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Cirurgião-Dentista

Influência dos fatores protéticos em implantes curtos e análise da distribuição de tensão proveniente dos torques de inserção

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

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RESUMO

Os implantes curtos são uma alternativa terapêutica para rebordos reabsorvidos. Entretanto, em regiões posteriores atróficas apresentam maior risco biomecânico, devido às coroas protéticas mais longas decorrente do aumento do espaço inter-maxilar. Com objetivo de compensar a biomecânica desfavorável é aconselhável utilizar materiais restauradores menos rígidos, sistemas de retenção da prótese que facilitem a dissipação de tensões e uso de implantes com diâmetros maiores. Contudo, a influência desses fatores protéticos e o torque de inserção na concentração de tensões não está claramente esclarecida. Assim, os objetivos deste trabalho foram avaliar por meio do método dos elementos finitos tridimensional: I) A influência dos fatores protéticos (proporção coroa-implante (C/I), sistema de retenção da prótese, material restaurador e tipo de carregamento oclusal) na concentração de tensões nas regiões do osso cortical, medular, parafuso protético e no implante de prótese unitária suportada por implante curto; II) Avaliar a influência de diferentes torques de inserção na distribuição de tensão e deformação do osso cortical e medular. Para o primeiro objetivo foram criados 32 modelos da parte posterior de uma mandíbula atrófica. Cada modelo recebeu uma coroa metalocerâmica ou cerâmica pura, cimentada ou parafusada, sobre um implante de 7 mm de comprimento e 5 mm de diâmetro na região de primeiro molar. A proporção coroa-implante variou 1:1, 1.5:1, 2:1 ou 2.5:1. Os modelos foram carregados simulando uma oclusão normal ou traumática. Após o teste de convergência a 5% para determinar o refinamento da malha à análise numérica foi realizada com o programa Ansys Workbench 10.0®. A tensão máxima principal (σ_{max}) para o osso cortical e osso medular e a tensão de von Mises (σ_{vM}) para o implante e parafuso protético foram obtidos e submetidos à análise da variância. Para o segundo objetivo, seis modelos da pré-maxila foram construídos com um implante e carregados com 30, 40, 50, 60, 70 ou 80 Ncm de toque de inserção. A σ_{max} e a deformação máxima principal (ε_{max}) foram obtidos para o osso cortical e medular. O teste de correlação de Pearson foi utilizado para determinar a correlação entre torque de inserção e a concentração de tensões e deformações no tecido ósseo periimplantar. Como resultados, observou-se que a oclusão traumática e o aumento da proporção C/I aumentaram significativamente a concentração de tensão no osso cortical, osso medular, parafuso protético e no implante. O sistema de retenção apresentou influência significativa ($p<0.02$) na concentração de tensão, porém menor do que a oclusão e a proporção C/I. As próteses parafusadas apresentaram maiores tensões quando comparadas as próteses cimentadas em todas as regiões avaliadas. A concentração de tensão não foi afetada pelo material restaurador. Para o segundo objetivo observou-se que o aumento do torque de inserção aumenta a σ_{max} e ε_{max} para o osso cortical e medular. Conclui-se que o tipo de carregamento oclusal foi o fator avaliado que mais influenciou na concentração de tensão em prótese unitária suportada por implante curto e que torques de inserção de maior magnitude aumentam as concentrações de tensão e deformação no tecido ósseo periimplantar.

Palavras-chave: Implantes dentais, implantes curtos, torque de inserção, método dos elementos finitos.

ABSTRACT

The short implants are an alternative treatment for edges reabsorbed. However, using short implant at the posterior atrophic mandibular has showed higher biomechanical risk due to higher crown following to the increase of inter-maxillary space. Aiming to offset the unfavorable biomechanics is advisable to use less rigid restorative materials, retention system for the prosthesis to facilitate the stress distribution and use of implants with larger diameters. However, the influences of these prosthetic factors and insertion torque on stress concentration are not clearly understood. Thus, the objectives were to evaluate by tridimensional finite element method the influence of: I) crown-to-implant (C/I) ratio, retention system, restorative material and occlusal loading on stress concentrations within a single posterior crown supported by a short implant; II) different insertion torques on the stress and strain distribution in cortical and cancellous bones. For the first objective, thirty-two finite element models of an atrophic posterior edentulous mandible were created. Each model received a metal-ceramic crown, cemented or screwed, over a single external hexagon implant with 7 mm length and 5 mm diameter at the first molar region. The C/I ratio ranged from 1:1, 1.5:1, 2:1 to 2.5:1. The models were loaded by simulating a normal and traumatic occlusion. After the convergence analysis of 5% to mesh refinement, the numerical analysis was performed on Ansys Workbench 10.0® software. The maximum principal stress for cortical and cancellous bone and von Mises stress (σ_{vM}) for the implant and abutment screw were computed and analyzed using analysis of variance. For the second objective, six models were built and each of them received an implant with one of the following insertion torques: 30, 40, 50, 60, 70 or 80 Ncm. The σ_{max} and the maximum principal strain (ε_{max}) were obtained for cortical and cancellous bone. Pearson's correlation test was used to determine the correlation between insertion torque and stress concentration in the periimplant bone tissue. The results showed that traumatic occlusion and increasing C/I ratio significantly increased the stress concentration in cortical bone, cancellous bone, implant and prosthetic screw. The prosthetic retention system significantly influenced the stress concentration, but at a lower level than the C/I ratio or occlusal loading. The screw-retained prosthesis displayed higher stress levels than the cement-retained prosthesis in all components. The stress concentration was not affected by the restorative material. For the second objective, the increase in the insertion torque generated an increase in the σ_{max} and ε_{max} values for cortical and cancellous bone. It is concluded that occlusion is main factor that most influences the stress concentration at the implant prosthodontic supported by short and high insertion torques that increase concentrations of stress and strain in the peri-implant bone tissue.

Keywords: Dental implants, short implants, insertion torque, finite element analysis.

Sumário

INTRODUÇÃO

A integração biológica entre o osso e óxidos de titânio denominada osseointegração foi atestada por Branemark *et al.* em 1969 e desde então a utilização de implantes dentários expandiu-se do edentulismo total para as próteses parciais fixas e posteriormente para elementos unitários anteriores e posteriores (Anitua & Orive 2010; Mangano *et al.,* 2010; Magne *et al.,* 2011).

A perda dentária associada a fatores sistêmicos e períodos longos de edentulismo leva a inevitáveis reabsorções em altura e largura do osso alveolar (Anitua & Orive 2010). A redução, principalmente, em altura pode ser considerado um fator de risco para o tratamento restaurador com implantes dentários, especialmente nas regiões posteriores de mandíbula e maxila, onde estão presentes estruturas anatômicas nobres, como o nervo alveolar inferior e o seio maxilar (Misch *et al.,* 2006; Rossi *et al.,* 2010) e são regiões submetidas a maiores forças mastigatórias (Koc *et al.,* 2010).

Como soluções terapêuticas para rebordos ósseos reabsorvidos a literatura científica apresenta o uso de implantes angulados (Jensen *et al.,* 2011), cirurgias prévias para ganho de volume e/ou altura óssea (Pelo *et al.,* 2010) ou uso de implantes curtos (das Neves *et al.,* 2006; Anitua & Orive 2010; Rossi *et al.*, 2010).

O uso de implantes angulados é uma técnica promissora (Malo *et al.,* 2005), todavia é descrita na literatura para a reabilitação de rebordos ósseos atróficos desdentados totais com implantes múltiplos (Jensen *et al.*, 2011). Porém em casos unitários e/ou em regiões posteriores de mandíbula atrófica esta técnica é pouco indicada (Malo *et al.*, 2005).

Os procedimentos cirúrgicos com o intuito de ganho ósseo como enxerto ósseo (Acocella *et al.,* 2010; Pelo *et al.*, 2010), distração osteogênica (Chiapasco *et al.,* 2007; Wolvius *et al.,* 2007) e lateralização do nervo alveolar inferior (Ferrigno *et al.,* 2005) são soluções com baixa previsibilidade de ganho ósseo em altura (Chiapasco *et al.*, 2007), alta morbidade e maiores riscos de complicações pós-operatórias. Além disso, as técnicas cirúrgicas avançadas são de difícil aceitação pelo paciente, maior risco de infecção, necessidade de dois sítios cirúrgicos (doador e receptor), custo mais elevado, possibilidade da necessidade de hospitalização do paciente e maior tempo para a reabilitação protética final (Misch *et al.*, 2006).

Outra alternativa terapêutica para a reabilitação posterior de mandíbulas ou maxilas atróficas envolve o uso de implantes curtos (das Neves *et al.*, 2006; Misch *et al.*, 2006). Até o momento, não existe consenso sobre a definição de implantes curtos, podendo ser considerados os implantes ≤ 7 mm (Hagi *et al.,* 2004), ≤ 8 mm (Renouard & Nisand 2006) ou ≤ 10 mm de comprimento (das Neves *et al.*, 2006).

A literatura científica apresenta divergências sobre o prognóstico dos implantes curtos, cujas taxas de sucesso são inferiores as de implantes longos. Winkler *et al.,* 2000 e Weng *et al.,* 2003 demonstraram taxa de sucesso de 74.4% e 89%, respectivamente, para implantes de 7 mm. Todavia, há estudos demonstrando sucesso comparável aos de implantes longos (Misch *et al.*, 2006; Rossi *et al.*, 2010), com resultados em torno de 99% para implantes ≤ 8 mm (Grant *et al.,* 2009 e Anitua *et al.*, 2010).

