UNICAMP

CAMILA LIMA DE ANDRADE

EFEITO DA MACROGEOMETRIA NO COMPORTAMENTO BIOMECÂNICO DE IMPLANTES OSSEOINTEGRADOS EM OSSO DE BAIXA QUALIDADE

"EFFECT OF MACROGEOMETRY IN THE BIOMECHANICAL BEHAVIOR OF OSSEOINTEGRATION DENTAL IMPLANTS IN LOW-QUALITY BONE"

PIRACICABA

2014

UNIVERSIDADE ESTADUALDE CAMPINAS
FACULDADE DE ODONTOLOGIA DE PIRACICABA

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Tese apresentada à Faculdade de Odontologia de Piracicaba da Universidade Estadual de Campinas como parte dos requisitos exigidos para obtenção do título de Doutora em Clínica Odontológica na área de Prótese Dental.

Thesis presented to the Piracicaba Dental School of the University of Campinas in partial fulfillment of the requirements for the degree of Doctor in Dental Clinic in Dental Prosthesis area.

Orientador: Prof. Dr. Bruno Salles Sotto-Maior

Este exemplar corresponde à versão final da tese defendida pela aluna Camila Lima de Andrade e orientada pelo Prof. Dr. Bruno Salles Sotto-Maior.

Assinatura da Orientador

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Prof. Dr. BRUNO SALLES SOTTO MAIOR

Fernanda Faot

Profa. Dra. FERNANDA FAOT

Profa. Dra. DALVA CRUZ LAGANÁ

Profa. Dra. ALTAIR ANTONINHA DEL BEL CURY

Profa. Dra. KARINA GONZALES SILVÉRIO RUIZ

RESUMO

A macrogeometria do implante está relacionada ao desenho do colar, conexão protética, formato das roscas e do corpo do implante. Diferentes desenhos do implante podem criar diferentes concentrações de tensão/deformação no tecido ósseo peri-implantar de boa qualidade, entretanto existe limitada informação sobre a influência desses parâmetros no comportamento biomecânico do implante instalado em osso de baixa qualidade. Nesse sentido, dois estudos foram conduzidos, sendo que o primeiro avaliou a influência do desenho do colar e das roscas na concentração de tensão e deformação no implante e no osso de suporte e o segundo estudo avaliou diferentes tipos de conexão protética e formatos do corpo do implante no comportamento biomecânico do osso peri-implantar. No primeiro estudo, seis modelos de implantes cilíndricos (4 x 10mm) hexágono externo foram obtidos pela combinação de dois desenhos de colar (liso e com microroscas) e três formatos de rosca (quadrado, trapezoidal e triangular). Para o segundo estudo, quatro modelos de implantes foram construídos com dois tipos de conexão protética (Hexágono Externo e Cone Morse) e dois formatos de corpo (cilíndrico e cônico). Em ambos estudos, os implantes receberam uma coroa unitária na região de 1° molar superior, a qual foi realizado um carregamento axial de 200N. Em seguida, foram analisados pelo método tridimensional de elementos finitos. Os modelos foram criados a partir de um software de desenho assistido por computador e o modelo ósseo foi construído a partir de tomografia computadorizada do tipo cone-beam da região posterior da maxila. Os dados do primeiro estudo foram analisados quantitativamente por ANOVA one-way com nível de significância a 5%. No estudo 2, utilizou-se os critérios de tensão de cisalhamento (τ_{max}) e deformação (ε_{max}) no osso peri-implantar. O estudo 1 mostrou que o desenho do colar afetou todos os parâmetros no implante e no osso cortical ($P < 0.05$), contribuindo com 99,79% no total de tensão de von Mises (σ_{vM}) e mais de 90% no total de tensões/deformação. O colar com microroscas apresentou maior σ_{vM} (54.91±1.06 MPa) no implante bem como maior τ_{max}

(11.98±0.07 MPa) e ε_{max} (0.97±0.07 x 10^{-3} μm) no osso cortical, embora tenha gerado um padrão de distribuição de tensões/deformação mais adequado no osso peri-implantar. O desenho das roscas influenciou biomecanicamente apenas o osso trabecular ($P < 0.05$), contribuindo com mais de 95% das tensões geradas. O desenho de rosca triangular foi responsável por produzir menor tensão de tração (3.83±0.34 MPa), tensão de cisalhamento (4.14±0.47 MPa) e deformação (0.90±0.04 x 10^{-3} μm). O estudo 2 mostrou que o tipo de conexão protética e formato do corpo influenciaram τ_{max} e ε_{max} no osso peri-implantar, sendo os implantes do tipo Cone Morse e formato cilíndrico responsáveis em produzir os menores valores de τ_{max} e ε_{max} no osso cortical e trabecular, respectivamente. Concluiu-se que a presença das microroscas no colar do implante, conexão Cone Morse, formato de rosca triangular e corpo cilíndrico são os parâmetros da macrogeometria que positivamente influenciam o comportamento biomecânico de implante unitário ancorado em osso de baixa qualidade.

Palavras-Chave: Implantes dentários. Osseointegração. Análise de elementos finitos.

ABSTRACT

Implant macro design is related to its collar design, prosthetic connection, thread design and body shape. Different implant macro designs can create distinct stress/strain concentrations in the peri-implant sites of good-quality bone, however there is limited information about the influence of these implant macro design parameters on the biomechanical behavior of the implant installed in a low-quality bone. Accordingly, two studies were conducted, and the first evaluated the effect of the collar and threads designs on the stress and strain distribution in the implant and low-quality bone and the second study evaluated different types of prosthetic connection and implant body shapes on the biomechanical behavior of the peri-implant bone. In the first study, six cylindrical external hexagon implants models (4 x 10 mm) were obtained by the combination of two collar designs (smooth and microthread) and three thread shapes (square, trapezoidal and triangular). For the second study, four implant models were constructed with two types of prosthetic connection (External Hex and Morse Taper) and two implant body shapes (cylindrical and conical). In both studies, the implants supported single upper first molar crowns and the restorations received 200 N axial loading and were analyzed by three-dimensional finite element method. The models were created from a computer-aided design modeling software and the bone model was constructed based on a cone-beam computer tomography of the posterior region of maxilla. Data of the first study were quantitatively analyzed by one-way ANOVA at a significance level of 5%. In the study 2, the criteria of shear stress (τ_{max}) and strain (ε_{max}) were used to evaluate peri-implant bone. The first study showed that collar design affected all parameters of the implant and cortical bone ($P < 0.05$), contributing to 99.79% of total von Mises stress (σ_{vM}) in the implant and more than 90% of total stresses/strain generated in the cortical bone. The microthread collar showed the highest values to σ_{vM} (54.91±1.06 MPa) in the implant, as well as to τ_{max} (11.98±0.07 MPa) and ε_{max} ($0.97 \pm 0.07 \times 10^{-3}$ μm) in the cortical bone, despite it had produced the more favorable stresses/strain distribution pattern on the peri-implant bone. Threads design influenced biomechanically only the trabecular bone ($P < 0.05$), contributing more than 95% of total stresses generated. The triangular thread shape was responsible for producing the lowest values to σ_{max} (3.83±0.34 MPa) and τ_{max} (4.14±0.47 MPa) stresses and ε_{max} ($0.90 \pm 0.04 \times 10^{-3}$ μm). The second study showed that the two types of prosthetic connection and implant body shape influenced ε_{max} and τ_{max} on the peri-implant bone and Morse taper and cylindrical implants were responsible to produce the lowest τ_{max} and ε_{max} values in the cortical and trabecular bone, respectively. It was concluded that the presence of microthread collar on the implant neck, Morse Taper connection, triangular thread shape and cylindrical implant are the implant macro design parameters that positively influence the biomechanical behavior of single implant restoration in the low-quality bone.

Keywords: Dental implantation. Osseointegration. Finite element analysis

SUMÁRIO

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INTRODUÇÃO

A terapia com implantes dentais tem sido bastante reportada na literatura científica nos últimos quarenta anos, por se tratar de um método eficiente para a reabilitações de áreas edêntulas unitárias, parciais ou totais (Arnhart et al. 2012) com taxas de sucesso superiores a 90% (Steigenga et al. 2003; Abuhussein et al. 2010; Koticha et al. 2012). Entretanto, menores taxas de sucesso são reportadas para implantes ancorados em maxila, principalmente em região posterior. Essa diferença se deve à diminuição da resistência óssea que está diretamente relacionada a densidade e qualidade óssea, a qual é frequentemente mais baixa na região posterior de maxila (Misch 1999; Steigenga et al. 2003).

O sucesso de um implante é avaliado a partir de duas perspectivas representadas pela resposta tecidual biológica e por fatores biomecânicos (Hermann et al. 2007; Abuhussein et al. 2010). Ambas dependem do grau e integridade de tecido ósseo formado ao redor do implante, que ditará o nível de estabilidade do implante. Inúmeros fatores têm sido apontados por influenciar a interface de ligação entre osso-implante e seus efeitos sobre a osseointegração, dentre eles destacam-se: técnica cirúrgica, densidade/qualidade óssea do sítio hospedeiro, condições de carregamento, superfície dos implantes e macro geometria do implante (Steigenga et al. 2003).

