figure Legends

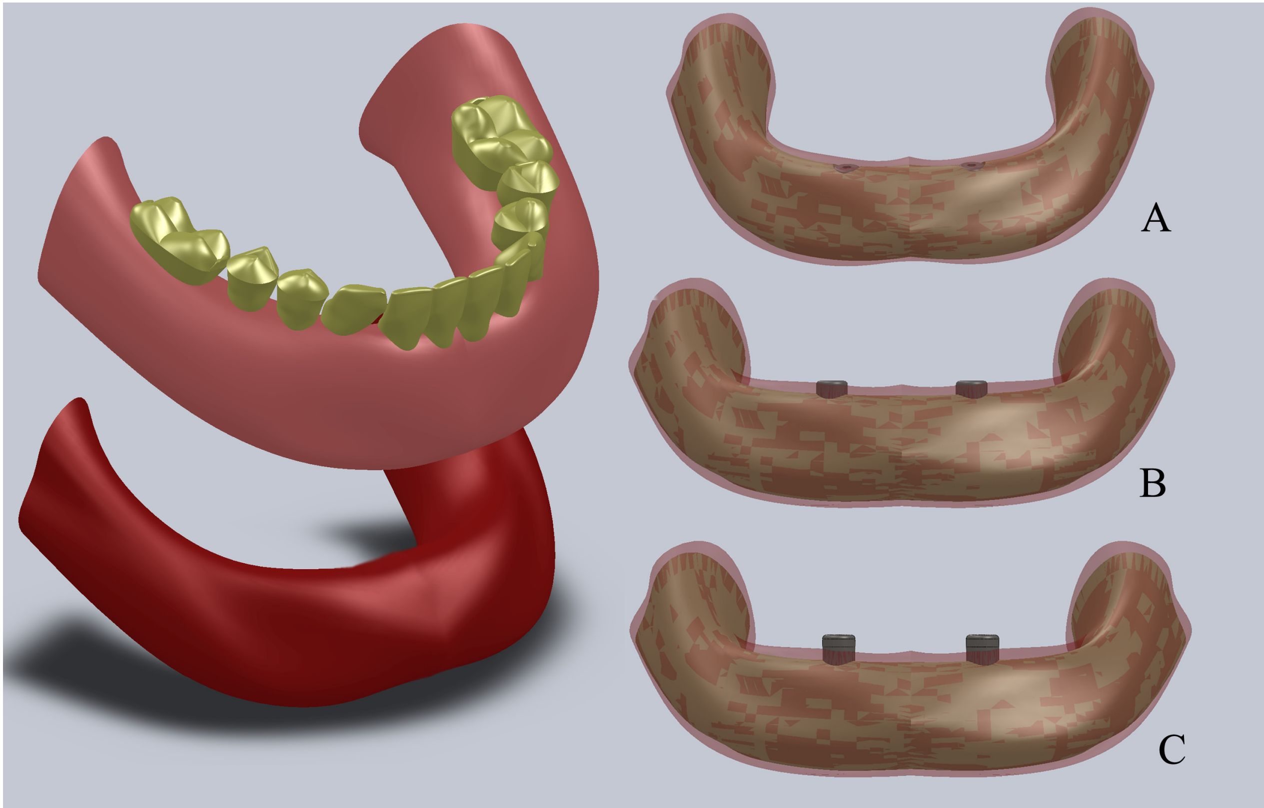

Figure 1 – Three-dimensional solid models: (A) Submerged implants; (B) Healing caps at gingival level; and (C) 1.5 mm supragingival implants.