Os implantes curtos apresentam coroas protéticas mais longas, devido a maior distância entre os arcos maxilo-mandibulares (Blanes *et al.,* 2007). Esse cenário apresenta risco biomecânico adicional, pois o braço de alavanca representado pelas coroas protéticas longas é superior ao braço de resistência representado pelo implante inserido no tecido ósseo (Urdaneta *et al.,* 2010). Esse fator associado a um carregamento não axial gera um momento fletor com o fulcro na região do tecido ósseo marginal representado pelo primeiro contato entre o implante e o tecido ósseo (Blanes *et al.*, 2007). Essa maior concentração de tensão pode provocar reabsorção óssea devido à indução de microfraturas no osso estimulando a ação de osteoclastos ou falhas protéticas como fratura ou soltura de parafusos protéticos, fratura de porcelana de cobertura ou até mesmo falha da osseointegração do implante (Kozlovsky *et al.,* 2007; Theoharidou *et al.,* 2008; Blanes 2009; Rossi *et al.*, 2010).

Com o objetivo de reduzir as concentrações de tensões no implante e no tecido ósseo de suporte, alguns autores sugerem que o material restaurador (Sevimay *et al.,* 2005; Conserva *et al.,* 2009) e o sistema de retenção da prótese ao implante, parafusado ou cimentado (Zarone *et al.,* 2007), podem facilitar a dissipação das forças mastigatórias. Também, o aumento da área de contato do osso com o implante por meio do uso de implantes com diâmetros aumentados, como indicado para implantes curtos, facilitaria a dissipação das tensões no implante e no tecido ósseo (Renouard & Nisand 2006; Olate *et al.,* 2010). Associado a esses fatos, a utilização de implantes largos, diâmetros ≥ 4.5 mm (Baggi *et al.,* 2008), favorecem a estabilidade inicial (Olate *et al.*, 2010), fator importante no sucesso dos implantes dentais, principalmente nos implantes com carregamento imediato (Duyck *et al.,* 2010).

A estabilidade inicial pode ser mensurada pelo torque de inserção durante a instalação do implante (Nedir *et al.,* 2004), que deve exceder a 30 Ncm (Ottoni *et al.,* 2005; Irinakis & Wiebe, 2009). Dessa forma evita micromovimentações do implante no leito cirúrgico e conseqüente formação de tecido fibroso, caracterizando falha na osseointegração (Degidi *et al.,* 2009; Irinakis & Wiebe 2009).

Entretanto, torques acima de 50 Ncm (Duyck *et al.*, 2010), podem ocorrer na presença de tecido ósseo com maior densidade (Irinakis & Wiebe, 2009; Turkyilmaz *et al.,* 2009), resultando em altos valores de compressão ao osso periimplantar. Estudos recentes (Lacroix *et al.,* 2002; Warreth *et al.,* 2009) sugerem que as altas tensões de compressão podem modular a diferenciação celular e o processo de reparo ósseo, favorecendo a formação de tecido fibro-cartilaginoso. Baseado no conceito de osseointegração, caracterizado pela união estrutural e funcional entre o osso e a superfície de um implante submetido ao carregamento protético (Branemark *et al.*, 1977), a presença de tecido fibro-cartilaginoso entre osso e implante caracteriza falha na osseointegração.

Devido à dificuldade clínica em quantificar a magnitude e a distribuição das tensões e deformações no tecido ósseo, nos implantes e nos componentes protéticos, o método dos elementos finitos tem sido proposto para estudos biomecânicos em implantodontia. Esta metodologia utiliza a resolução de sistemas de equações algébricas relacionando a aplicação de forças que promove deslocamentos da malha resultando em tensões e deformações de uma estrutura complexa (Geng *et al.,* 2001).

Considerando os poucos trabalhos disponíveis sobre avaliação de tensões nos implantes e no tecido ósseo com diferentes proporções coroa-implante e torque de inserção durante a instalação do implante foram propósitos desta pesquisa avaliar por meio do método dos elementos finitos tridimensionais a influência de 1. proporção coroa-implante, sistema de retenção, material restaurador e tipo de oclusão na concentração de tensão nas regiões do osso cortical, medular, parafuso protético e do implante em prótese unitária suportada por implante curto. 2. diferentes magnitudes de torques de inserção na distribuição de tensão e deformação no tecido ósseo cortical e medular.

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CAPÍTULO 1

Influence of crown-to-implant ratio, retention system, restorative material, and occlusal loading on stress concentrations in single short implants

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ABSTRACT

Purpose: The aim of this study was to assess the contributions of some prosthetic parameters such as crown-to-implant ratio, retention system, restorative material, and occlusal loading on stress concentrations within a single posterior crown supported by a short implant. **Materials and Methods:** Computer-aided design (CAD) software was used to create 32 finite element models of an atrophic posterior partial edentulous mandible with a single external hexagonal implant (7 x 5 mm) in the first molar region. Finite element analysis software with a convergence analysis of 5% to mesh refinement was used to evaluate the crown-to-implant ratio (1:1; 1.5:1; 2:1 or 2.5:1), the prosthetic retention system (cemented or screwed), and the restorative material (metal-ceramic or all ceramic). The crowns were loaded with simulated normal or traumatic occlusal forces. The maximum principal stress (σ_{max}) for cortical and cancellous bone and von Mises stress (σ_{vM}) for the implant and abutment screw were computed and analyzed using ANOVA. The contribution (% TSS) of each variable to the stress concentration was calculated from the sum of squares analysis. **Results:** Traumatic occlusion and a high C/I ratio increased the stress concentration. The C/I ratio was responsible for 11.45% of the total stress at the cortical bone while the occlusal loading contributed 70.92% to the total stress at the implant. The retention system contributed 0.91% of the total stress at the cortical bone. The restorative material was responsible for only 0.09% of the total stress at the cancellous bone. **Conclusion:** Occlusal loading was the most important stress concentration factor in a single short implant-supported posterior crown.

Key-words: Dental Implant, Finite Element analysis, Alveolar Bone Atrophy

INTRODUCTION

Dental implant therapy is a well-documented method for replacing missing teeth[1,2]. Although literature reports describe the efficacy of implants in replacing single missing teeth[3], the amount of bone available for implant anchorage dictates the clinical procedure, with the goal of balancing the tooth biomechanics and bone stability[1].

In clinical situations characterized by reduced bone height, the use of short implants (length up to 10mm) has been considered[4]. However, the prognosis under these conditions is controversial[4,5], with some reports claiming success rates comparable to longer-length implants[1,6] and others describing higher failure rates for short implants[7,8], with most failures occurring after occlusal loading[4].

A proper transfer of the occlusal loading to the bone through the implant components is an important factor in biomechanical success[9,10]. Occlusal overloading above the physiological bone limit induces microfractures in the bone, stimulating osteoclastic activity that leads to peri-implant crestal bone loss[11]. When using short implants, this bone loss is critical as the small contact area with the bone creates an additional risk of implant failure[4,11]. Nevertheless, several studies have agreed that the biomechanical behavior is important to the success of single prostheses supported by short implants[10,12].

The use of short implants in association with an atrophic mandible has also been proposed as a biomechanical risk due to the increased maxillo-mandibular space[13] and the creation of an unfavorable crown-to-implant (C/I) ratio[5,13]. The greater crown height acts as a lever, creating a bending moment in the presence of lateral forces[13,14]. This moment can induce a stress concentration at the implant-to-bone interface and in the prosthetic components, eventually resulting in peri-implant bone loss[15] or prosthetic complications[16]. Besides the occlusal loading and the C/I ratio, the restorative material[17] and retention system[18] may influence the stress distribution arising from mastication[14]. Determining the contributions of these parameters to stress concentrations in the bone, the implant, and the abutment screw under normal or traumatic applied loads may be relevant to clinical decision-making aimed at reducing stress and failure rates for single short implants.

In this study, it was investigated the influence of C/I ratio, retention system, restorative material, and occlusal loading on stress concentrations in the cortical and cancellous bone, the implant, and the abutment screw using a three-dimensional finite element analysis.

MATERIAL AND METHODS

Experimental design

A total of 32 3D models of a posterior atrophic partial edentulous mandible were virtually constructed. Each model consisted of a single crown supported by one short implant in the first molar region. The C/I ratio (1:1, 1.5:1, 2:1, or 2.5:1), the prosthetic retention system (cemented or screwed) and the restorative material (metal-ceramic or all-ceramic) were varied. All combinations were loaded with normal and traumatic occlusal forces. Finite element analysis (FEA) was used to determine the maximum principal strain (σ_{max}) for the cortical and cancellous bone tissue and the von Mises stress (σ_{vM}) for the implant and abutment screw.

Model construction

The right posterior region of a partially edentulous mandible was reproduced using the Solidworks 2010 3D computer-aided design software (SolidWorks Corp., Concord, MA, USA) based on computed tomography (CT) images (*Digital Imaging and Communications in Medicine* - DICOM format) of a mandible with alveolar resorption at the posterior region. The bone model was composed of cancellous bone surrounded by 2 mm of cortical bone, corresponding to type 2 bone tissue quality[7]. The single crown rehabilitation was simulated at the first mandibular molar region and was supported by a short external hexagonal implant (Titamax Ti cortical; Neodent®, Curitiba, PR, Brazil) with a height of 7 mm height and a diameter of 5 mm, a UCLA prosthetic component, and an abutment retention screw.

After establishment of the implant location in the bone segment, the crown portion (consisting of a type IV gold or zirconium infrastructure with a uniform feldspathic ceramic cover layer) was reproduced. The cement in cemented crown models was represented by a 50 µm thickness layer[19]. All materials were considered homogeneous, isotropic, and linearly elastic.

The computer-aided design models were exported to Ansys Workbench 10.0 finite element analysis software (Swanson Analysis Inc., Houston, PA, USA).

Numerical analysis

Convergence (5%) in all models was achieved using a tetrahedral mesh containing 0.6 mm elements. Table 1 lists the elements and nodes of each model.

Table 1. Elements and nodes of each model.