A compreensão e avaliação destes têm sido foco de estudos recentes (Yamanishi et al., 2012; Amid et al., 2013; Chowdhary et al., 2013). O entendimento e aplicação desses fatores de forma apropriada na ciência da implantodontia pode auxiliar no controle da remodelação peri-implantar e na manutenção da osseointegração e, consequentemente, resultar no aumento das taxas de sucesso dos implantes dentais (Ausiello et al. 2012).

As características geométricas dos implante são um dos elementos fundamentais com efeito significativo não apenas na estabilidade primária, como também na habilidade do implante em sustentar as forças da mastigação e a osseointegração (Chang et al. 2012). O desenho do implante pode ser dividido em duas principais categorias: macro e microgeometria. A macrogeometria refere-se a presença ou ausência de roscas, formato do corpo do implante, desenho da rosca (geometria da rosca, ângulo de face, passo de rosca, profundidade da rosca [altura], espessura da rosca [largura] ângulo de hélice da rosca) e ao tipo de conexão protética (Abuhussein et al. 2010; Desai et al. 2012). A microgeometria é composta pelo material do implante, sua morfologia e tratamento da superfície. A Figura 1 ilustra as características da macrogeometria que compõem o corpo do implante.

Figura 1: Características da macrogeometria básica de um implante.

A macrogeometria do implante é idealizada para conduzir as forças mastigatórias incididas no conjunto prótese-implante e transferi-las aos tecidos adjacentes de suporte, de modo a dissipar e distribui-las para o tecido ósseo (Desai et al., 2012; Orsini et al., 2012; Chowdhary et al., 2013). Portanto, a funcionalidade e longevidade dos sistemas de implantes estão intimamente relacionadas à integridade mecânica da prótese e do implante, à estabilidade interfacial e à capacidade das estruturas de suporte em resistir e adaptar-se positivamente à aplicação das forças mastigatórias (Eraslan and Inan, 2010; Aparna et al., 2012). É neste contexto que a macrogeometria dos implantes, principalmente no que diz respeito à configuração do colar e da conexão protética, do formato das roscas e do corpo do implante, torna-se um fator de extrema importância para a otimização biomecânica e funcional das próteses implanto-suportadas.

Um fator-chave para o sucesso ou falha do implante é a maneira pela qual as tensões são transferidas ao tecido ósseo peri-implantar (Chun et al. 2002; Fuh et al. 2013). Alguns desenhos de implantes estão associados à redução de perda óssea na região da crista e nas interfaces osseointegradas por dissipar de maneira mais homogênea as tensões para o tecido ósseo de suporte (Huang et al. 2007; Lee et al. 2007; Hudieb et al. 2011). Estudos prévios revelam que tensões e deformação podem aumentar nas áreas ao redor das roscas localizadas no corpo e no colar, a depender da configuração dessas (Huang et al. 2007; Amid et al. 2013), e que o formato do corpo do implante e da conexão protética podem induzir níveis de tensões elevadas para o osso marginal (Maeda et al. 2007; Kong et al. 2008; Pessoa et al. 2010), consideradas como fator de risco para reabsorção óssea. Assim, avaliar o tipo de desenho de colar, conexão protética, formato de roscas e do corpo do implante que melhorem a dissipação de tensões em uma interface osso-implante comprometida pela densidade e qualidade óssea, poderia contribuir para a diminuição da remodelação óssea peri-implantar e perda da osseointegração dos implantes maxilares.

Um dos fatores que afetam a interface de ligação entre osso-implante e que está intimamente relacionado à macrogeometria do implante, têm-se o colar do implante, também chamado de pescoço do implante ou módulo da crista; representa a zona de transição entre o corpo do implante para a região transosteal na crista do rebordo, podendo ser de desenho liso ou com microroscas. O conceito da incorporação de microroscas na porção coronal surgiu na tentativa de preservar os tecidos duros e moles peri-implantares (Hansson and Werke, 2003; Aparna et al., 2012). Estudos experimentais e clínicos têm demonstrado que a adição das microroscas no colar do implante proporciona estabilidade primária dos implantes, pois aumenta a área de contato entre osso-implante e reduz a reabsorção óssea e a recessão tecidual (Abrahamsson and Berglundh, 2006; Lee et al., 2007; Choi et al., 2009; Song et al., 2009). Adicionalmente, estudos biomecânicos, mostram que a presença das microroscas podem melhorar a dissipação de tensões e a deformação na interface osso-implante, levando à manutenção da crista óssea de acordo com a lei de Wolff, que afirma que o aumento das tensões tende a eliciar o estímulo ósseo, ao passo que baixos níveis de tensão tendem a eliciar a perda óssea (Schrotenboer et al., 2008; Hudieb et al., 2011; Merıç et al., 2011). Esse postulado mostra que níveis moderados de tensão/deformação podem manter a massa óssea em resposta ao desafio mecânico, fornecendo um osso mais maduro e mais resistente a alterações periódicas nas condições de carregamento. Entretanto níveis de tensão/deformação excessivas ou sub-normais podem resultar em deformação significativa do osso, suficiente para causar reabsorção óssea do ponto de vista biomecânico celular (Misch 1999; Hansson 2003). Dessa forma, a presença de elementos retentivos no colar do implante poderia auxiliar na dissipação de forças incidentes ao carregamento oclusal que por sua vez, auxiliariam na manutenção da altura da crista óssea (Hansson, 1999; Aparna et al., 2012; Choi et al., 2012).

A conexão protética é um dos aspectos envolvidos na macrogeometria do implante e também considerada fator de extrema importância para a manutenção da interface osso-implante (Lin et al. 2013). A conexão pode ser do tipo interna ou externa, a depender das características geométricas da extensão acima ou abaixo da superfície coronal dos implantes. Estudos biomecânicos apontam que a conexão protética do tipo Cone Morse (CM) distribuem mais uniformemente as tensões no tecido cortical quando comparada à conexão Hexágono Externo (HE). Além disso, as tensões localizadas próximas a crista óssea alveolar e ao corpo do implante são diminuídas com a utilização da conexão CM (Quaresma et al., 2008; Hansson, 2000; Pessoa et al., 2010)

Outro aspecto da macrogeometria do implante está relacionado ao desenho das roscas. Dentre os principais desenhos disponíveis atualmente no mercado destacam-se formatos de roscas quadrado, triangular (em forma de V) e trapezoidal (Chun et al., 2002; Steigenga et al., 2003; Geng et al., 2004; Abuhussein et al., 2010; Eraslan and Inan, 2010), como mostra a Figura 2 abaixo, sendo que alguns sistemas de implantes adotam variações desses desenhos iniciais.

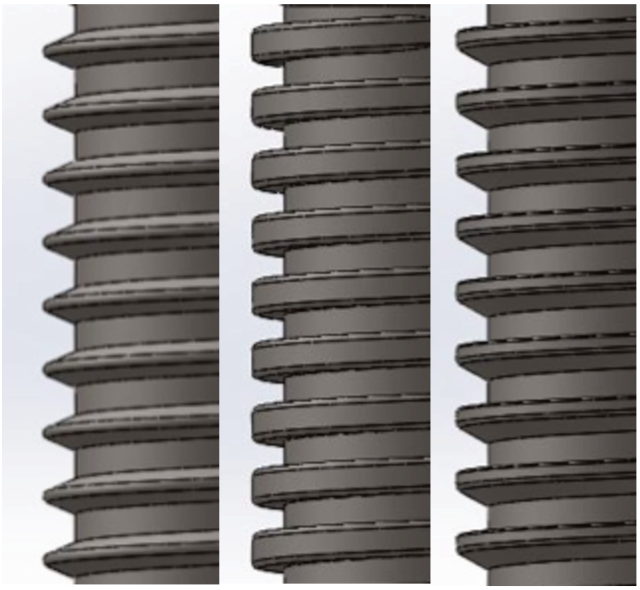
Triangular Rosca em V
Rosca Quadrada
Rosca Trapezoidal

Figura 2: Principais desenhos de roscas disponíveis no mercado: rosca em V (triangular), rosca quadrada e rosca trapezoidal.

Há controvérsias na literatura quanto ao desenho de rosca que produz menor concentração de tensão para o tecido ósseo adjacente de boa qualidade. É sabido que maiores concentrações de tensão são encontradas nas áreas das cristas das roscas, enquanto menores concentrações são notadas nas áreas de vales das roscas, mostrando um padrão de distribuição de tensão descontínuo ao longo do corpo do implante. Menores níveis de tensão são benéficos para a manutenção da osseointegração e para o aumento da área de contato osso-implante (Huang et al. 2007). Desai *et al.* (2012) mostraram que as roscas trapezoidais foram as que transmitiram menor tensão e deformação para o osso cortical comparada aos demais modelos de roscas. Já Geng et al. (2004) e Chowdhary et al. (2013) mostraram que o formato em V gerou menores tensões quando comparado ao desenho de rosca quadrada e trapezoidal, o que foi suportado pelo estudo de Hansson & Werke (2003).