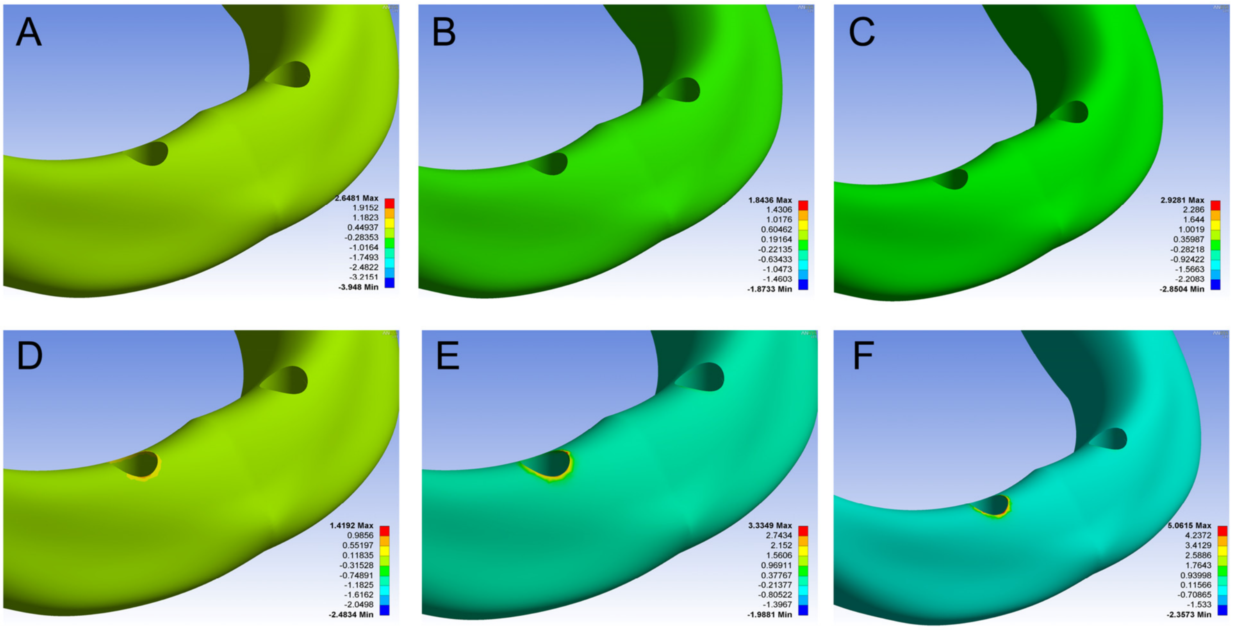

Figure 2 – Maximum of stress (MPa) in the peri-implant bone tissue when load was applied to canine (35 N): (A) submerged implants and relined dentures; (B) healing caps at gingival level and relined dentures; (C) 1.5-mm supragingival implants and relined dentures; (D) submerged implants and dentures not relined; (E) healing caps at gingival level and non-relined dentures; and (F) 1.5-mm supragingival implants and dentures not relined.

CAPÍTULO 3

Influence of thickness and area of reline on the stress distribution in peri-implant bone during healing period

Key words: Finite element analysis, Healing period, Osseointegration, Dental implant, Soft liners.

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Abstract

Purpose: To evaluate the influence of thickness and area of reline on the stress distribution in peri-implant bone during masticatory function in conventional complete dentures during healing period through finite element analysis.

Material and methods: Three-dimensional models of a severely resorbed mandible with two recent placed implants in the anterior region were created and divided into the following situations: (1) 3-mm and (2) 1.5-mm thick layer of soft liner material covering the entire length of the denture base; and localized application of soft liner in the implants' region with (3) 3-mm and (4) 1.5-mm thick. The models were exported to mechanical simulation software; it was done two simulations with load in inferior right canine (35N) and inferior right first molar (50N). Data were qualitatively evaluated using Maximum Principal Stress given by the software.

Results: All models showed stress concentration in cortical bone corresponding to the cervical part of the implant. The simulations with 3-mm thick of soft liner material showed lower values of stress concentration than 1.5-mm thick. Likewise, the situations with localized application of soft liner in the implants' region showed better results than when the entire denture base was relined.

Conclusions: The thickness and the area of reline in conventional complete dentures have direct influence on the stress distribution in the peri-implant bone tissue during the healing period. Considering the values obtained in this study, the localized use of soft liners in implants' region with the thickest layer possible becomes the most suitable for use during the period of osseointegration.

Introduction

Since the late 1960s, when dental implants were introduced for rehabilitation of the completely edentulous patients[1], an awareness and subsequent demand for this kind of therapy has increased[2]. Long-term success rates of 95% for mandibular implants and 90% for maxillary implants have been reported[3]. Still, implant failure is a source of frustration and disappointment for both the patient and clinician, and strategies for prevention of failure are crucial[4-6].