C/I ratio	Cemented Prostheses		Screwed Prostheses	
	Elements	Nodes	Elements	Nodes
1:1	72,625	131,257	66,910	120,049
1.5:1	80,285	145,166	70,798	126,471
2:1	87,150	157,774	74,413	133,103
2.5:1	92,425	169,116	75,029	133,383

The implants, UCLA components, and prosthetic screws were Ti6Al4V titanium alloy with an elastic modulus of 110 GPa and a Poisson's ratio of 0.35[20]. The elastic moduli and Poisson's ratios of the cortical and cancellous bone were 13.6 and 1.36 GPa and 0.26 and 0.31[20]. In the crown, the ceramic cover layer had an elastic modulus of 70 GPa and a Poisson's ratio of 0.19[21] and the gold and zirconium of the infrastructure were assigned elastic moduli of 90 and 210 GPa and Poisson's ratios of 0.33 and 0.27[21].

The boundary conditions were defined by fixing the medial and distal exterior surfaces of the bony segment in all directions. The models were loaded in two stages: an initial manufacturer-specified 32 N·cm pre-load torque on the prosthetic screws, followed by the occlusal loading. Normal occlusal loading was simulated using a 200 N force distributed over eight 1.5 mm^2 points. The forces were in the normal occlusion direction, perpendicular to the cusp of the tooth[22]. Traumatic occlusion was simulated in the form of premature contact as the same

200 N force was distributed over five 1.5 mm² occlusal points in a 45° oblique direction (Fig. 1).

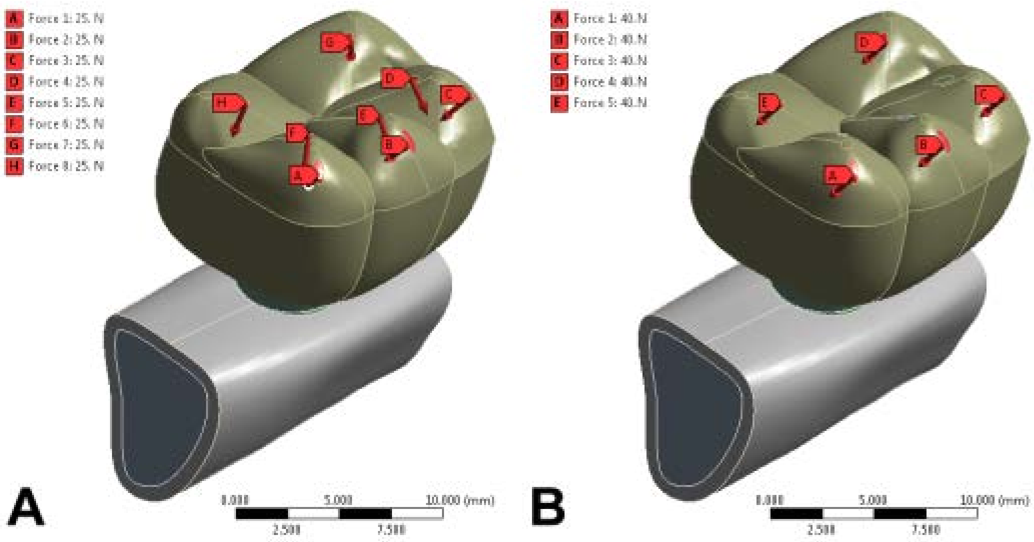

Fig.1 Loading points for occlusal simulation: A. normal occlusion and B. traumatic occlusion.

The values of σ_{max} for the cortical and cancellous bone tissue and σ_{vM} for the implants and abutment screws were obtained for all models[23].

Statistical analysis

The combination of the four variables (four levels of C/I ratio and two levels each of retention system, restorative material, and occlusal loading) were considered, resulting in 32 calculation sets. The data from each factorial design were analyzed using ANOVA (SAS Institute Inc., version 9.0, Cary, NC, USA) at a significance level of 5%. The sum of squares was used to calculate the contribution (%TSS) of each variable to the stress concentration. A confidence interval was determined for each value to indicate the reproducibility of the measurements.

RESULTS

The stress values, standard deviations, and confidence intervals for all parameters are presented in Table 2.

Table 2. Maximum principal and von Mises stresses in the evaluated regions (implant, abutment screw, cortical bone and cancellous bone) for each parameter.

Parameter studied	Variables	Mean± Standard Deviation (MPa)				95% confidence interval			
						Minimum-Maximum			
		Implant	Screw	Cortical Bone	Cancellous Bone	Implant	Screw	Cortical Bone	Cancellous Bone
Proportion crown-to-implant	1:1	94.2 (±25.4)	21.5 (±5.2)	23.1 (±2.1)	10.3 (±1.3)	72.9-115.5	17.1-25.9	21.3-24.9	9.2-11.4
	1.5:1	118.6 (±57.4)	27.3 (±14.0)	31.9 (±12.3)	11.1 (±3.5)	70.5-166.6	15.5-39.0	21.6-42.3	8.2-14.1
	2:1	142.5 (±88.9)	33.4 (±22.5)	43.3 (±25.3)	11.5 (±5.6)	68.2-216.8	14.5-52.3	22.0-64.5	6.8-16.2
	2.5:1	167.5 (±120.4)	40.5 (±30.9)	55.4 (±39.0)	13.1 (±7.1)	66.85-268.2	14.7-66.4	22.8-88.0	7.2-19.1
Retention system	Cemented	125.0 (±77.1)	29.1 (±22.7)	36.0 (±22.7)	11.1 (±4.4)	83.9-166.1	18.9-39.2	23.9-48.1	8.7-13.5
	Screwed	136.4 (±88.6)	32.3 (±29.5)	40.9 (±29.5)	11.9 (±5.2)	89.1-187.7	20.0-44.5	25.1-56.6	9.2-14.7
Prothesis Material	Metal-ceramic	131.7 (±84.2)	30.9 (±21.3)	38.7 (±26.7)	11.7 (±4.7)	86.8-176.6	19.5-42.3	24.5-52.9	9.1-14.2
	All ceramic	129.7 (±82.3)	30.5 (±21.0)	38.1 (±26.1)	11.4 (±4.9)	85.8-173.6	19.2-41.7	24.2-52.1	8.7-14.0
Occlusial loading	Normal	62.7 (±6.0)	13.8 (±1.9)	20.3 (±0.6)	7.6 (±1.6)	59.5-65.6	12.7-14.9	20.0-20.6	6.7-8.4
	Traumatic	198.6 (±63.2)	47.6 (±16.8)	56.5 (±26.4)	15.5 (±3.3)	164.9-232.3	38.6-56.6	42.5-70.6	13.7-17.3

The stress in the implant was concentrated in the cervical portion and the first thread (Fig. 2a) regardless of C/I ratio, restorative material, or occlusal loading. In contrast, the stress in the prosthesis screw was distributed over all of the threads (Fig. 2b). The σ_{max} in the cortical bone was concentrated at the buccal side near the implant (Fig. 2c), while in the cancellous bone the stress was uniformly distributed (Fig. 2d).

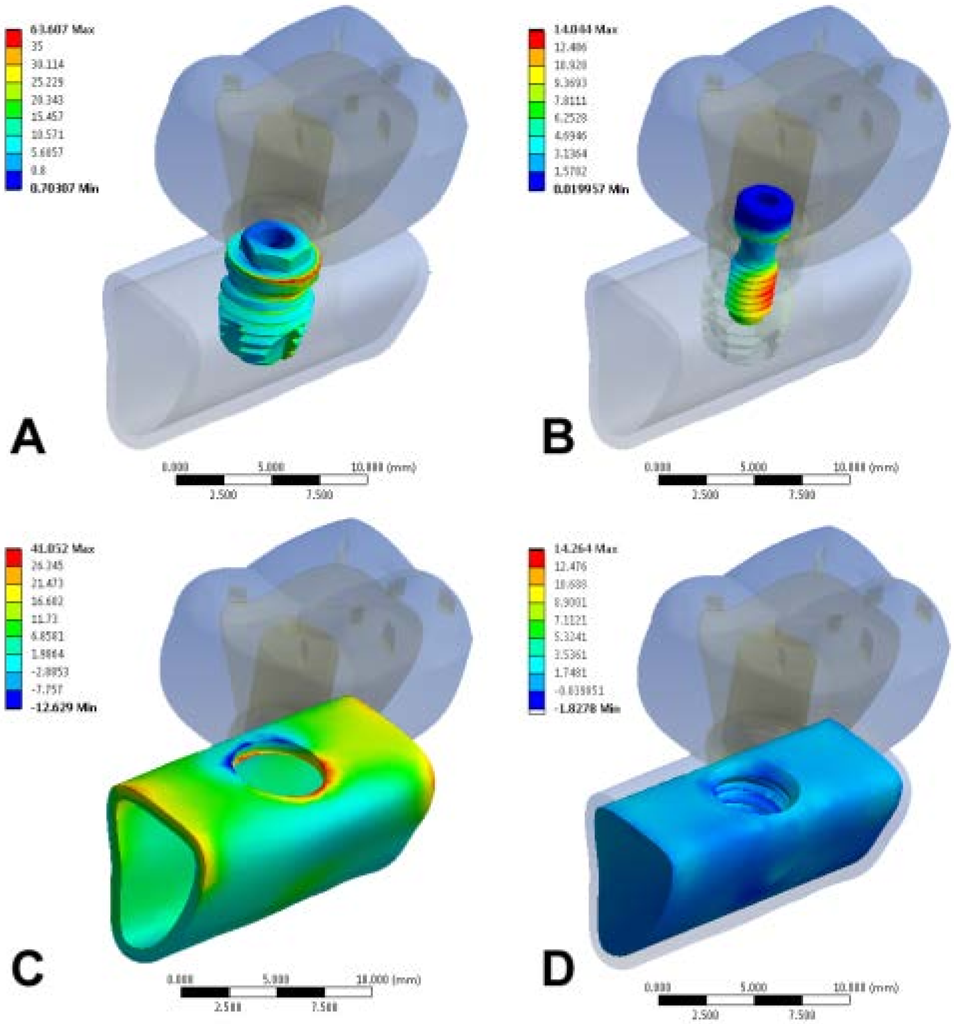

Fig. 2 Mean stress distribution at implant (A), abutment screw (B), cortical bone (C), and cancellous bone (D).