Outro importante aspecto relacionado à macrogemotria dos implantes é o formato do corpo. O formato cônico foi idealizado para otimizar a estabilidade primária, por permitir expansão óssea de forma gradual e produzir menores tensões na interface osso-implante (Wu et al. 2012). Entretanto, alguns estudos de elementos finitos apontam menor concentração de tensão/deformação em osso de maior densidade para o formato cilíndrico quando comparado ao cônico (Rismanchian et al., 2010; Atieh and Shahmiri, 2013), cuja diminuição de tensão/deformação seria mais adequada para manter a osseointegração.

Dessa forma, para aumentar o sucesso clínico principalmente de implantes maxilares, é necessário entender como a concentração de tensão/deformação no implante e tecido ósseo peri-implantar de baixa qualidade é afetada pelo desenho do colar, da conexão protética e pelo formato das roscas e corpo do implante. O uso do método de elementos finitos na análise da biomecânica peri-implantar oferece muitas vantagens sobre outros métodos, pois permite simular a complexidade de situações clínicas e compreender o comportamento de estruturas internas do modelo (Kong et al. 2008). Entretanto, estudos prévios com esta metodologia têm avaliado o efeito dos parâmetros de desenho do implante no tecido ósseo de forma simplificada e independente e que não reproduzem a complexidade da situação clínica, devido à diferenças na morfologia do osso alveolar e nas propriedades dos materiais adotadas (Hudieb et al. 2011). Além disso, esses estudos avaliam regiões de maior densidade óssea, como a região mandibular (Schrotenboer et al., 2008; Tetè et al., 2012; Chowdhary et al., 2013). Não há elucidação sobre a influência biomecânica dos aspectos da macrogeometria de implantes instalados em sítios ósseos maxilares posteriores.

Assim, o presente estudo avaliou os parâmetros da macrogeometria do implante referentes ao desenho do colar, conexão protética, desenho das roscas e formato do implante quanto a influência biomecânica na concentração de tensão/deformação no implante e no osso cortical e trabecular de baixa qualidade. Além disso, o padrão de distribuição de tensão/deformação também foi examinado. Os resultados obtidos a partir dessa perspectiva poderão elucidar a forma como a macrogeometria do implante interfere no comportamento biomecânico do tecido ósseo de baixa qualidade, o qual possui menor módulo de elasticidade quando comparado aos demais tipos ósseos, auxiliando na diminuição da perda óssea peri-implantar e falha dos implantes maxilares por problemas mecânicos.

CAPÍTULO 1*

Biomechanical analysis of the dental implant macro design in low-quality bone

Camila Lima de Andrade[1], Marco Aurélio de Carvalho[1], Wander José da Silva[1], Dimorvan Bordin[1], Altair Antoninha Del Bel Cury[1], Bruno Salles Sotto-Maior[2].

[1] Department of Prosthodontics and Periodontology, Piracicaba Dental School, State University of Campinas - UNICAMP, Piracicaba, São Paulo, Brazil.

[2] Department of Restorative Dentistry, Federal University of Juiz de Fora, Juiz de Fora, Minas Gerais, Brazil.

Corresponding author:

Altair Antoninha Del Bel Cury. Department of Prosthodontics and Periodontology; Piracicaba Dental School, University of Campinas. Avenida Limeira, 901. Zip Code: 13414-903. Piracicaba, São Paulo, Brazil. Phone: +55 19 21065294; fax +55 19 2106-5211. E-mail: altcury@fop.unicamp.br

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ABSTRACT

Statement of Problem. Limited information is available about the influence of implant macro design parameters on stress/strain in low-quality bone.

Purpose. This study investigated the influence of implant macro design on stress/strain distributions in low-quality bone.

Material and Methods. Six groups were obtained from the combination of two collar designs (smooth [SC] and microthread [MC]) and three thread shapes (square, trapezoidal, and triangular) in external hexagon implants (4 × 10 mm) supporting a single zirconia crown in the upper first molar region. A 200-N axial occlusal load was applied to the crown, and measurements were made of the von Mises stress (σ_{vM}) for the implant, and tensile stress (σ_{max}), shear stress (τ_{max}), and strain (ε_{max}) for the surrounding bone. Data were evaluated by one-way ANOVA at a 5% significance level.

Results. Collar design significantly influenced biomechanical behavior in the implant and cortical bone. The MC increased σ_{vM} (54.91 ± 1.06 MPa) in the implant, as well as τ_{max} (11.98 ± 0.07 MPa) and ε_{max} ($0.97 \pm 0.07 \times 10^{-3}$ μm) in the cortical bone, despite the more favorable stress/strain distribution pattern. Thread design affected the biomechanic in the trabecular bone. Triangular shape showed the lowest values of σ_{max} (3.83 ± 0.34 MPa), τ_{max} (4.14 ± 0.47 MPa), and ε_{max} ($0.90 \pm 0.04 \times 10^{-3}$ μm).

Conclusions. Stress/strain distribution patterns were influenced by collar design in the implant and cortical bone, and by thread design in the trabecular bone. MC and triangular thread-shape designs presented improved biomechanical behavior in low-quality bone.

Clinical Implications: For posterior implant-supported restorations, a microthread collar and triangular thread-shape are the implant macro designs that provide better mechanical behavior in low-quality bone.

Keywords: dental implant, macro design, osseointegration, finite element analysis.

INTRODUCTION

The predictability and long-term success rates of osseointegrated implants have been related to several factors, including material biocompatibility, implant design, surface treatment, surgical technique, micromovement control, bone quality, and loading conditions.[1–3] Lower success rates for osseointegrated dental implants have been reported for maxillary implants, especially those in the posterior maxilla, which is usually characterized by low bone quality (type IV).[4–6] Implants that essentially have only trabecular anchorage may have greater biomechanical challenge, due to the reduced implant-bone contact and poor immobilization, which can lead to micromotion, loss of osseointegration, and consequent implant failure.[7]

As bone quality cannot be changed, selection of the appropriate implant design is imperative to improve the magnitude of stress that is transmitted to the bone-implant interface in the posterior maxilla.[8] Implant design refers to three-dimensional implant structure, comprising all elements and features of the implant. The implant design may be categorized into two modalities: macro and micro designs. Macro design refers to the shape of the thread, implant body, prosthetic connection, and collar design. Micro design refers to the implant material, surface morphology, and surface treatment.[3,9,10]

Researchers have targeted the implant macro design, in attempts to understand the biomechanical factors that most affect long-term implant success during anchorage in low-quality bone.[11–23] The role of the thread as the retentive element in the implant collar and body is related to an increased contact surface area, which provides greater bone-implant interaction and implies better stress distribution at the peri-implant bone site.[24–29] Moreover, the thread design helps determine the maintenance of the surrounding bone and the primary stability for immediate loading conditions, especially when implants are inserted in low-quality bone.[4,8,9,30] However, there is a lack of data in the literature about the biomechanical influence of implant macro designs on osseointegrated implants anchored in sites of low bone quality. Therefore, new insights are needed to understand the biomechanical behavior of type IV bone around implants with different collar and thread designs.[2,5,6]

In this context, finite element analysis (FEA) has become an increasingly powerful approach to predict the biomechanical behavior of the bone-implant interface and to identify areas of greater stress/strain concentration.[4,31–34] Therefore, the objective of this study was to evaluate the influence of different collar and thread designs of single implant restorations anchored in low-quality bone in the posterior maxilla, in terms of the stress and strain concentrations in the implant and peri-implant bone.

MATERIAL AND METHODS

Experimental design

With the help of a computer-aided design software (SolidWorks 2014; SolidWorks Corporation), maxillary models were constructed on the basis of cone-beam computer tomography cross-sectional images of an edentulous posterior human maxilla. The bone segments were 20.0 mm in mesio-distal length, 11.53 mm in height, and 8.95 in width, with a cortical bone thickness of 1.40 mm. Cortical and trabecular bone were subdivided into peri-implant bone in direct contact with the implant and remaining bone, to isolate the region of highest interest for analysis.[35]

External hexagon implants (4 mm in diameter × 10 mm in length) were used to support cemented zirconia crowns. Implants were modeled with two types of implant collar designs (smooth collar [SC] and microthread collar [MC]) and three different implant-body thread designs (square [SQ], trapezoidal [TP], and triangular [TR]), providing six groups in total. Implant models were placed vertically at the crestal bone level and constructed under similar conditions of position, height, width, and pitch thread (0.55 mm). Thread dimensions were chosen as those providing the optimal stress distribution around the osseointegrated implants, in accordance with reported studies.[10,36,37] The collar design was obtained with a height of 1.45 mm. Collar and thread designs are specified in Fig. 1.