The mechanical situation at the osseointegrated implant-bone interface is quite different to the tooth-bone interface. While teeth hangs on the alveolar bone by means of the periodontal ligament, osseointegrated implants are tightly and directly attached to the bone[7]. That is the reason why the implants and the adjacent bone tissue are exposed to different stresses under bite forces when compared with natural teeth[8].

Biomechanical principles are one of the most important factors for implant success. Implant treatment involves both biological and mechanical components[9-11]. Due to the lack of micromovement of osseointegrated implants, most of the stresses are concentrated on the crest of the alveolar ridge, which may lead to bone resorption and subsequent loss of the implant[12].

When implants are been placed, the rehabilitation process can follow two different paths: the prosthesis can be installed immediately or within a few hours after implant placement (immediately loaded implants), or can wait for the healing period (delayed loaded implants). When this latter process is chosen in edentulous patients, a conventional denture is used as a provisional denture in order to maintain the aesthetic and functional condition of the patient.

During chewing, forces are distributed throughout the support area of this provisional prosthesis, including on implants in healing process, transmitting these loads to them and to the peri-implant bone tissue. To reduce the transmission of loads to the implants it is indicated to reline the denture with a soft liner material. The reline may have different thicknesses and can be applied throughout the denture base or just in the region of the implants.

Load transfer at the bone-implant interface may be influenced by several factors, such as type of loading, the material properties of the implant, nature of the bone-implant interface, quality and quantity of the surrounding bone, implant geometry, length, diameter, and shape, and the implant surface structure[13, 14]. If the occlusal force exceeds the capacity of the interface to absorb stress, the implant will fail[7, 15-17].

An increasing number of studies had investigated the causes of implant failure in clinical practice using various stress analysis methods[18, 19]. The major expectation from these studies is to extrapolate relevant findings of risk factors, rather than learning them by clinical experience[20]. Finite element analysis (FEA) has been utilized to evaluate the induced stresses around implant components and surrounding bone tissue. To study a complex mechanical problem, FEA can be used to divide the problem into a collection of much smaller and simpler elements. Thus, complicated geometric structures are converted into a mesh in a computer set[11], and then the stress analysis are made in an engineering software.

The purpose of the present study was to verify, through a three-dimensional (3-D) finite element analysis (FEA), the influence of the thicknesses and area of reline on the stress concentration in peri-implant bone tissue in fully edentulous mandible when forces were applied in posterior or anterior teeth of conventional complete dentures. The following null hypotheses were set: (1) the thickness of the soft liner material does not affect the stress concentration in the peri-implant bone tissue, and (2) there is no difference in the stress concentration in the peri-implant bone tissue when the entire denture base or just the implants' region were relined.

Material and Methods

Three-dimensional finite element models reproducing a severely resorbed jaw with two titanium implants (4.0-mm diameter x 10-mm length) at gingival level in the anterior region, and a conventional complete denture seated on the mucosa were modeled, as standard models, using specific 3-D modeling software (SolidWorks 2010, SolidWorks Corp., Concord, Massachusetts, USA). The implant thread was removed, because after convergence tests, they were found to be not relevant to the analysis and provided a relevant reduction in elements.

Finite element models were obtained by importing the solid model into mechanical simulation software (ANSYS Workbench 11, Ansys Inc., Canonsburg, Pennsylvania, USA). The models were divided into two groups according to the area of reline (entire denture base relined with soft liner material or localized reline in implants' region) and thickness of soft liner material (3 or 1.5-mm).

All materials used in the models were considered to be isotropic, homogeneous, and linearly elastic. The elastic properties used were taken from literature (Table 1)[21-23].

The model stability was carried out to obtain a reliable model, which was regarded as relevant to engineering and clinical aspects[24]. The total numbers of elements generated in the FE models were 350,078 for the group with 3-mm layer of soft liner in the entire base and 351,130 for the group with 1.5-mm; 349,672 and 350,978 to dentures relined just in the implants' region with 1.5 and 3-mm layer of soft liners, respectively. The shape of the element was tetrahedral with 10 nodes. The investigated models showed the configurations presented in Figure 1. Stability of the model was checked, and particular attention was paid to the refinement of the mesh resulting from the convergence tests at the bone/implant interface.