The lowest stresses at the implant (68.76 MPa), abutment screw (16.25 MPa), cortical bone (21.12 MPa), and cancellous bone (8.15 MPa) were observed under normal occlusion in the model of an all-ceramic cemented crown and 1:1 C/I ratio. In contrast, the highest stresses were observed under traumatic occlusion in the metal-ceramic screwed crown model with a 2.5:1 C/I ratio, which exhibited stresses of 297.83, 74.79, 100.61, and 21.56 MPa for the implant, abutment screw, cortical, and cancellous bone.

The C/I ratio significantly influenced the stress concentration (*P* <0.001), contributing 11.45%, 11.90%, 22.47%, and 4.74% to the total generated stress in the implant, abutment screw, cortical bone and cancellous bone (Table 3). Increasing the C/I ratio to 2.5:1 resulted in 1.78, 1.88, 2.4, and 1.27-fold increases in the stresses at the implant, abutment screw, cortical bone, and cancellous bone.

The prosthetic retention system significantly influenced the stress concentration (*P* <0.001), but at a lower level than the C/I ratio or occlusal loading. Its contributions to the total generated stresses were 0.49%, 0.61%, 0.91%, and 0.82% in the implant, abutment screw, cortical bone and cancellous bone. The screw-retained prosthesis displayed higher stress levels than the cement-retained prosthesis in all components.

The stress concentration was not affected by the restorative material (*P* >0.05).

Occlusal loading was the most influential variable (*P* <0.001) with respect to stress magnitude. The traumatic occlusal force exhibited higher stress concentrations than normal occlusion in all analysis regions. The occlusion contributed 70.92% of the total generated stress in the implant, 67.78% in the abutment screw, 50.12% in the cortical bone, and 70.32% in the cancellous bone (Table 3).

Table 3. Summary of ANOVA results for maximum stress and von Mises stress in implant, abutment screw, cortical bone, and cancellous bone.

Source	Implant		Screw		Cortical Bone		Cancellous Bone	
	Sig	%TSS	Sig	%TSS	Sig	%TSS	Sig	%TSS
C/I ratio*	<.0001	11.45%	<.0001	11.90%	<.0001	22.47%	0.0004	4.74%
Retention system*	0.01	0.49%	<.0001	0.61%	<.0001	0.91%	0.02	0.82%
Prothesis Material*	0.22	0.015%	0.42	0.02%	0.54	0.01%	0.42	0.09%
Occlusion*	<.0001	70.92%	<.0001	67.78%	<.0001	50.12%	<.0001	70.32%
C/I ratio X Retention system#	0.04	0.10%	0.07	0.15%	0.02	0.38%	0.08	1.07%
C/I ratio X Prothesis Material#	0.99	0%	0.98	0.002%	0.99	0.006%	0.80	0.13%
C/I ratio X Occlusion#	<.0001	16.61%	<.0001	18.79%	<.0001	24.79%	<.0001	21.05%
Retention system X Prothesis Material#	0.60	0%	0.71	0.002%	0.72	0.004%	0.69	0.02%
Retention system X Occlusion#	<.0001	0.28%	<.0001	0.52%	<.0001	0.90%	0.46	0.07%
Prothesis Material X Occlusion#	0.26	0.01%	0.55	0.006%	0.55	0.01%	0.75	0.01%
Error		0.12%		0.22%		0.4%		1.68%
Total		100%		100%		100%		100%

% TSS = total of sum square; * indicates one-way ANOVA; # two-way ANOVA.

DISCUSSION

The use of short implants in the posterior region of the maxilla or mandible has been associated with biomechanical problems[4,6,12,13] such as bone resorption[14], loosening or fracture of abutment screws, and implant or ceramic veneer fracture. However, it is difficult to clinically quantify the magnitude of occlusal forces and to define which parameters are the strongest contributors to short implant failures. Thus, the finite element method has been used in conjunction with experimental results to describe dental implant biomechanical behavior[24].

The combination of 3D-FEA and statistical analysis provides an accurate tool for interpreting the relative influence of the parameters on stress concentration.[25] Considering the *in silico* nature of the present study, a confidence interval was reported to indicate the reliability of the measurements and the relative effects of the parameters on the stress concentration.

In the development of a finite element model, the assumptions regarding material properties, boundary conditions, model accuracy, and stress criteria are important for analysis of stress/strain behavior and displacement[26]. The boundary conditions included the abutment screw preload and occlusal forces, in which the preload was defined as the tensile force produced in the abutment screw as a consequence of the screw tightening[24]. Although it has been neglected in other FEA studies[10,11,20,26-28], we included a preload in the form of a 32 N·cm torque in the abutment screw, while the occlusal loading of 200 N was based on the force at the first molar of a healthy male subject[22].

The dimensional accuracy of the models was ensured by generating the components from cross-sections of CT and CAD images. The stress analysis in the present study was in accordance with Dejak and Mlotkowski[23], who reported that σ_{max} is adequate to establish the stress behavior in brittle materials such as bone tissue, and σ_{vM} may be used to evaluate the behavior of ductile materials such implants and prosthetic screws.

The occlusal loading proved to be the most influential parameter, responsible for 70.92% of the total stress generated in the implant, 67.78% in the abutment screw, 50.12% in the cortical bone, and 70.32% in the cancellous bone. These results were in agreement with previous studies[29,30] suggesting that a traumatic occlusion is the major cause of biomechanical complications, peri-implant bone loss, and eventual implant failure. The findings of the present study are in agreement with previously described mathematical models[26,27] and *in vitro* studies[9] that revealed higher stresses at the implant, prosthetic components, and peri-implant bone areas during traumatic occlusion.

The C/I ratio also contributed to the stress concentration, being responsible for 11.45%, 11.90%, 22.47%, and 4.74% of the total generated stresses in the implant, abutment screw, cortical bone, and cancellous bone. Similar results were reported by Sütpideler et al[28], who indicated that an increased C/I ratio leads to higher stresses. In the present study, the 2.5:1 C/I ratio exhibited a 1.88-fold higher stress concentration on the abutment screw and a higher σ_{vM} in the cortical bone surrounding the implant. In this case, the crown acts as a lever, creating a bending moment and transferring stress to the peri-implant bone[13], which may result in crestal bone loss[30].

However, the stress concentrations in the peri-implant bone did not lead to bone resorption as observed in previous animal studies[15,31]. The loading conditions may result in bone remodeling, since the bone morphology is regulated by mechanical loading (Wolff's law)[32]. However, there is no evidence regarding the limit of stress at which bone remodeling ceases and resorption begins, leading to crestal bone loss[13,32]. It is difficult to clinically quantify the magnitude and direction of occlusal forces, which complicates the isolation of force as a variable[10]. The cancellous bone exhibited a lower stress concentration and variation than the cortical bone due to its lower elastic modulus[26].

In the present study, the retention system contributed less to stress concentration than the C/I ratio or occlusal loading. The cement-retained prostheses also displayed lower stress concentrations than screw-retained prostheses, in accordance with previous studies[33,34]. This lower stress may be attributed to the cement line acting as a cushion layer due to its lower elastic modulus, assisting in the distribution of masticatory forces[34].

Effects of the restorative materials on stress concentration were not apparent in the present study, and no differences were observed between metal-ceramic and all-ceramic crowns. These results are in agreement with other studies[17,35] in which no differences in stress concentration were noted between composite, gold alloy, and porcelain restorative materials. However, Sevimay et al[17] reported that the stress localization and distribution in abutment and crown structures were affected by the material rigidity and that composite crowns absorbed occlusal loading better than ceramic crowns[35], leading to a lower stress concentration in the bone surrounding composite crowns.

The differences in length of the implants and material properties may be the reason for the discrepancies in the literature. Additional studies using short implants and different platforms and restorative materials should be conducted with the goal of improving simulation of the complex buccal environment.

CONCLUSION

Within the limits of this FEA study, simulated traumatic occlusion and high C/I ratios increased stress concentrations in single short implant-supported posterior crowns. Cemented prostheses promoted lower levels of stress concentration than screwed prostheses. The stress concentration was not affected by the restorative material.

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CAPÍTULO 2

Influence of high insertion torque on implant placement. Anisotropic bone stress analysis.

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ABSTRACT

Aim: The aim of this study was to evaluate the influence of the high values of insertion torques on the stress and strain distribution in cortical and cancellous bones. **Material and Methods:** Based on tomography imaging, a representative mathematical model of a partial maxilla was built using Mimics 11.11 and Solid Works 2010 software programs. Six models were built and each received an implant with one of the following insertion torques: 30Ncm, 40Ncm, 50Ncm, 60Ncm, 70Ncm or 80Ncm on the external hexagon. The cortical and cancellous bones were considered anisotropic. The bone/implant interface was considered perfectly bonded. The numerical analysis was carried out using Ansys Workbench 10.0. The convergence of analysis (5%) drove the mesh refinement. Maximum principal stress (σ_{max}) and maximum principal strain (ε_{max}) were obtained for cortical and cancellous bones around to implant. Pearson´s correlation test was used to determine the correlation between insertion torque and stress concentration in the peri-implant bone tissue, considering the significance level at 5%. **Results**: The increase in the insertion torque generated an increase in the σ_{max} and ε_{max} values for cortical and cancellous bone. The σ_{max} was smaller for the cancellous bone, with greater stress variation among the insertion torques. The ε_{max} was higher in the cancellous bone in comparison with cortical bone. **Conclusion:** According to the methodology used and the limits of this study, it can be concluded that higher insertion torques increased tensile and compressive stress concentrations in the peri-implant bone tissue.