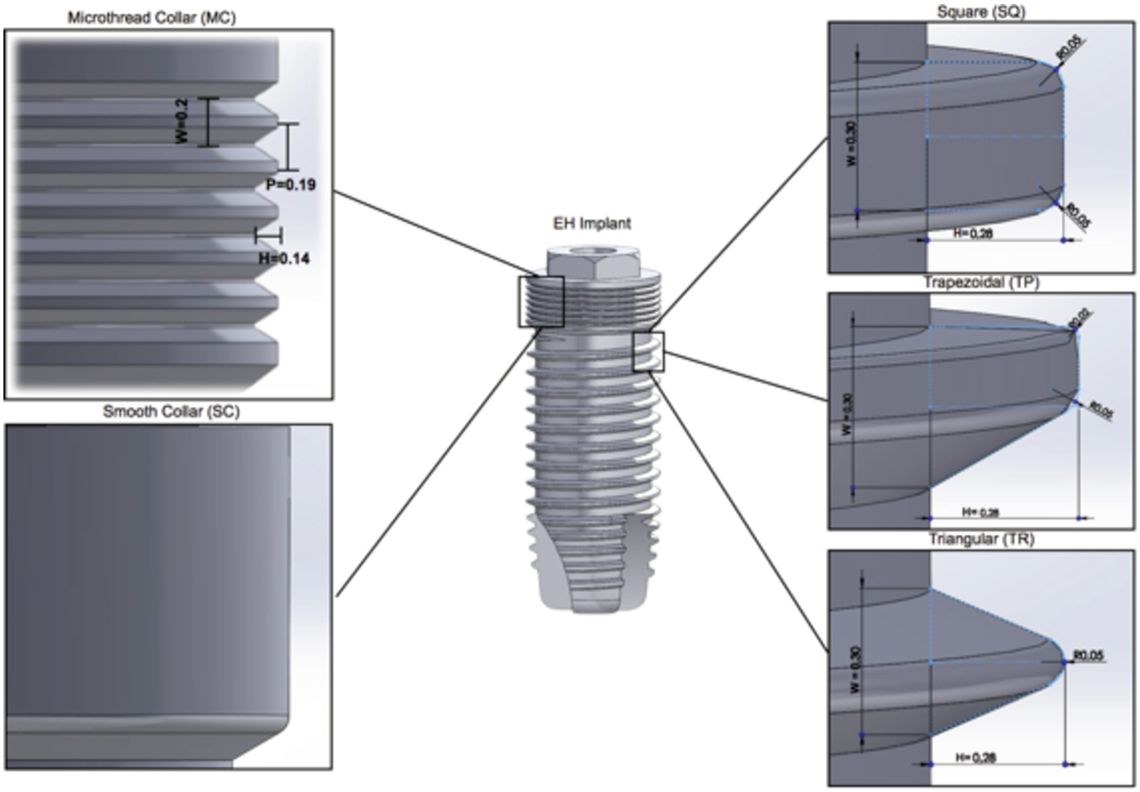

Fig. 1. Schematic illustration of the collar and thread-shape designs used in the study. Height (H), width (W), and pitch (P) of the threads are specified for the microthread collar and for different thread shapes.

Numerical Analysis

All models were exported to ANSYS Workbench FEA software (ver. 14.0; Swanson Analysis Inc.) for mesh acquirement and numerical analysis. The mesh was generated with 0.5-mm quadratic tetrahedral elements, after convergence analysis (5%) as a refinement process to improve the accuracy of the results.[38] Cortical and trabecular bone were assumed to be anisotropic, homogeneous and linearly elastic. All other materials were considered to be isotropic, homogeneous, and linearly elastic. Mechanical properties of materials were determined from the literature (Table I). The “bonded” contact type was used for all contact areas, including the bone-implant interface, to simulate osseointegration. The models were fully constrained in all directions at the nodes on the mesial and distal borders. A 200-N occlusal load was distributed in five 1.5-mm² contact areas on the occlusal surface of the crown.

Table I. Mechanical properties assigned to the materials used in the study.

	Young’s modulus (E) (MPa)	Shear modulus (G) (MPa)	Poisson ratio (δ)
Cortical bone [33]	E_x 12,600	G_{xy} 4,850	δ_{xy} 0.30
	E_y 12,600	G_{yz} 5,700	δ_{yz} 0.39
	E_z 19,400	G_{xz} 5,700	δ_{xz} 0.39
Trabecular bone [29,33]	E_x 1,150	G_{xy} 6,800	δ_{xy} 0.001
	E_y 2,100	G_{yz} 4,340	δ_{yz} 0.32
	E_z 1,150	G_{xz} 6,800	δ_{xz} 0.05
Titanium (Implant and abutment)[39]	104,000	38,800	0.34
Cement[40]	17,000	14,500	0.30
Zirconia [12]	210,000	33,000	0.31

The subscripts *x*, *y* and *z* correspond to the axis of the global coordinate system.

Statistical Analysis

Quantitative analysis was performed according to the von Misses (σ_{vM}) criteria for the implant, and the tensile stress (σ_{max}), shear stress (τ_{max}), and strain (ε_{max}) for the cortical and trabecular bone.[41] Data were analyzed qualitatively according to the stress distribution patterns in the implant and the cortical and trabecular bone. All combinations of the implant collar designs (SC and MC) and implant-body thread shapes (SQ, TP, and TR) were considered, resulting in six calculation sets. Data from each factorial design were evaluated by one-way analysis of variance (ANOVA; SAS version 9.0; SAS Institute Inc.). This analysis allowed the authors to calculate the percentage contribution (% total sum of squares) of each of the evaluated variables. The significance level was set at 5%.

RESULTS

Stress distribution in the implant

Collar design affected the von Mises stress in the implant (*P* < .001), contributing 99.79% of the total generated stress. Thread design did not significantly influence the von Mises stress (contribution < 1%, *P* > .05, Table II). Lower stress was noted in the SC compared to the MC (24.13 ± 0.63 vs. 54.91 ± 1.0 MPa; Fig. 2). Maximal stress appeared at the palatal side, under the flank of the first microthread. The stress distribution pattern differed between collar designs. Stress in the SC decreased in the apical direction, with a gradual curving pattern, whereas stress in the MC had a wavy pattern along the implant neck (Fig. 3).

Table II. ANOVA for von Mises stress in implant and for tensile stress, shear stress and strain in the cortical and trabecular bone.

	Implant		Cortical						Trabecular					
			Tensile Stress		Shear Stress		Strain		Tensile Stress		Shear Stress		Strain	
Parameters	*P*	%TSS	*P*	%TSS	*P*	%TSS	*P*	%TSS	*P*	%TSS	*P*	%TSS	*P*	%TSS
Collar Design	<.001	99.79	.01	96.43	<.001	99.86	.02	89.08	.69	0.27	.78	0.15	.36	6.69
Thread Design	.81	0.04	.65	1.26	.19	0.11	.43	6.16	.02	97.06	.03	96.92	.10	83.44
Error		0.17		2.31		0.03		4.76		2.66		2.94		9.86
Total		100		100		100		100		100		100		100

%TSS = total sum of squares.

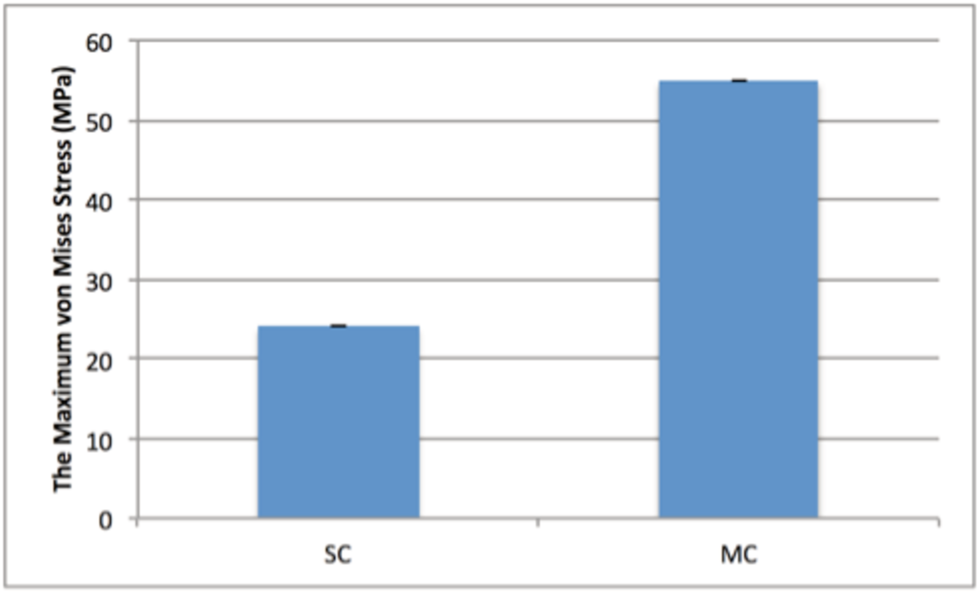

Fig. 2. Concentration of von Mises stress (MPa) in the implant for different collar designs.