The base of the mandible was set to be the fixed support and loads were applied separately in the right inferior canine (35 N) and inferior right first molar (50 N), as observed in a clinical study that evaluated the bite force of complete denture wearers[25]. Data for Maximum Principal Stresses were produced numerically, color coded, and compared among the models.

Results

Maximum Principal Stresses that occurred in peri-implant bone in the groups with 3- and 1.5-mm layer thick of soft liner material when the load was applied to canine are presented in Figure 2. The quantitative values of stress in the peri-implant bone are presented in the Table 2.

All the models and situations showed stress concentration in the cortical bone corresponding to the cervical part of the implant. Different thickness and areas of the soft liner layer showed to be relevant in the stress distribution bone adjacent to the implants.

Discussion

Nowadays, there are many reports that suggest that 2 implants may be immediately loaded in the anterior mandible, presenting success rates comparable to a staged healing protocol. However, there are greater risks with this approach[26-28]. Screw loosening, prosthesis breakage, overloading, and/or parafunction can lead to significant micromovement of the implant resulting in failure[27, 29, 30]. Thus, if unfavorable conditions are present or discovered at the time of surgery, the patient should be treated with the traditional submerged healing approach. It was reported that prostheses used during healing period can cause uncontrolled implant loading, which may lead, in some cases, to failed integration[27, 31].

The application of resilient denture liners to the denture base enables stress to be absorbed, thereby reducing the load on the implants in healing process. The load is distributed over the denture bearing area by preventing localized areas of stress concentration[32].

Our first hypothesis was that the thickness of the reline in provisional complete dentures does not affect the stress concentration in the peri-implant bone tissue during the healing process. However, when the force was applied to the canine teeth, the denture relined with a layer of 3-mm of a soft liner material showed lower concentration of stress in the peri-implant bone tissue than those relined with a thinner layer (1.5-mm). This can be attributed to the elasticity and resiliency of the soft liner materials, which in thicker layers, produces a more uniform distribution of the functional loads over the entire denture-bearing area[33], providing shock-absorbing effects[34] and avoiding local concentration of stress[23]. When the loads were applied to the inferior right molar this situation was inverted, but in a smaller proportion of values, being that the denture relined whit a thinner layer presented lowest values of stress in peri-implant region. This can be attributed to the fact that a lower layer of relining material promote less distribution of the functional forces[34, 35], thus much of the stress is distributed in the region of the load. In this way, when a thicker layer of soft liner material was used the forces are better distributed along the denture-bearing area, so in the region of the load the stress concentration decreases while in the rest of the denture-bearing area the stress concentration increases[33], including over the implants' region. This hypothesis was rejected because the values of stress, when the load was applied to canine, were lower for the group with a 3-mm thick of soft liner material than compared with a thinner reline. The fact of thinner layers of soft liner material promote lower stress concentration when the load was applied to molar do not seems to be clinically relevant due to the values of stress concentration to be very low.

Our second hypothesis that there is no difference in the stress concentration in the peri-implant bone tissue when the entire denture base or just implants' region were relined was also rejected. The dentures relined in implants' region presented the lowest stress values compared with dentures relined in the entire base, independent of the thickness of the layer. When the load was applied to canines, the dentures with 3-mm thick in the implants' region presented the lowest stress values in peri-implant region when compared to all the others test groups, followed by 3-mm thick in entire denture base. With respect of the groups relined in the implants' region, the thickness of the soft liner material seems to be an important factor in reducing the stress concentration in the peri-implant bone once the group with 3-mm thick presented a reduction of almost one third of the 1.5-

mm group. In molar, the previously situation observed when the entire denture base was relined, where the thinner layer of soft liner presented lowest values of stress in peri-implant region was not observed, it can be attributed to the absence of relining material in the posterior region that makes the most of the load to be dissipated in there.

The stresses in all groups were concentrated in the cortical bone around the implant neck, a possible explanation is that the elastic modulus of cortical bone is higher than cancellous bone and that cortical bone is much strong and more resistant to deformation[36, 37].