Key-words: dental implants, insertion torque, finite element method

INTRODUCTION

Over the last thirty years, clinical studies with osseointegrated implants have shown excellent long-term results, with a success rate of over 90% (1,2). However, early flaws may occur during the healing process affecting osseointegration (3). These flaws may have biological causes, such as peri-implantitis and systemic diseases. In addition, biochemical factors can negatively influence implant success; for instance, bone over heating during the surgical procedure, occlusal overload, besides the effects of tensile strength, shear and compressive stresses in the peri-implant bone tissue (4).

The osseointegration process requires ideal stress levels to maintain normal bone repair (5). Excessive tension may cause irreversible damage to the peri-implant bone tissue (6). Conversely, too low tension may unsatisfactorily stimulate the bone repair process (4). Recent computerized simulations suggest that compressive stresses and hydrostatic tensions of the intersticial liquid may modulate tissue differentiation and bone remodeling (4,7,8). Byrne *et al.* (7) using mathematical models about cellular differentiation in bone repair verified that the stress increase changes the bone repair process, reducing the amount of newly formed bone tissue by 23% and increasing the amount of cartilage by 21%. Similarly, Checa and Prendergast (8) verified less newly formed bone and greater connective tissue formation under elevated compressive stresses.

During osseointegrated implant placement, the insertion torque may result in varied levels of compressive stresses transmitted to the adjacent bone, given that the implant bed is slightly narrower than the diameter of the implant to be placed in order to optimize primary stabilization (9,10). Clinical studies have demonstrated a close relationship between initial stabilization and the success of an osseointegrated implant (11,12,13), which can be measured through the insertion torque during implant placement (12). The insertion torque must exceed 30Ncm to obtain predictable success rates (12,14), aiming to avoid implant micro movement and consequent connective tissue formation (6,13). However, an excessively elevated insertion torque, above 50 Ncm (15), can occur during dense bone implant placement (12,16,17), resulting in the transmission of high compressive stresses to the adjacent bone, besides compromising osseointegration success (3).

Thus, the understanding of the high values of insertion torque that can be used during implant placement, without causing excessive stress in the bone tissue, would be helpful for the success of implant osseointegration.

Considering the sparse studies associating compressive stress and strain with the high values of the insertion torques during implant placement, the aim of the present study was to evaluate the influence of different insertion torques on stress and strain distribution in cortical and cancellous bones, using the three dimensional finite element method.

MATERIAL AND METHODS

After approval of the Local Research Ethics Committee and signature of the written consent form, a computerized tomography (CT) scan was performed in a patient to obtain *dicom* format images. A representative mathematical model of the anterior segment of the maxilla was built using Mimics 11.11 software (Interactive Medical Image Control System, Materialise Inc., Leuven, Belgium) and Solid Works 2010 (Dassault Systèmes SolidWorks Corporation, Massachusetts, USA).

The geometry of an external hexagonal implant of 4.5 X 11.5mm (Strong SW model, Sistema de Implantes-SIN, São Paulo, Brazil) was used to build the implant design (Figure 1A) aided by Solid Works 2010 software. This implant was adapted to the bone segment corresponding to the region of tooth number 11 (Figure 1B).

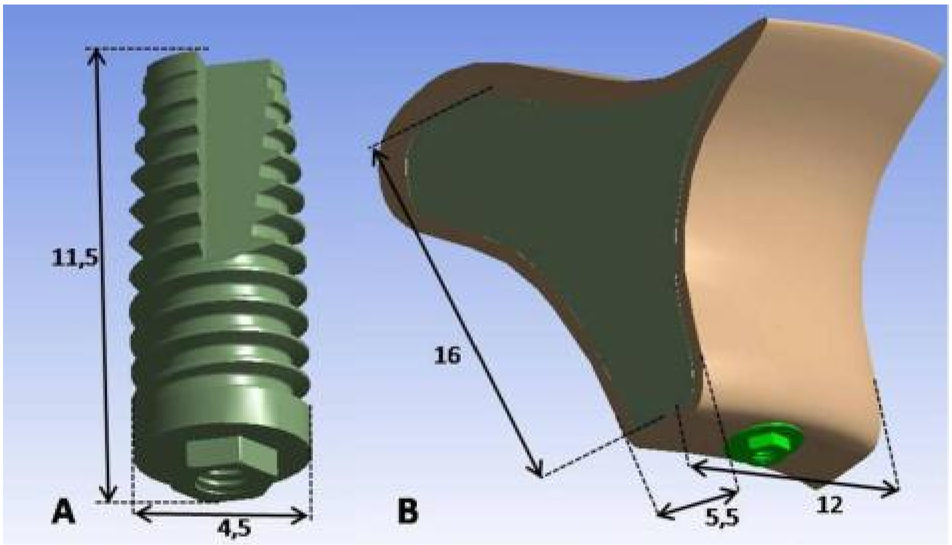

Figure 1. Dimensional implant (a) and model dimensions with cortical and cancellous bones (b).

After building the initial model, it was imported to the finite elements program Ansys Workbench 10.0 (Swanson Analysis Inc., PA, USA) to determine the regions and generate the finite element mesh. Each model received an implant with one of the following insertion torques: 30Ncm, 40Ncm, 50Ncm, 60Ncm, 70Ncm or 80/cm on the external hexagon. These values were applied using six forces on the implant external hexagon, perpendicular to the long axis and tangent to the implant platform, determined by the following equation (Figure 2):

$$F = T / 6 \times D \times sen\theta$$

Where T is the insertion torque; D a point of force application to the rotating axis; and θ the angle formed by the direction of the force applied and the plan of force application.

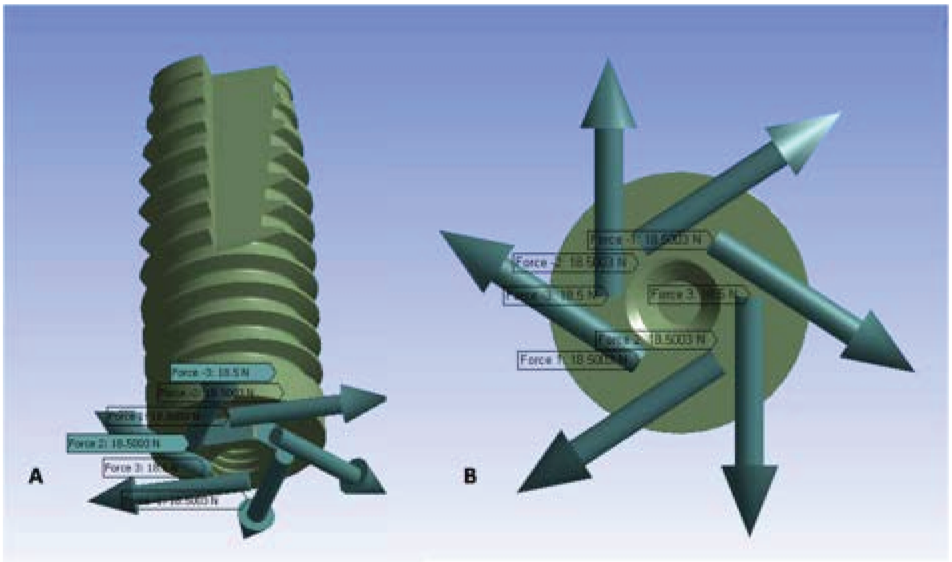

Figure 2. Torque applied to implant on implant external hexagon.

The mechanical properties for the anisotropic behavior of the cancellous and cortical bones were based on specific literature (18) (Table 1). The implant material was considered homogeneous (Titanium) and isotropic with values of Young's modulus = 104.000 (MPa); shear modulus = 38.806 (MPa); Poisson's ratio = 0.340 (MPa) (18). The bone/implant interface was considered perfectly bonded.

Table 1. Material properties used in anisotropic model. Material axes correspond to global coordinate system shown in figure 1. E=Young's modulus. G=shear modulus. v_{ij}=Poisson's ratio for strain in j-direction when loaded in i-direction.

	Cancellous boné	Cortical bone
E_X (MPa)	1.148	12.600
E_Y (MPa)	210	12.600
E_Z (MPa)	1.148	19.400
G_{XY} (MPa)	68	4.850
G_{YZ} (MPa)	68	5.700
G_{XZ} (MPa)	434	5.700
ν_{YX}	0.010	0.300
ν_{ZY}	0.055	0.390
ν_{ZX}	0.322	0.390
ν_{XY}	0.055	0.300
ν_{YZ}	0.010	0.253
ν_{XZ}	0.322	0.253

Parabolic tetrahedral elements of 0.8mm were used for the mesh. The mesh refinement was established by the convergence of analysis (5%). The models presented 170504 nodes and 112507 elements. The implant presented 92432 nodes and 62483 elements. The cancellous and cortical bones presented 58463 and 19609 nodes and 39442 and 10582 elements, respectively. A zero-displacement boundary condition was applied to the three Cartesian axes (x=y=z=0).

Maximum principal stress (σ_{max}) and maximum principal strain (ε_{max}) were obtained for the cortical and cancellous bones around the implant. Pearson´s correlation test was used to determine the relationship between the insertion torques and stress concentrations, considering the significance level at 5%.

RESULTS

In general, it was observed higher stress in the cancellous and cortical bones after increasing the insertion torques. The σ_{max} was smaller for the cancellous bone, with greater stress variation among the insertion torques. The ε_{max} was higher in the cancellous bone in comparison with cortical bone.