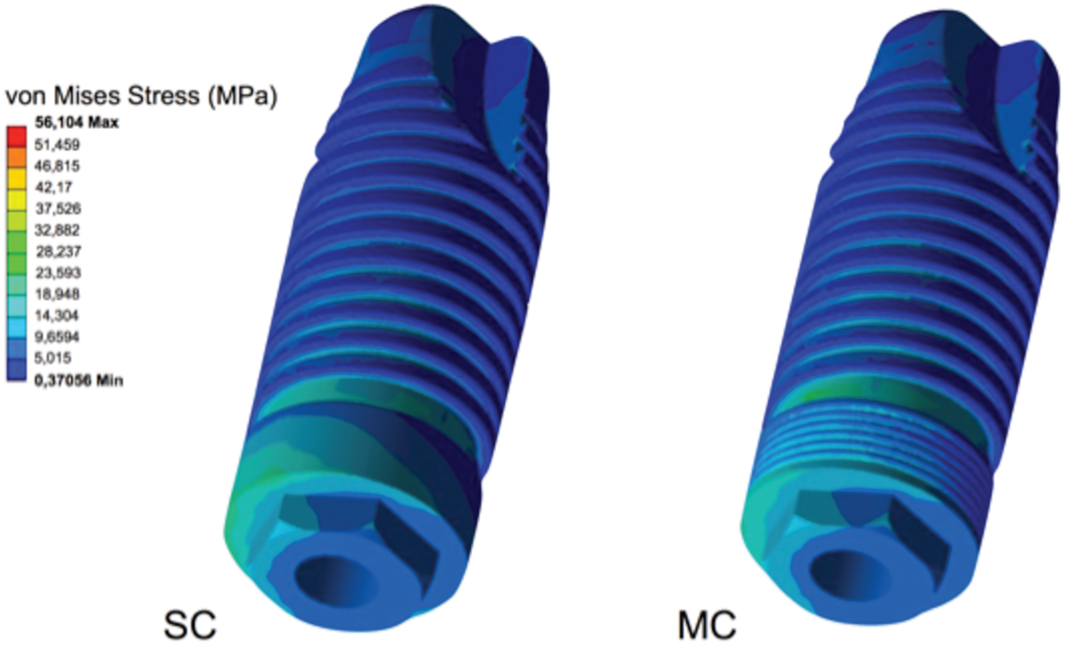

Fig. 3. Distribution of von Mises stress (MPa) in the implant with the trapezoidal thread shape for the smooth collar (SC) and microthread collar (MC) designs.

Stress/strain distributions in cortical bone

Collar design not only significantly affected tensile (*P* = .01) and shear (*P* = .001) stresses, but also influenced strain in the cortical bone (*P* = .02), with contributions of 96.43%, 99.86%, and 89.08% of the total generated tensile stress, shear stress, and strain, respectively. Thread design did not affect cortical bone (Table II). Maximal tensile stress was observed with the SC (11.16 ± 0.16 MPa), whereas maximal shear stress (11.98 ± 0.07 MPa) and strain ($0.97 \pm 0.07 \times 10^{-3}$ μm) were noted with the MC (Table III). The stress/strain distribution pattern in cortical bone differed between collar designs (Fig. 4).

The MC exhibited a uniform tensile stress concentration around the cortical bone, whereas the shear stress and strain distributions had heterogeneous patterns. Shear stress and strain concentrations were higher at the thread crest and lower at the thread base, thus creating a wavy pattern downward along the interface. Tensile stress in the SC exhibited a U-shaped pattern, whereas the shear stress and strain created uneven curves around the cortical bone (Fig. 4).

Table III. Tensile stress (MPa), shear stress (MPa) and strain (× 10^{-3} μm) values for the collar and thread designs in the cortical and trabecular bone (Mean ± SD).

Parameters	Cortical Bone			Trabecular Bone		
	Tensile stress	Shear stress	Strain	Tensile stress	Shear stress	Strain
Collar design						
Smooth	11.16±0.16	9.54±0.03	0.74±0.00	5.87±2.09	6.19±2.24	0.98±0.18
Microthread	9.07±0.31	11.98±0.07	0.97±0.07	6.05±2.16	6.33±2.18	1.04±0.11
Thread design						
Square	10.11±1.24	10.72±1.71	0.82±0.12	6.03±0.43	6.16±0.52	0.95±0.12
Trapezoidal	10.27±1.41	10.74±1.71	0.85±0.15	8.02±0.48	8.49±0.34	1.17±0.02
Triangular	9.98±1.79	10.81±1.77	0.90±0.22	3.83±0.34	4.14±0.47	0.90±0.04

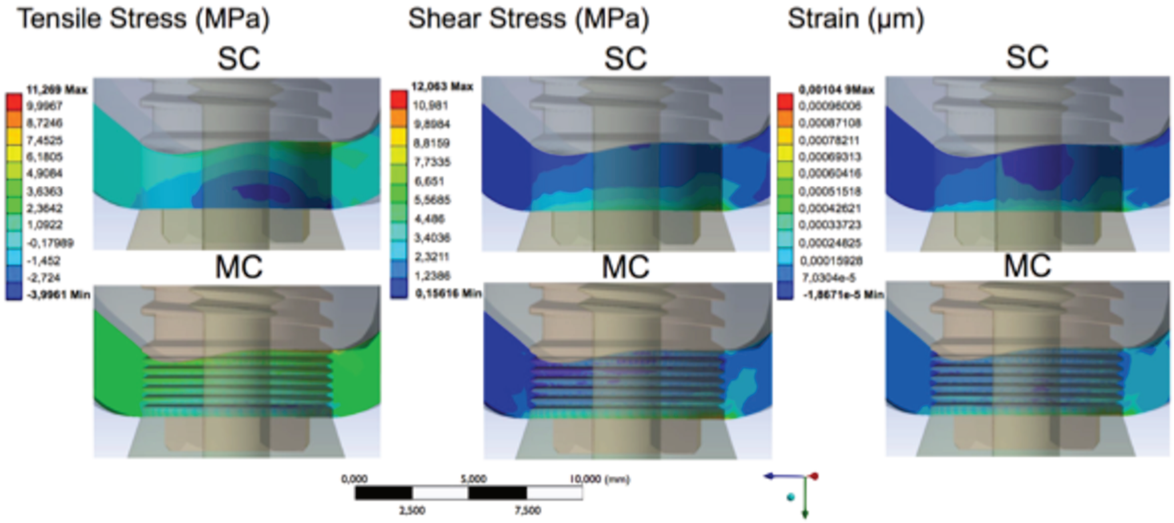

Fig. 4. Distribution of tensile stress (MPa), shear stress (MPa), and strain (µm) in the cortical bone for the trapezoidal thread-shaped implant with the smooth collar (SC) and microthread collar (MC) designs.

Stress/strain distributions in trabecular bone

In trabecular bone, the thread design significantly influenced the tensile and shear stresses (*P* < .05), but collar design had no influence. Thread design contributed 97.06% and 96.92% of the total generated tensile and shear stresses, respectively (Table II). The TR thread shape produced lower tensile stress (3.83 ± 0.34 MPa), shear stress (4.14 ± 0.47 MPa), and strain ($0.90 \pm 0.04 \times 10^{-3}$ µm) than the SQ and TP thread shapes, for which the stresses were twice those of TR (Table III). Stress and strain were observed in the areas surrounding the threads in the middle and apex of the implant. For all thread designs, the lowest stress values were observed at the bottom of the threads, represented by the thread base (Fig. 5).

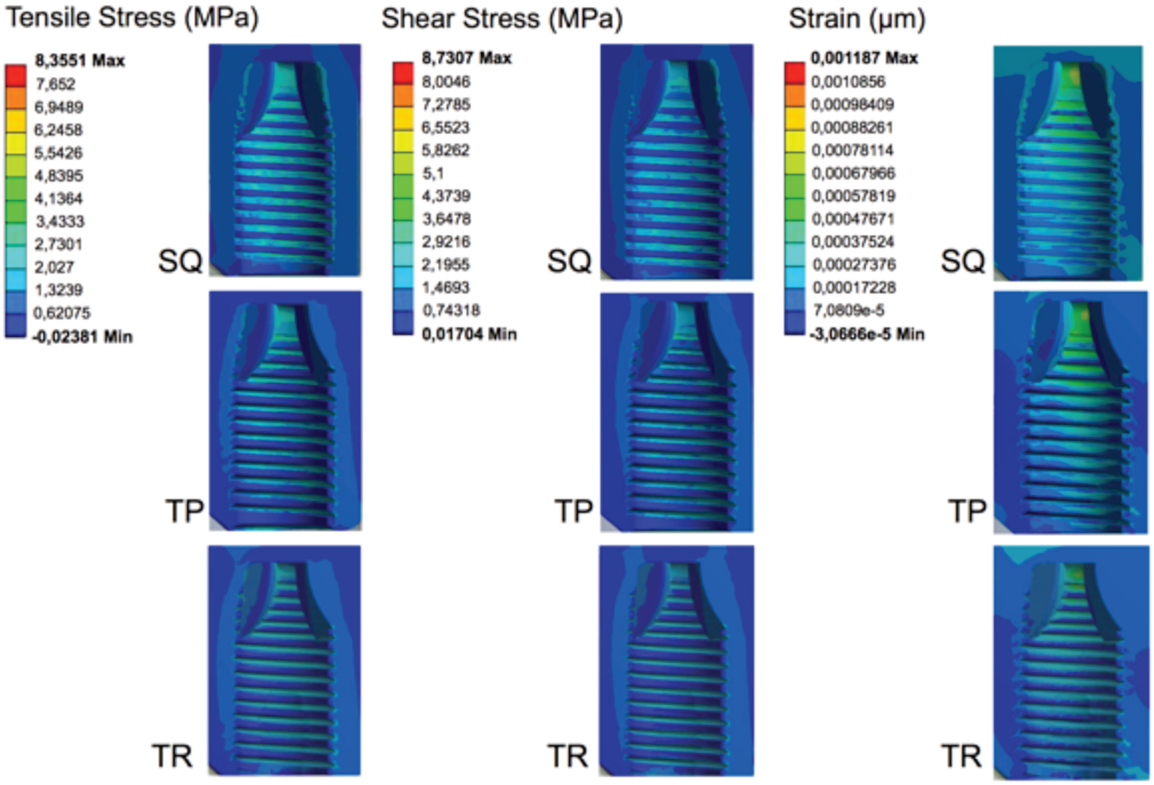

Fig. 5. Distribution of tensile stress (MPa), shear stress (MPa), and strain (µm) in trabecular bone for threads with square (SQ), trapezoidal (TP), and triangular (TR) shapes.