FEA allows researchers to overcome some ethical and methodological limitations and thus enables them to verify how the stresses are transferred to the studied structures, and for this reason is gaining more space in the research field[13]. A possible limitation of this study is that the model used in the present study involved several assumptions regarding the simulated structures. All the structures were assumed to be homogeneous, isotropic, and to have linear elasticity. The properties of the materials modeled in this study, particularly the living tissues, however are different[24]. Also, the implant-bone interface was established to be bonded which does not match clinical situations. The effect of the bone-implant contact ratio at the bone-implant interface on stress distribution in the peri-implant bone has been argued. However, previous studies found that the results based on complete osseointegration and non-linear frictional contacts among bone-implant are very similar[38, 39].

The stress levels that actually cause biological response, such as resorption and remodeling of the bone, are not comprehensively known. Therefore, the data of stress provided from the FEA need substantiation by clinical research[38, 40]. It should also be taken into consideration the fact that these strains are generated every time the patient bites with the provisional prosthesis, and that this repetitive act during osseointegration can lead to marginal bone loss and/or implant failure.

Conclusions

Within the limitations of the adopted methodology, it is possible to conclude that functional forces applied to relined dentures during healing period generates stress forces in the peri-implant bone tissue. It is also possible to conclude that dentures relined only in the region of the implants with the thickest layer possible showed the lowest stress values.

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Tables

Table 1 – Materials properties adopted in the study.

Material	Young's modulus (MPa)	Poisson's ratio	References
Artificial teeth	2,940	0.30	†
Acrylic resin	1,960	0.30	†
Mucosa	340	0.45	†
Cortical bone	13,700	0.30	*
Cancellous bone	1,370	0.30	*
Implant	110,000	0.33	*
Soft Liner (Coe-Comfort ®)	7.32	0.30	§

*Rubo & Capello Souza, 2010; † Kawasaki *et al.*, 2001; § Sato *et al.*, 2000.

Table 2 - Maximum principal stress values (MPa) in the peri-implant bone in the different simulations.

		Stress value
Canine	3 mm thick	0.308
	1.5 mm thick	0.387
	3 mm thick on implant region	0.244
	1.5 mm thick on implant region	0.349
Molar	3 mm thick	9.639×10^{-2}
	1.5 mm thick	2.141×10^{-2}
	3 mm thick on implant region	2.392×10^{-4}
	1.5 mm thick on implant region	3.278×10^{-4}