Cancellous bone

The stresses distribution in cancellous bone is presented in figure 3. The σ_{max} for different insertion torques of 30Ncm, 40Ncm and 50cm were 0.114MPa, 0.144MPa and 0.168MPa, respectively. There was an increase in the principal stresses between insertion torques of 50Ncm and 60Ncm, varying from 0.168MPa to 1.09MPa, maintaining a linear increase with 70Ncm and 80Ncm, exhibiting 1.17MPa and 1.34MPa, respectively. The insertion torques showed significant correlation with σ_{max} and ε_{max}(r=1.0, p=0.001) .

The 30Ncm and 80Ncm insertion torques showed the lowest and highest ε_{max} (7.20×10^{-4} MPa, 19.2×10^{-4} MPa), respectively.

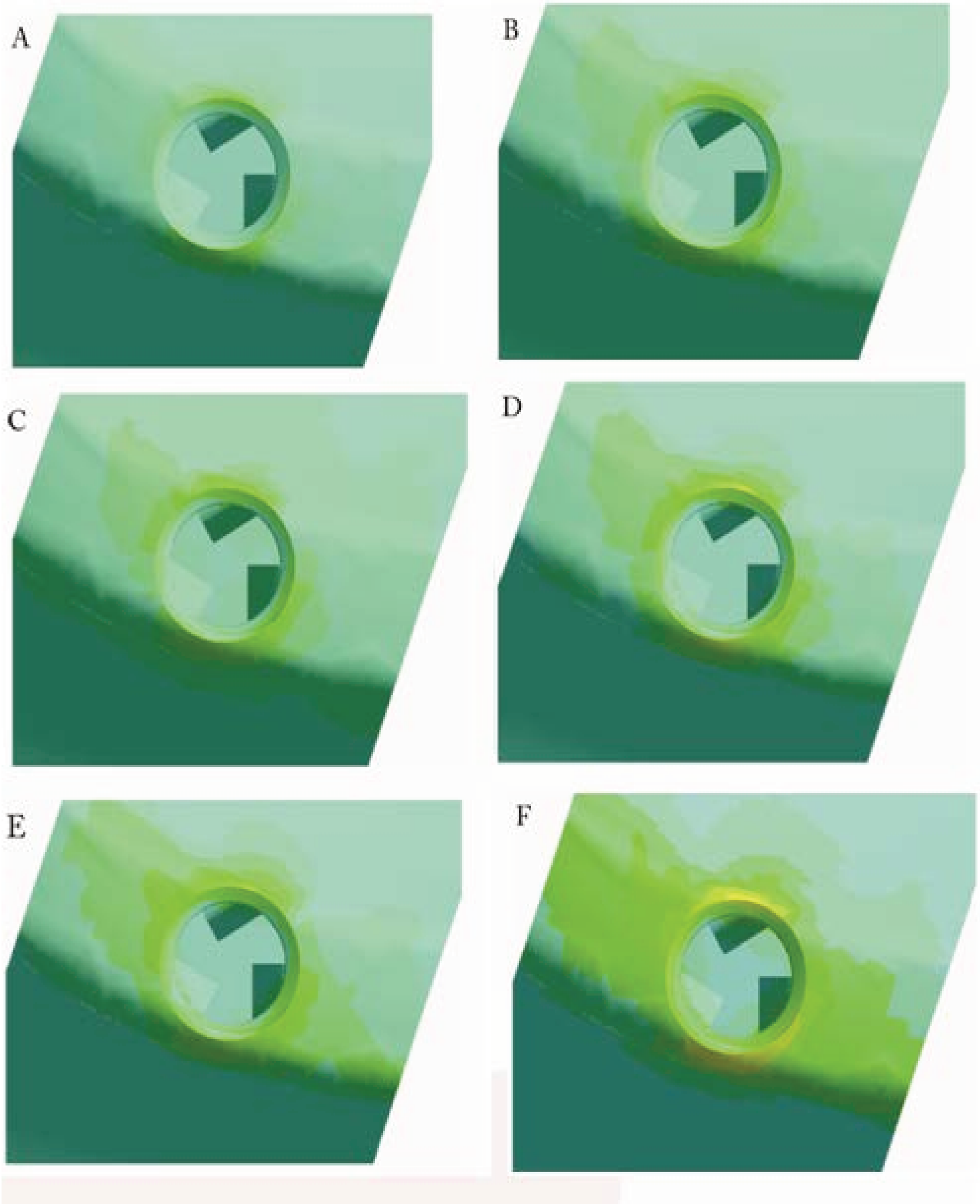

Figure 3. Stress profile within cancellous bone at each torque insertion. (a) 30 Ncm; (b) 40 Ncm; (c) 50 Ncm; (d) 60 Ncm; (e) 70 Ncm; (f) 80 Ncm.

Cortical bone

The stresses distribution incortical bone is presented in figure 4. The insertion torques showed significant correlation with σ_{max} and ε_{max} (r=1.0, p=0.001). The models with insertion torques of 30Ncm and 80/cm showed the lowest σ_{max} (4.15MPa) and ε_{max} (3.64×10^{-4}), and the highest σ_{max} (11.1MPa) and ε_{max} (9.72×10^{-4}) values, respectively.

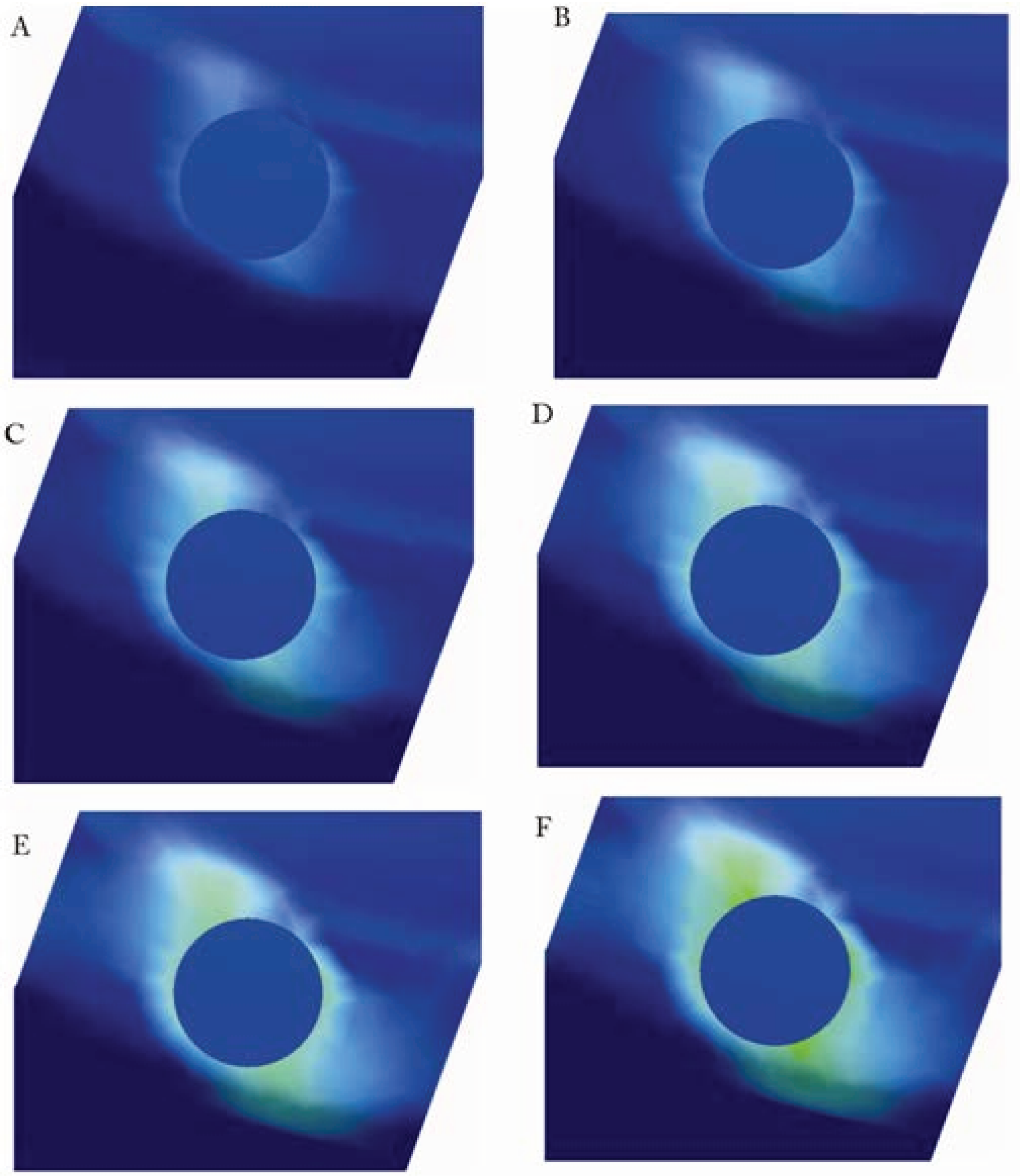

Figure 4. Stress profile within cortical bone at each torque insertion. (a) 30 Ncm; (b) 40 Ncm; (c) 50 Ncm; (d) 60 Ncm; (e) 70 Ncm; (f) 80 Ncm.

DISCUSSION

An adequate stability of the dental implant in the surrounding bone plays an important role in the bone healing processes, avoiding micromovement and damage to the bone healing process (17,19). Clinical assessment of primary stability can be performed by the implant insertion torque at the moment of placement (19). Considering the importance of the insertion torque for the osseointegration process, this study was performed by mimicking a dental implant placement using the anisotropic finite element technique. It was hypothesized that high values of the insertion torque can be generate overcompressive stress to the peri-implant tissues and compromising osseointegration process.

According to Ottoni *et al. (*14*)* and Irinakis and Wiebe (12), the insertion torque must exceed 30Ncm, especially for immediate load implants. However, insertion torques above 50Ncm are considered high insertion torques (15) and generally induce excessive compressive stresses to the bone peri-implant. Some studies report that the increase of compressive stress in the bone tissue may lead to failure in the bone healing (5) and osseintegration process (3).