DISCUSSION

Several studies have investigated implant macro design, attempting to minimize crestal bone resorption and osseointegration loss after restoration by improving the stress/strain distribution at the marginal crest and in peri-implant bone.[1,15,27,32–34] To enhance the clinical success of maxillary implants, it is necessary to understand how the biomechanical behaviors of the implant and supporting bone are affected by different collar and thread designs, as well as to determine which parameters most contribute to the generated stress and strain. The present study used FEA with statistical analysis to interpret the biomechanical behavior of implants with different macro designs. The novelty of this study was the association of FEA methodology with the percentage contribution of the implant macro design.

Von Mises stress was significantly affected by collar design. The highest stress value was observed with the MC, and the stress distribution was characterized by a wavy pattern along the microthreads at the palatal side. A higher stress concentration was seen in the flank of the microthreads, with lower stress localized on top of them. This stress distribution pattern could have been influenced by the discontinuity of the microthreads.[26] Stress in the SC decreased from top to bottom, exhibiting a curved pattern. This decreasing stress was likely influenced by the decreasing functional surface area of the SC, which would have led to the dissipation of stress at the cervical region.[13,22]

Mechanical behavior of the peri-implant bone was evaluated on the basis of the tensile and shear stresses and strain.[38,41] Strain magnitude can provide particular insight into bone biomechanics, although few studies have used this criterion.[16,34] Bone responds to local mechanical stress and strain stimulation by a constantly modified modeling/remodeling process.[23,32] This study evaluated the magnitude and distribution of stresses and strain in the bone tissue under an occlusal load. Compared to the MC design, the SC design presented a higher tensile stress, which was concentrated in a small apical area of the cortical bone. Tensile stress was distributed throughout all of the cortical bone with values below 1.1 MPa (Fig. 4). However, the literature reports that 1.6 MPa of stress are needed to prevent disuse bone atrophy in cortical bone.[13,19,23,32] Therefore, bone loss around the SC is often a consequence of disuse atrophy, due to subnormal mechanical stimulation of the bone in accordance with Wolff’s Law.[13,23]

Clinical findings have confirmed that initial bone loss around an SC implant coincides with exposure of the implant to the intraoral environment in the second stage of surgery or after loading, and that the resorption pattern is V- or U-shaped (referred to as “saucerization”).[6] In the present study, the tensile stress distribution around the SC formed a U-shaped pattern, compatible with the crestal bone loss reported in the literature.[3,6] In contrast, for the MC, the magnitude of the tensile stress exceeded 1.6 MPa. Moreover, the tensile stress was concentrated uniformly around the cortical bone, exerting an optimal effect for stress distribution and maintaining the peri-implant marginal bone level.[18,32]

In cortical bone, greater magnitudes of shear stress and strain were observed with the MC compared to the SC. The effects of the microthreads as retentive elements can explain the increase of stress/strain in cortical bone.[26] Stress and strain tended to be more concentrated at the thread crest. Their magnitudes were decreased at the thread base, creating a heterogeneous stress/strain distribution pattern. The microthread-induced stress concentration in the cortical bone was analogous to the stress concentration in the implant. Specifically, when shear stress was higher in the microthread flank in the implant, it was lower in the cortical bone in the same area; whereas when shear stress was lower on the microthread crest, it was higher in the cortical bone. Hence, microthreads can control stress/strain transference from the implant to the cortical bone.

Moreover, microthreads at the implant neck can mechanically stimulate cortical bone, maintaining an appropriate level of stimulus.[4,13] Nonphysiological levels of stress will stimulate osteoclastic activities, resulting in microdamage and bone resorption.[14,22,23,31] In contrast, the SC does not provide sufficient stimulus to preserve the cortical bone.[23] The high stress concentrations at the thread crest induced by microthreads were considered to have a positive effect on the cortical bone, because moderate stress/strain levels were maintained. The mechanical stress theory states that mild overload at the thread crest triggers osteoblasts to initiate bone formation in the stressed area. Indeed, active bone formation at the thread crest has been demonstrated in experimental studies.[11,21,30] This theory is also consistent with clinical studies, which have shown that microthreads reduce cortical bone loss and stabilize the osseointegration process.[14,18,20]

The findings of this study showed that the thread design significantly influenced tensile and shear stresses only in trabecular bone, contributing more than 95% of the total stress. The SQ and TP thread shapes presented twice as much stress/strain as the TR thread shape. The lower stress levels produced by the TR thread shape can be explained by its smaller flank angle and smaller straight part at the bottom of the thread.[22,31] Lower stresses in trabecular bone reportedly can improve osseointegration and enhance bone-implant contact.[12,15,29] In trabecular bone, the stress/strain was localized at the top of the threads and apex of the implant, with lower concentrations at the thread base. Compared to other thread designs, the TR thread shape not only showed lower stresses near the top of the thread, but also a greater area of low stress on the thread base in contact with trabecular bone. Thus, this thread shape may be more appropriate for stress/strain dissipation in low-quality bone. Overall, the thread morphology played an important role in the stress concentration at the implant-bone interface.[17,22,31,37]

This study analyzed only a bonded bone-implant interface and axial loading. Studies have demonstrated that nonbonded contact surfaces and oblique loading influence stress/strain patterns in bone near the interface, producing doubled stresses and strains compared to a bonded interface and axial loading.[12,27,29] The effects of a nonbonded interface and oblique loading in the posterior maxilla need to be investigated.

From a biomechanical perspective, both the collar and thread designs are important factors affecting stress/strain in the surrounding tissue and implant osseointegration. The MC design can be suggested for the maintenance of cortical crestal bone. The TR thread shape showed the ability to decrease the stress concentration and better dissipate bone stresses in trabecular bone.

CONCLUSION

The presence of the MC design and TR thread shape positively influenced the biomechanical behavior of a single implant restoration anchored in posterior maxillary bone.

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CAPÍTULO 2*

Biomechanical effect of prosthetic connection and implant body shape in low-quality bone of upper posterior single implant-supported restorations

Short title: Prosthetic connection and implant shape influence the low-quality bone.

Camila Lima de Andrade DDS, MSc[a], Marco Aurélio Carvalho DDS, MSc[a]; Altair Antoninha Del Bel Cury, DDS, MSc, PhD[b]; Bruno Salles Sotto-Maior DDS, MSc, PhD[c]

[a] PhD Student, Department of Prosthodontics and Periodontology, Piracicaba Dental School, University of Campinas, Piracicaba, São Paulo, Brazil.
[b] Prosthodontics Professor, Department of Prosthodontics and Periodontology, Piracicaba Dental School, University of Campinas, Piracicaba, São Paulo, Brazil.
[c] Prosthodontics Professor, Department of Restorative Dentistry, Federal University of Juiz de Fora, Juiz de Fora, Minas Gerais, Brazil.

Corresponding author:
Altair Antoninha Del Bel Cury, Department of Prosthodontics and Periodontology. Piracicaba Dental School, University of Campinas. Avenida Limeira, 901. Zip Code: 13414-903. Piracicaba, São Paulo, Brazil. Phone: +55 19 21065294; Fax +55 19 2106-5211. E-mail: altcury@fop.unicamp.br

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ABSTRACT

Purpose: Dental implant macro geometry properties, such as the prosthetic connection and implant body shape, can influence the biomechanical behavior of the restoration. Using tridimensional finite-element analysis (3D-FEA), the current study evaluated the biomechanical behavior of two parameters of the implant macro design (prosthetic connection and implant body shape) in low-quality bone.

Material and Methods: Four groups were obtained by the combination of external hexagon (EH) and Morse taper (MT) connections, and cylindrical and conical body shapes. Implants (10 mm in length and 4 mm in diameter) with a microthread collar and triangular thread shape received a single abutment and monolithic zirconia crown on the upper first molar. Bone was constructed on the basis of cross-sectional images of the posterior human maxilla obtained by cone-beam computer tomography. A 200-N axial loading was distributed on five points of the occlusal surface. Data were analyzed as shear stress (τ_{max}, in MPa) and strain (ε_{max}, in μm) in the cortical and trabecular bone.

Results: The EH groups generated higher shear stress/strain values compared to MT groups in the cortical bone, regardless of implant body shape. In the trabecular bone, the highest τ_{max} and ε_{max} values were observed in the MT conical implant group (6.94 MPa and 21.926×10^{-4} μm, respectively), and the lowest values were observed in the EH cylindrical implant group (4.47 MPa and 9.3155×10^{-4} μm, respectively).