Figures

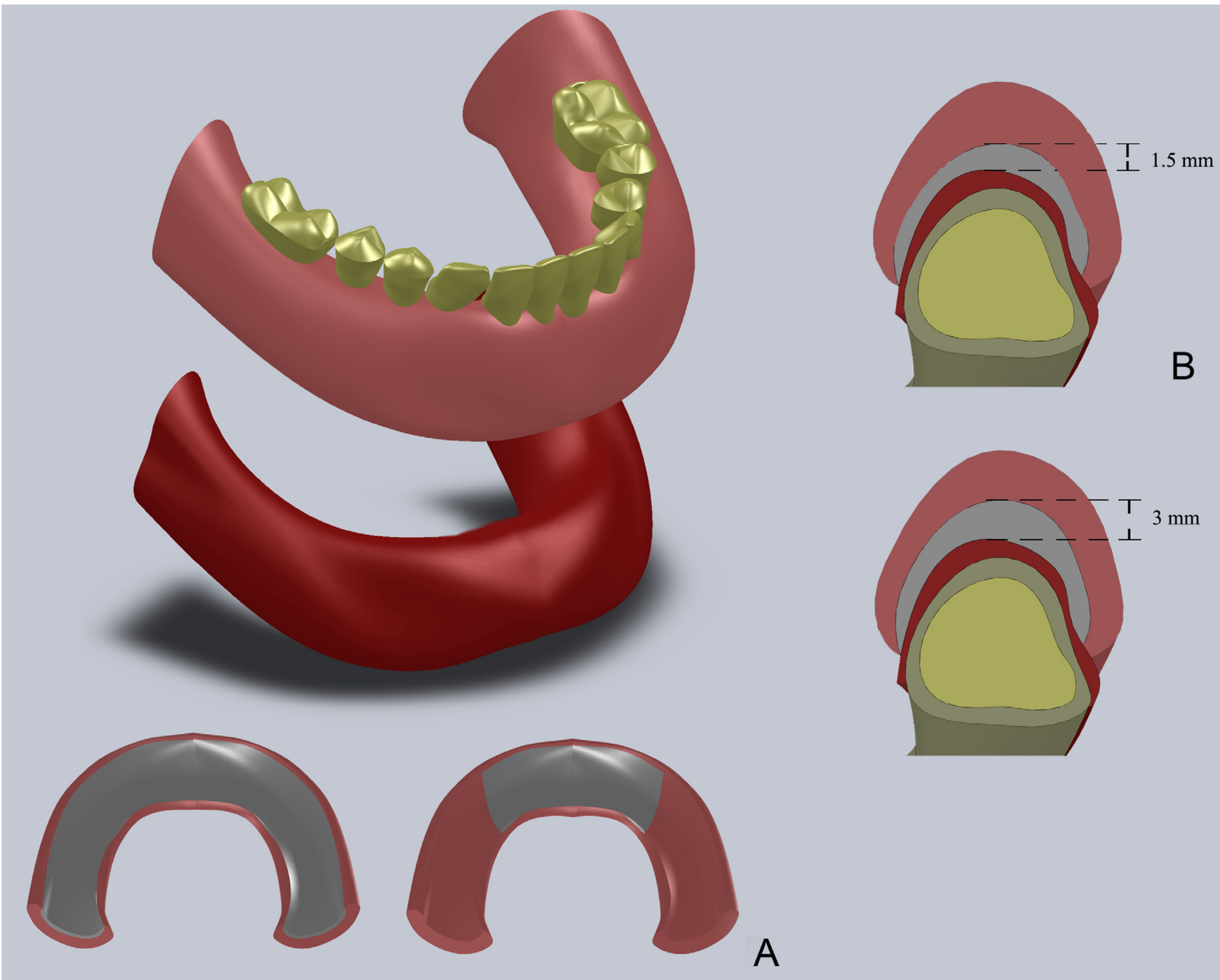

Figure 1 – Three-dimensional solid models: (A) Entire denture base relined with soft liner material and reline only in the region of the implants; (B) Differences on the thicknesses of soft liner layer.