The present study showed similar results to those of Van Staden *et al.*, in which the increase of the insertion torque generates higher compressive stress concentrations to the peri-implant bone tissue. In the present study, for the cancellous bone tissue, the increase of insertion torque (from 30Ncm to 80Ncm) showed an increase of 1175% for the maximum principal stress and 266% for the maximum principal strain. In the cortical bone tissue both stresses were higher (267%).

Studies based on mathematical analyses of the bone healing process presented a correlation between the compressive stress and the type of tissue formed during bone remodeling (8) *in vivo*. It is important to draw attention to the fact that under high stresses, significant alterations occurred in the angiogenesis dynamics impairing the formation of new blood vessels, causing hypoxia in the peri-implant tissues, thus inhibiting bone formation and favoring the formation of cartilage and connective tissue (8). Also, Burger and Klein-Nulend (20) emphasized the model of bone tissue formed by a complex tridimensional canaliculus network filled with an intersticial fluid that supplies bone cells. This fluid would be able to transmit external stresses to bone cells through a mechanism known as mechanotransduction, which refers to the conversion of mechanical energy from external stresses into bioelectrical and biochemical signals that modulate the bone cell metabolism (20). Therefore, when this mechanical energy is too high, osteocytes are induced to death, followed by recruitment of osteoclasts and bone destruction (8,20).

The results of the present study demonstrated that the maximum principal stress increased 648%, from 0.168MPa to 1.09MPa, between torques of 50Ncm and 60Ncm in the cancellous bone. High insertion torques above 50N//cm (15) can generate high compressive stresses to the peri-implant tissues causing blood supply deficiency and bone necrosis during the osseointegration phase and early implant failure (3) usually within the first month after placement (3). A high insertion torque may occur during implant placement in high density bone tissue (12,16,17). This observation can be confirmed by Turkilmaz *et al.* (17) who evaluated the relationship between bone density and the maximum insertion torque supported by the bone tissue, evaluated by tomography images and Hounsfield scale, showing a statistically significant correlation between bone density, the insertion torque and primary stability (17).

The cortical bone tissue showed lower capacity to dissipate stress as well as a more uniform increase of the insertion torque, showing higher principal maximum stress in comparison with the cancellous tissue. These results are similar to those of Natali *et al.* (9,10) who analyzed the influence of the osteotomy diameter for implant placement and the stress concentration on implant threads. These results are explained by the different mechanical properties between cancellous and cortical bones.

The computational analysis by the finite elements shows great versatility in the analysis of complex models. This analysis method allowed to identify the homogeneity between different models with varied insertion torques that are difficult to obtain in an experimental study with physical models, as well as the same mechanical properties and dimensions for cancellous and cortical bones. The anisotropy found in the bone tissue was reproduced in the present study for the cortical and cancellous bones; being characterized by different stress responses under forces applied in varied directions (9). Although the results of the present study can add data to the implant/bone behavior influenced by the high values of the insertion torque, animal and clinical investigation studies are needed to confirm these findings.

According to the methodology used and the limitations of the present study, it could be concluded that high insertion torques can generate higher tensile and compressive stresses to the peri-implant bone tissue.

RESUMO

Objetivo: O objetivo deste estudo foi avaliar a influência dos altos valores de torque de inserção na distribuição de tensões e deformações no osso cortical e medular. **Material e Métodos:** Com base em imagens de tomografia computadorizada, um modelo matemático representativo de um segmento da maxila foi construído utilizando os programas Mimics 11.11 e Solid Works 2010. Seis modelos foram construídos e cada um recebeu um implante com os seguintes torques de inserção no hexágono externo: 30Ncm, 40Ncm, 50Ncm, 60Ncm, 70Ncm ou 80Ncm. O osso cortical e medular foi considerado anisotrópico. A interface osso/implante foi considerada perfeitamente unida. A análise numérica foi realizada através do Ansys Workbench 10.0. A convergência de análise (5%) determinou o refinamento da malha. A tensão máxima principal (σmax) e a deformação máxima principal (εmax) foram obtidos para o osso cortical e medular ao redor do implante. O teste de correlação de Pearson foi utilizado para determinar a correlação entre torque de inserção e de concentração de tensões e deformações no tecido ósseo peri-implantar, considerando o nível de significância de 5%. **Resultados:** O aumento no torque de inserção gerou um aumento nos valores σmax e εmax para o osso cortical e medular. O σmax foi menor para o osso medular, com maior variação de tensão entre os torques de inserção. O εmax foi maior no osso medular em relação ao osso cortical. **Conclusão:** De acordo com a metodologia utilizada e dos limites do estudo, pode-se concluir que altos torques de inserção aumentaram as concentrações tensões de tração e compressão no tecido ósseo peri-implantar.

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DISCUSSÃO GERAL

O objetivo deste estudo foi avaliar por meio do método dos elementos finitos tridimensional a influência da proporção coroa-implante, sistema de retenção, material restaurador e tipo de oclusão na concentração de tensão nas regiões do osso cortical, medular, parafuso protético e do implante de uma prótese unitária suportada por um implante curto e a influência dos diferentes torques de inserção na distribuição de tensão e deformação no tecido ósseo cortical e medular.

A tensão que o tecido ósseo é submetido durante o procedimento de instalação do implante (van Staden *et al.,* 2008) e o conjunto implante-componente da prótese pelas forças mastigatórias (Eskitascioglu *et al.,* 2004; Miyata *et al.,* 2000) é um fator preponderante para o sucesso dos implantes dentais. Entretanto, quando a tensão ultrapassa o limite fisiológico do osso ou o limite de resistência dos materiais utilizados na confecção dos implantes e dos componentes protéticos ocorrem falhas nas reabilitações orais, reabsorções ósseas ou até mesmo a perda da osseointegração (Eskitascioglu *et al.*, 2004).

Os resultados para concentração de tensão no tecido ósseo foram semelhantes nos dois estudos, com áreas de maiores concentração de tensão no tecido ósseo cortical ao nível da plataforma do implante e melhor distribuição de tensão no osso medular, o que corrobora com os resultados encontrados na literatura (Ding *et al.,* 2009; Anitua *et al.,* 2010). Resultado que pode ser justificado pelo maior módulo de elasticidade do osso cortical em comparação ao osso medular.

Dentre os fatores protéticos relacionados, a oclusão foi o que teve maior influência na concentração de tensão em todas as regiões avaliadas. Resultados semelhantes com estudos prévios (Miyata *et al.*, 2000; Kim *et al.,* 2005) que, adicionalmente, sugerem qua a oclusão traumática pode ser a principal causa de perda óssea marginal, fratura de implantes e soltura ou fratura de parafusos protéticos.

O aumento da proporção-coroa implante também contribuiu para maior concentração de tensão nas regiões avaliadas, sendo justificado pelo maior braço de alavanca e a criação de um momento fletor no sistema protése-implante, principalmente quando submetido a forças oclusais traumáticas. Os dados do presente estudo corroboram com os achados de Sütpideler *et al.*, 2004 que encontraram resultados similares, com aumento da proporção coroa-implante e maior concentração de tensão no tecido ósseo periimplantar, sugerindo que o aumento da tensão pode justificar a reabsorção óssea marginal. Entretanto, Kozlovsky *et al.*, 2007 e Heitz-Mayfield *et al.*, 2004 em estudos com animais não observaram a relação de aumento de tensão marginal com reabsorção óssea.

O sistema de retenção contribuiu para a concentração de tensão, porém com menor influência quando comparado a oclusão e a proporção coroa-implante. As próteses cimentadas, apresentaram menores concentrações de tensões quando comparadas às protéses parafusadas, resultados concordes com os de Zarone *et al.*, 2007 e Al-Omari *et al.*, 2010. A menor concentração de tensão pode ser atribuída a camada de cimento, que devido ao menor módulo de elasticidade, pode absorver parte da tensão das forças mastigatórias. Para os modelos avaliados o material restaurador não apresentou influência significativa na concentração de tensão nas regiões avaliadas.

Em relação a influência de diferentes torques de inserção na distribuição de tensão e deformação no tecido ósseo cortical e medular os resultados demonstraram haver maiores tensões e deformações no tecido ósseo cortical e medular com o aumento do torque de inserção, em concordância com o estudo de Van Staden *et al.,* 2008.

O torque de inserção pode ser utilizado para mensurar a estabilidade inicial do implante no momento da sua instalação, o qual é um fator importante no prognóstico dos implantes dentais (Rodrigo *et al.,* 2010). Entretanto, o aumento da magnitude dos torques de inserção induz maiores tensões e deformações ao tecido periimplantar. Alguns estudos (Byrne *et al.*, 2007; Checa & Prendergast 2010) demonstram que o aumento de tensão e deformação ao tecido ósseo durante a fase de reparação óssea pode induzir a formação de tecido fibro-cartilaginoso, o que caracteriza falha na osseointegração. Essa alteração na reparação óssea pode ser explicada pela alteração na angiogênese na fase inicial da osseointegração, causando hipoxia aos tecidos periimplantares. Um ambiente de baixo nível de oxigênio favorece a formação de tecidos cartilaginoso e fibroso quando comparado à formação óssea (Checa & Prendergast 2010).

Como limitação do estudo pode-se questionar o modelo de obtenção e análise dos dados. Entretanto, deve ser destacado que o método dos elementos finitos utiliza a resolução de um sistema de equações algébricas que auxiliam na compreensão do comportamento das tensões e deformações de uma estrutura complexa (Geng *et al.,* 2001). Uma das críticas ao método deve-se ao fato de que em alguns estudos não há o cuidado de se fazer um refinamento da malha dos elementos finitos, o que pode levar a inacurácia na obtenção resultados. Entretanto, no presente estudo, o refinamento da malha de elementos finitos foi realizado com 5% de convergência de acordo com o estudo de Kong et al, 2009.