Conclusion: A single implant restored with an MT connection and cylindrical body shape showed improved biomechanical behavior in the peri-implant region of low-quality bone.

Keywords: dental implant, prosthetic connection, implant body shape, osseointegration, finite element analysis

INTRODUCTION

The biomechanical behavior of implants has been the subject of research in both dentistry and engineering fields, with the aim of providing high success rates in the rehabilitation of partially or totally edentulous patients.[1] Although the success rate can vary in different areas of the mouth and different patients, lower success rates have been associated with implants placed in the posterior maxilla and in sites characterized by thin cortical bone or low trabecular density.[2,3] The challenge of improving this scenario underlies scientific research to identify the implant macro design parameters involved in the stress/strain magnitude and to match the physiologic levels in peri-implant bone.[4,5] Excessive occlusal loads can induce microfracture at the bone-implant interface, implant fracture, screw loosening, or bone resorption.[6,7] In this context, the prosthetic connection and implant body shape may have major roles in dissipating the stress and strain that compromise osseointegration.[8]

Bone tissue responds differently depending on the load type.[9] Shear stress is considered to be the most harmful force to the bone.[10] Strain is harmful to the bone-implant interface because strain can cause micromotion, which can lead to osseointegrative failure.[11,12] Depending on the prosthetic connection and body shape, the force may vary in magnitude, concentration, and distribution.[7,13] Studies have been conduced to analyze these parameters in bone of higher density.[4,8,11,14,15] However, few studies have evaluated implant macro design parameters in low-quality bone. Therefore, the purpose of the present study was to investigate the magnitude and concentration of shear stress and strain in osseointegrated implants with different prosthetic connections and implant body shapes inserted in low-quality bone.

MATERIAL AND METHODS

Experimental Design

With the help of a computer-aided design software (SolidWorks 2014, SolidWorks Corporation, Concord, MA, USA), four groups of implants were modeled with two types of prosthetic connections (external hexagon [EH] and Morse taper [MT]) and two body shapes (cylindrical and conical), as shown in Fig 1. Implant dimensions were 10 mm in length and 4 mm in diameter. Implants had a microthread collar and triangular thread shape. Cortical and trabecular bone were modeled on the basis of a cross-sectional image of the human posterior maxilla acquired by cone-beam computer tomography, in order to simulate bone architecture in the region of interest. The thickness of cortical bone around the implant neck was set at 1.40 mm. Implant models received a single titanium abutment and cemented zirconia crown. They were positioned at the crestal bone level.

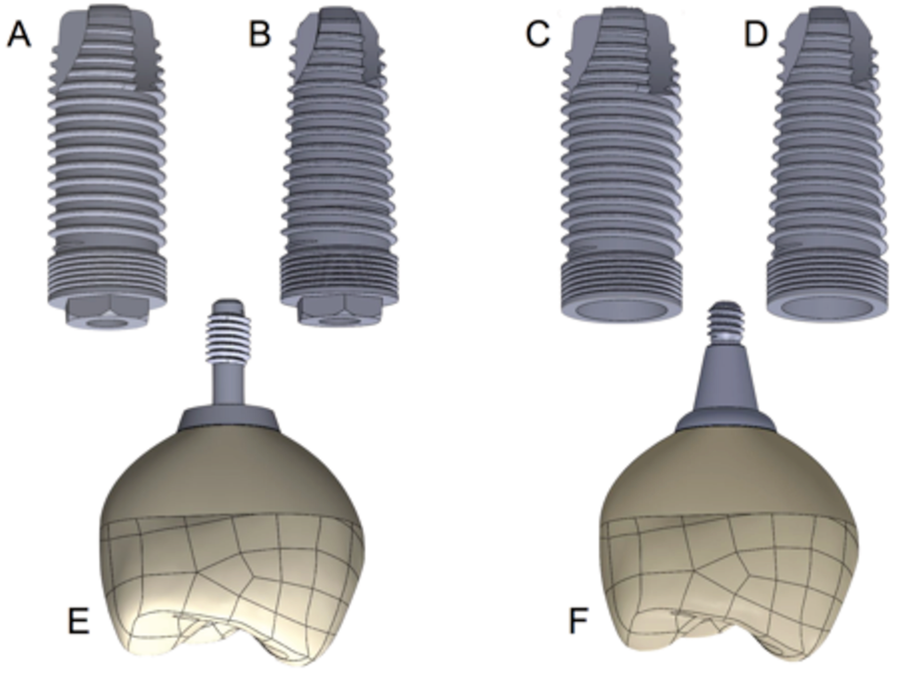

Fig 1 Schematic illustration of the four groups used in the study and their prosthetic components. (A-B) EH and (C-D) MT implants; (A-C) cylindrical and (B-D) conical

body shapes. Also shown are the zirconia crown, abutment, and abutment screw used for the EH (E) and MT (F) connections.

Numerical Analysis

For mesh acquirement and numerical analysis, all models were exported to a finite element analysis (FEA) software (Ansys Workbench 10.0 Swanson Analysis Inc., Houston, TX, USA). Convergence analysis (5%) was performed as a mesh refinement process to improve the accuracy of the results. The mesh was generated with 0.5-mm quadratic tetrahedral elements (Fig 2). Materials used in the current study were considered isotropic, homogenous, and linearly elastic, except for the cortical and trabecular bone that were assumed to be anisotropic. Mechanical properties of materials were taken from the literature (Table 1).

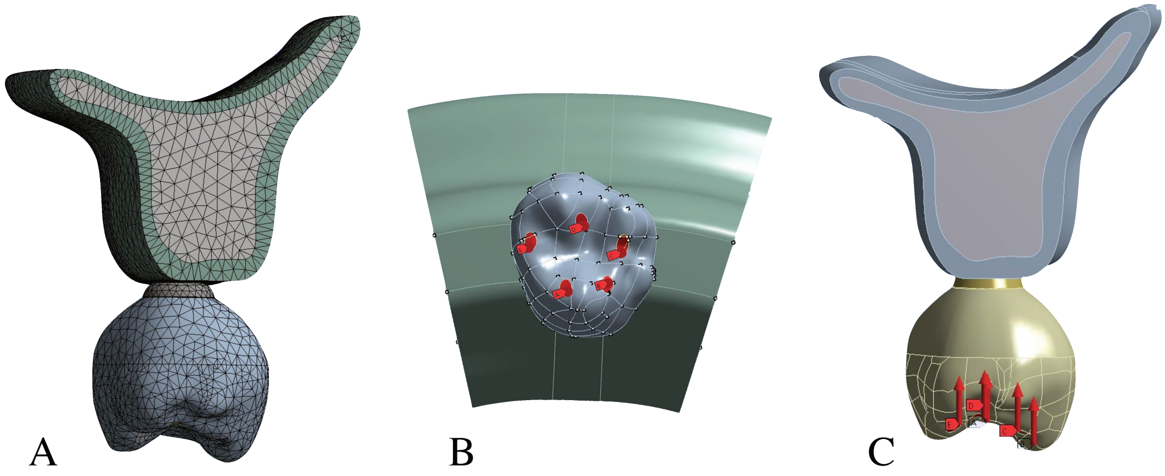

Fig 2 (A) Mesh generated manually with 0.5-mm elements after convergence analysis (5%). (B-C) Axial loading distributed on the occlusal surface of the zirconia crown.

Table 1 Properties of materials used in the FEA models.

	Young's modulus (E) (MPa)	Shear modulus (G) (MPa)	Poisson ratio (δ)
Cortical bone [16]	E_x 12,600	G_{xy} 4,850	δ_{xy} 0.30
	E_y 12,600	G_{yz} 5,700	δ_{yz} 0.39
	E_z 19,400	G_{xz} 5,700	δ_{xz} 0.39
Trabecular bone [14,16]	E_x 1,150	G_{xy} 6,800	δ_{xy} 0.001
	E_y 2,100	G_{yz} 4,340	δ_{yz} 0.32
	E_z 1,150	G_{xz} 6,800	δ_{xz} 0.05
Titanium (Implant and abutment)[17]	104,000	38,800	0.34
Cement[18]	17,000	14,500	0.30
Zirconia [19]	210,000	33,000	0.31

The subscripts x, y and z correspond to the axis of the global coordinate system

A bonded contact type between the bone and implant surfaces was used to simulate integration with the bone and with all other contact areas. Models were constrained in all directions at nodes on the mesial and distal borders of the bone segment. A 200-N axial loading was applied and distributed on five points of the occlusal surface of the crown (Fig 2). The magnitudes and distributions of the shear stress (τ_{max}, in MPa) and strain (ε_{max}, in μm) adjacent to the peri-implant interface were investigated for all models using tridimensional FEA (3D-FEA).

RESULTS

Higher shear stress/strain values in cortical bone were found in the EH groups compared to the MT groups. The EH groups showed three times the amount of shear stress/strain in cortical bone, regardless of the implant body shape (Table 2). The connection type also influenced shear stress/strain in trabecular bone, with lower magnitudes of shear stress/strain being observed in the

EH groups. In trabecular bone, the shear stress/strain values were higher in conical than in cylindrical implants (Table 2).