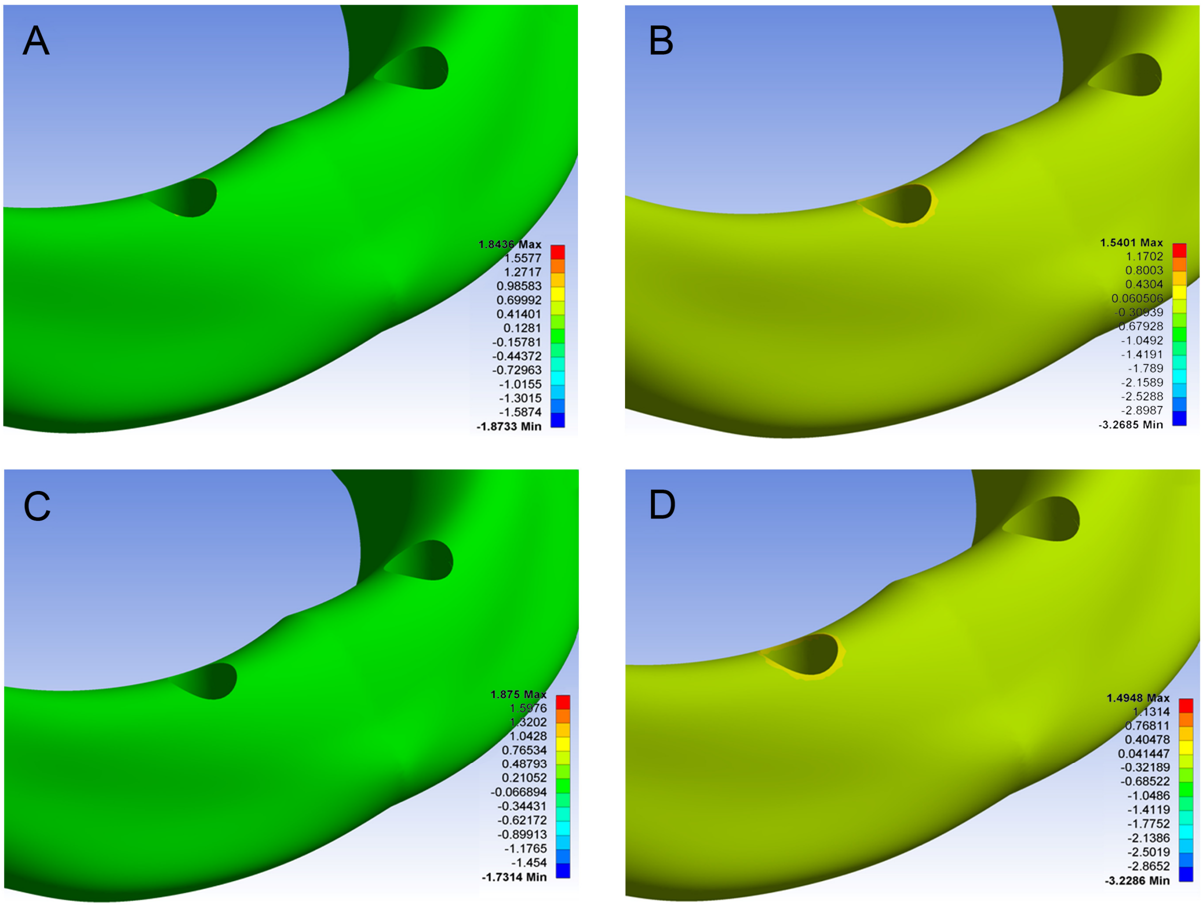

Figure 2 – Maximum of stress (MPa) in the peri-implant bone tissue for the different thicknesses and area of reline when load was applied to canine (35 N): (A) 3-mm relined in the entire base; (B) 1.5-mm relined in the entire base; (C) 3-mm relined only in the region of the implants; and (D) 1.5-mm relined in the region of the implants.

CONSIDERAÇÕES GERAIS

Atualmente, o principal desafio encontrado pelos profissionais que atuam no campo da Reabilitação Oral é restabelecer função, conforto, estética e fonética que fora perdida ao longo da vida dos pacientes. Neste contexto, a implantodontia tem característica única que seria o desafio em obter sucesso clínico qualquer que seja a existência de atrofias, doenças ou injúrias do sistema estomatognático (Tatum, 1988). Entretanto, existe uma relação que torna a tarefa mais difícil, ou seja, quanto menor for o número de dentes que o paciente possui maior a dificuldade de sucesso (Misch, 2005).

Em pacientes desdentados totais, as alterações anatômicas decorrentes desta condição têm grande influência no resultado final da reabilitação quando, muitas vezes, o tratamento com próteses totais convencionais fica prejudicado devido à severa reabsorção do tecido ósseo alveolar e, consequentemente, perda da estabilidade e retenção das próteses. A velocidade e quantidade da perda óssea podem ser influenciadas por diversos fatores, tais como hormônios, metabolismo, parafunções, próteses mal adaptadas e sexo do paciente (Misch, 2005).

Outro fato que deve ser levado em consideração é em relação à eficiência mastigatória, considerando que a diminuição da eficiência é frequentemente observada em portadores de próteses totais duplas, sendo cerca de 30% da eficiência de uma pessoa com dentição natural (Kapur & Soman, 2006), tendo influência direta na saúde dos pacientes. Em estudo realizado na década de 90 do século passado (Misch & Misch, 1991) foi constatado que pacientes com menor eficiência mastigatória usavam cerca de 40% mais medicamentos que pacientes com capacidade mastigatória considerada normal, sendo que 28% destes medicamentos eram relacionados à problemas gastrointestinais. É possível presumir que a reabilitação e conseqüente restabelecimento das condições próximas da normalidade do sistema estomatognático melhora a condição de saúde geral dos pacientes (Carlsson, 1984; Loesche, 1994).

As reabilitações totais sobre implantes apresentam alto índice de sucesso e satisfação por parte dos pacientes (Branemark *et al*., 1977; Albrektsson *et al*., 1986; Cune *et al.*, 1994b; a; Mericske-Stern, 1998; Attard & Zarb, 2004a; b; Baracat *et al.*, 2009) apresentando muitas vantagens quando comparadas às próteses totais convencionais. Dentre elas, maior estabilidade, retenção, fonética, estética, bem como melhora da eficiência mastigatória (Bakke *et al.*, 2002).