Além da malha de elementos finitos a geometria dos modelos tridimensionais pode influenciar na obtenção dos resultados com o método dos elementos finitos (Lin *et al.,* 2010). No estudo apresentado, os modelos virtuais foram baseados em imagens de tomografias computadorizadas para os tecidos ósseos cortical e medular, em imagens microtomograficas para a coroa protética e em medidas reais dos modelos físicos para os implantes e componentes protéticos. Com auxílio de um programa CAD, Solidworks, os modelos virtuais foram criados e posteriormente exportados para o programa de análise de elementos finitos, Ansys Workbench 10.0®.

Os critérios de análise dos dados das tensões do presente estudo estão em concordância com o Iplikçioglu & Akça, 2002 e Dejak & Mlotkowski, 2008, que relatam que a tensão principal é adequada para estabelecer o comportamento de tensões de materiais friáveis como no tecido ósseo e a tensão de von Mises o comportamento das tensões em materiais dúctil como os implantes e parafusos protéticos.

CONCLUSÃO GERAL

De acordo com os resultados obtidos e dentro das limitações desse estudo concluí-se que:

- A oclusão e a proporção coroa-implante são os fatores de maior influência na concentração de tensão no osso periimplantar, no implante e parafuso protético em uma prótese unitária sobre implante curto.

- As próteses cimentadas promoveram menores valores de tensão no osso periimplantar, implante e parafuso protético em uma prótese unitária sobre implante curto quando comparadas às próteses parafusadas.

- O material restaurador não interferiu na concentração de tensão.

- O aumento da magnitude dos torques de inserção aumentam os valores de tensão e deformação no tecido ósseo periimplantar o que pode comprometer a osseointegração.

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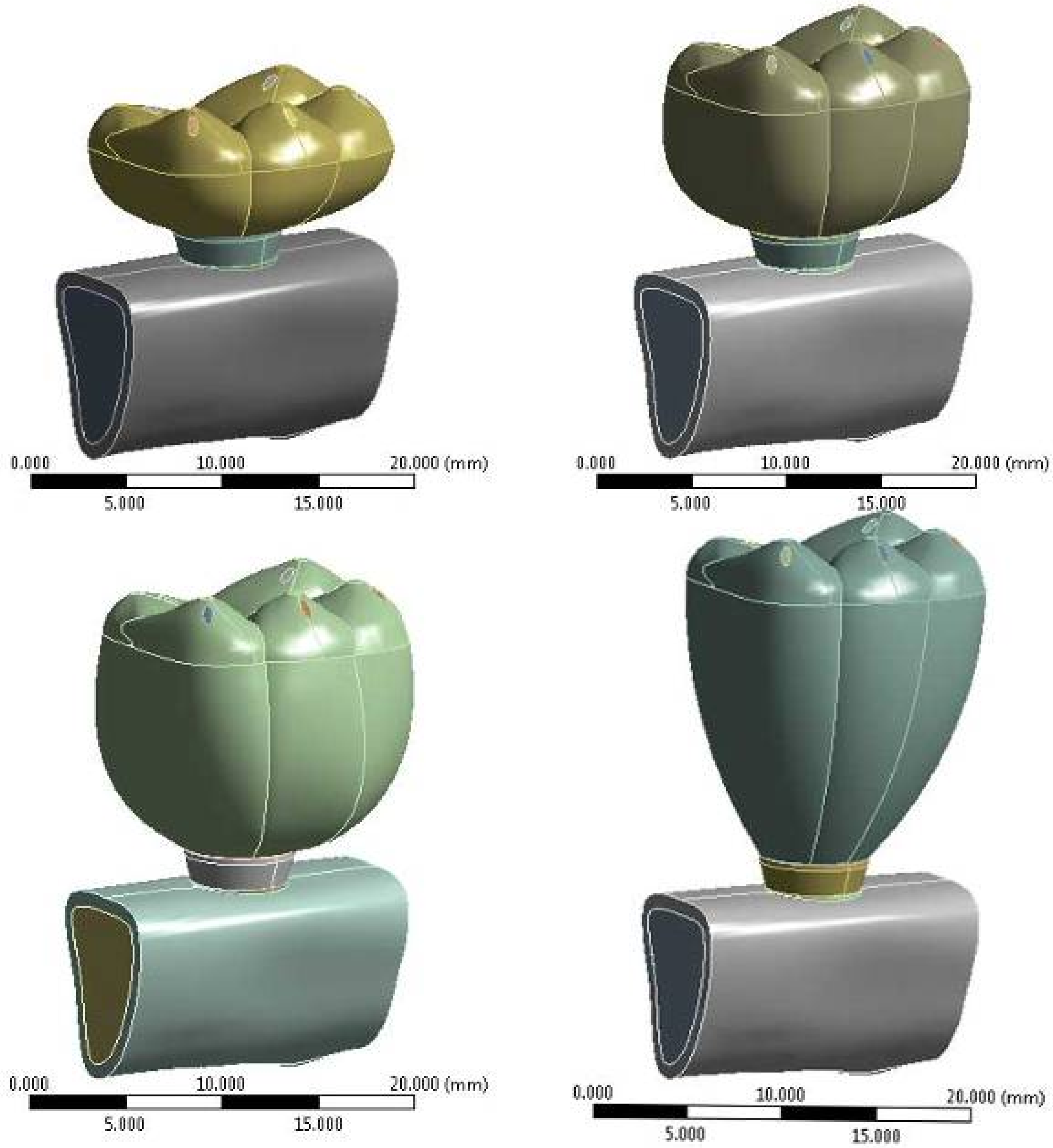
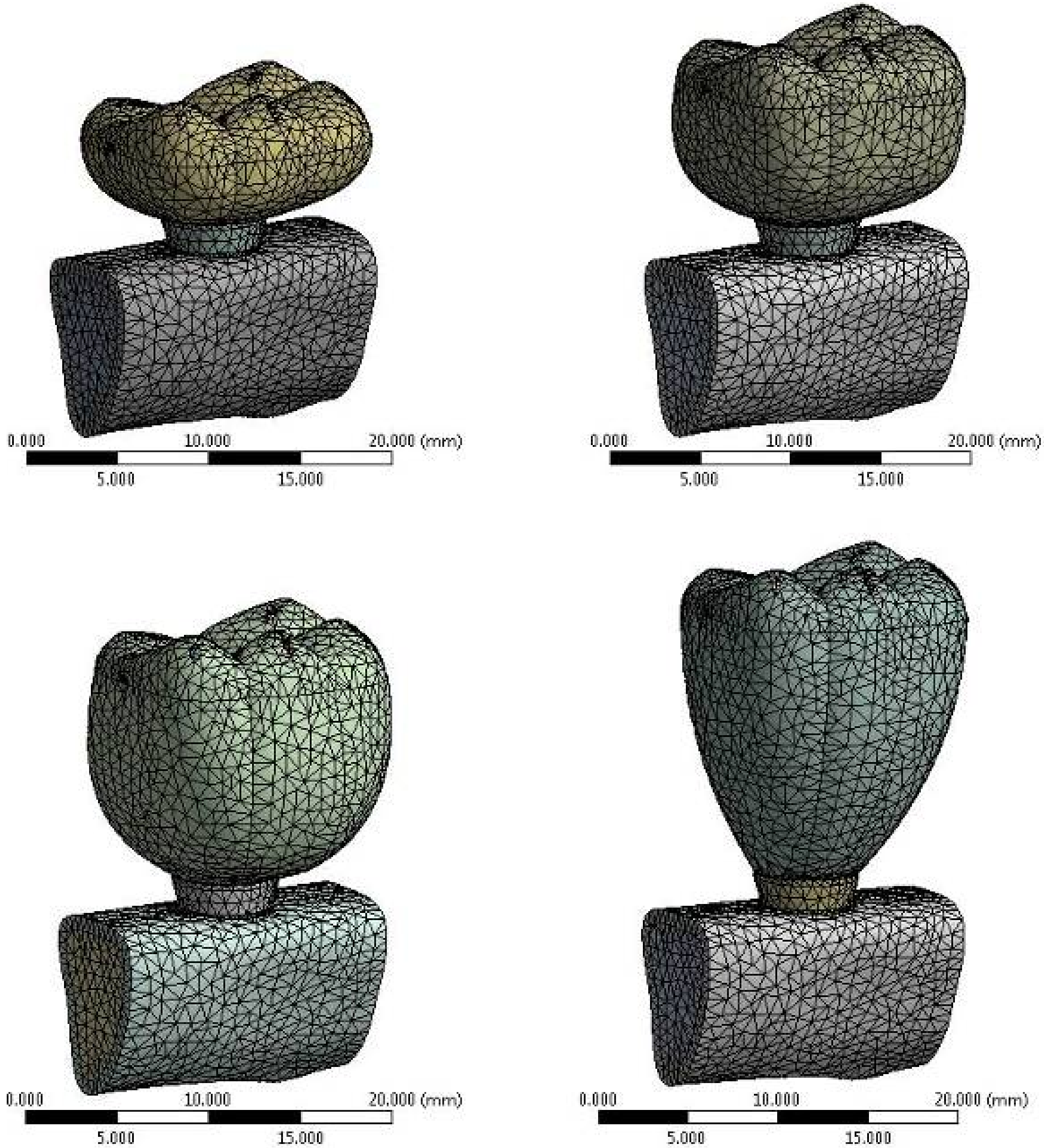
ANEXOS

Anexo 1: Modelos do capítulo 1 com as diferentes proporções coroa-implante: A) proporção 1:1; B) proporção 1.5:1; C) proporção 2:1 e D) 2.5:1.



Anexo 2: Malhas dos modelos do capítulo 1 com as diferentes proporções coroa-implante: A) proporção 1:1; B) proporção 1.5:1; C) proporção 2:1 e D) 2.5:1.



Anexo 3: Malha do modelo do capítulo 2.