O protocolo cirúrgico de dois estágios, introduzido por Branemark *et al.* (1977) e preconizado por diversos autores (Adell, 1981; Albrektsson *et al.*, 1986), tem a fundamentação que os implantes devem permanecer sem distúrbios entre 3 e 6 meses para permitir a osseointegração sem complicações. Entretanto, sabe-se que a utilização de protocolo com estágio único, colocação de cicatrizadores expostos ao meio bucal e carga imediata proporcionam similar formação de tecido ósseo ao redor do implante e, consequentemente, possibilidade de osseointegração (Chiapasco *et al.*, 1997; Randow *et al.*, 1999; Gatti *et al.*, 2000; Horiuchi *et al.*, 2000; Malo *et al.*, 2000). Apesar de apresentar taxa de sucesso similar aos implantes com carga tardia, os procedimentos com carga imediata têm indicação para casos muito bem selecionados, quando deve ser ponderada a relação existente entre os fatores sistêmicos, de risco (tabagismo, etilismo) e locais (estabilidade primária, quantidade e qualidade óssea, higiene) (Prisco & Marchini, 2010).

Durante o período de osseointegração diversos fatores exercem influência direta sobre a possibilidade de sucesso. Transtornos de ordem endógena, como as doenças sistêmicas (diabetes e osteoporose) podem prejudicar ou diminuir a taxa de formação de osso ao redor do implante. Transtornos exógenos, como infiltração bacteriana por falta de higiene ou proximidade de sítios periodônticos contaminados e tabagismo podem causar infecção e possível perda do implante (Prisco & Marchini, 2010). A sobrecarga dos implantes pode ocasionar formação de tecido ósseo fibroso ao redor do implante culminando no insucesso (Adell et al., 1981).

Neste trabalho, o objetivo foi avaliar *in vitro* a concentração de tensões por meio da metodologia de elementos finitos do tecido ósseo peri-implantar ocasionada por próteses totais convencionais de uso provisório durante o período de osseointegração. A hipótese estabelecida no Capítulo 1 que o reembasamento da prótese total com diferentes materiais macios não teria influência na distribuição de tensões no tecido ósseo peri-implantar foi rejeitada. Os resultados permitem inferir que os materiais mais macios absorvem melhor as tensões que seriam concentradas na região dos implantes.

No Capítulo 2, a hipótese nula que diferentes níveis de altura de exposição dos cicatrizadores ao meio bucal (submerso, nível gengival, 1,5 mm exposto ao meio bucal) não influenciariam a concentração de tensões no tecido ósseo peri-implantar também foi rejeitada. Quanto mais expostos os cicatrizadores, maiores foram os valores de tensão no tecido ósseo peri-implantar, fato que pode ser explicado pela formação de alavanca e consequente ação sobre a distribuição das tensões durante o esforço exigido.

Os resultados apresentados no Capítulo 3 também rejeitam a hipótese nula que o reembasamento somente na região dos implantes ou em toda a extensão basal com diferentes espessuras de material não influenciariam a concentração de tensões no tecido ósseo peri-implantar. Um fato interessante foi que quando a carga foi aplicada no molar, a relação entre carga e maciez do material se inverteu e o grupo controle do Capítulo 1 (sem reembasamento) apresentou os menores valores de tensão. Talvez este fato possa ser relacionado com o resultado do Capítulo 3, onde os grupos com material macio na região dos implantes apresentaram os menores valores de tensão, tanto quando a carga foi aplicada no canino quanto no molar.

Como qualquer metodologia, o método de análise dos elementos finitos apresenta limitações que podem, de alguma maneira, mostrar resultados não compatíveis com o que acontece *in vivo*. As possíveis limitações do presente estudo seriam que para a realização das análises foram feitas algumas simplificações para que todos os materiais fossem considerados homogêneos e isotrópicos, quando se sabe que as estruturas, principalmente dos tecidos vivos, apresentam características diferentes. Novos estudos são necessários com outras metodologias ou análises de elementos finitos de caráter não-linear, para comprovar ou não os resultados deste estudo.

CONCLUSÃO GERAL

De acordo com a metodologia, resultados obtidos e discutidos e dentro das limitações do estudo, pode-se concluir que:

1. O procedimento que promoveu menor concentração de tensões no osso peri-implantar foi com implantes submersos, reembasamento realizado somente na região dos implantes, com 3 mm de espessura de material reembasador e material macio.

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