Table 2 Maximum shear stress (MPa) and strain values ($\times 10^{-4}$ μm) in the peri-implant bone in accordance with the type of prosthetic connection (EH and MT) and implant body shape (cylindrical and conical).

	Cylindrical		Conical	
Bone Response	EH	MT	EH	MT
Shear Stress				
Trabecular Bone	4.4755	5.0731	6.8529	6.9436
Cortical Bone	12.063	4.6433	12.444	4.773
Strain				
Trabecular Bone	9.3155	9.3675	21.753	21.926
Cortical Bone	10.49	3.5089	10.461	3.6207

In cortical bone, higher shear stress/strain values were found coronally adjacent to the implant-abutment interface. This effect was more evident in the EH than in the MT groups (Figs 3 and 4). In trabecular bone, the highest shear stress/strain values were concentrated in the thread crest and implant apex, especially in conical implants, whereas the lowest shear stress/strain values were found at the thread base (Figs 3 and 4).

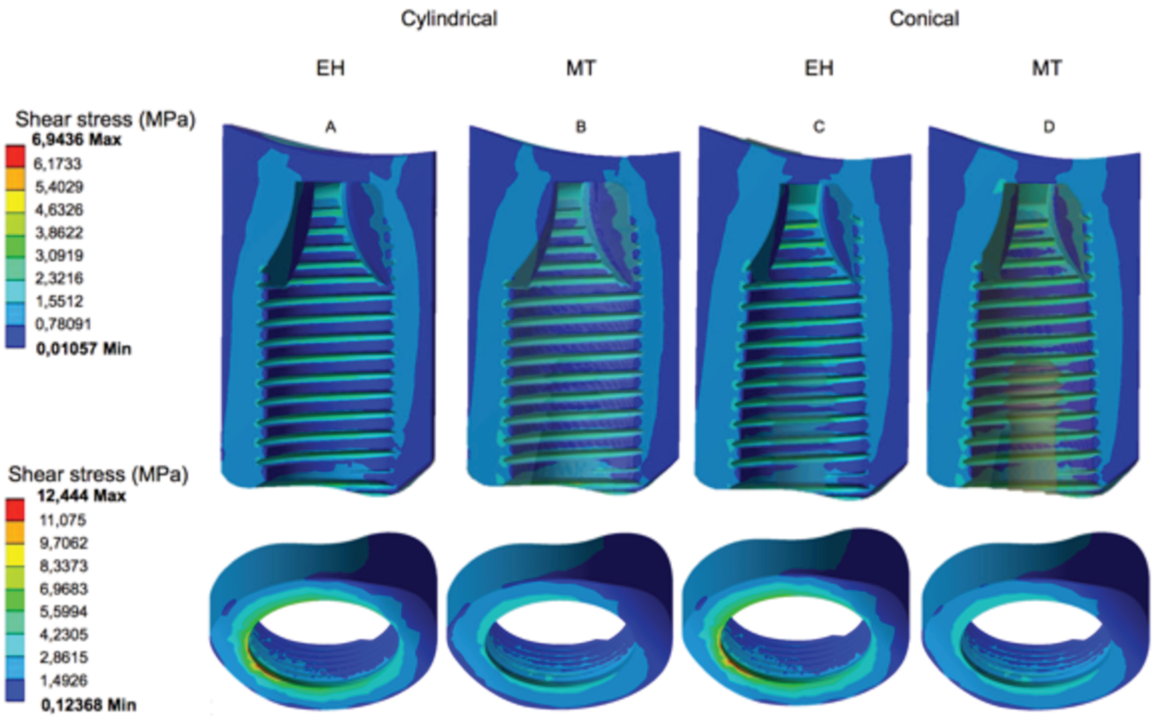

Fig 3 Shear stress in the trabecular (above) and cortical (below) bones in the four groups, with (A-B) cylindrical and (C-D) conical implant body shapes, and with (A-C) EH and (B-D) MT connections.

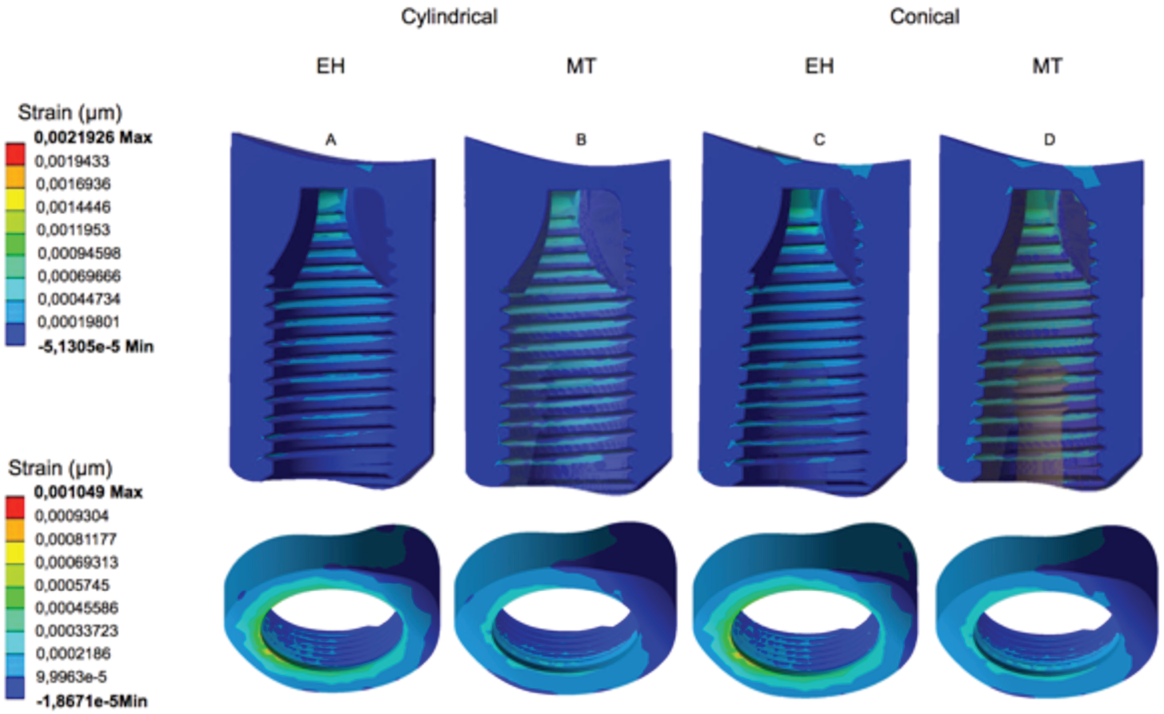

Fig 4 Strain in the trabecular (above) and cortical (below) bones in the four groups of implants, with (A-B) cylindrical and (C-D) conical implant body shapes, and with (A-C) EH and (B-D) MT connections.

DISCUSSION

FEA is a useful tool for obtaining internal biomechanical behavior in complex models that could not be evaluated by fatigue laboratory tests or clinical trials.[8] In this study, four 3D models with different prosthetic connections (EH and MT) and implant body shapes (cylindrical and conical) were constructed to evaluate shear stress and strain in low-quality (type IV) cortical and trabecular bone in the posterior maxilla. Most commonly, FEA studies only examine the effect of a single implant macro design parameter.[4,15] The results in this study highlight the importance of the interaction between these parameters on the biomechanical behavior of the peri-implant bone. Underestimating this interaction may compromise the interpretation of the results, which consist of a set of interrelated parameters. In this study, the type of prosthetic connection influenced the shear stress/strain in both cortical and trabecular bone, but the implant body shape affected shear stress/strain only in trabecular bone.

The EH connection type has been associated with higher rates of crestal bone resorption,[20] due to the higher stress generated at the cervical area, greater abutment micromovements, and formation of microgaps that lead peri-implant tissue inflammation.[8,11,21,22] In the present study, the EH groups provided three times the shear stress and strain on top of the marginal crestal bone compared to the MT groups. In previous biomechanical studies[7,11,21], the maximum stress and strain occurred at the top marginal surface of the bone in flat-top interfaces, such as EH connections, but more apically in conical interfaces, such as MT connections. The low shear stress/strain values found in the MT groups can be explained by the differences in the internal taper interface surface area when compared with straight interface and reduced hexagon size found in the EH groups. MT connection promotes better mechanical friction between the external wall of the abutment and internal wall of the implant, and no rotation of the abutment is observed. Therefore, the lateral wall of the abutment helps dissipate the vertical forces to the implant.[23] In contrast, EH connection presents some degree of freedom to micromovements owing to its reduced hexagon size. In addition, its higher rotation center promotes less resistance to rotation and creates a possible gap on the implant-abutment interface, which might lead to bone resorption.[23] Lower stress and strain at the cervical area have been shown to contribute to bone preservation, whereas higher stress at the tip area can be a risk factor for bone resorption,[21] as was observed in the present study for the EH connection.

Both prosthetic connections had a microthread collar on the implant neck. Microthreads, which were present on the cervical region of the implant in contact with cortical bone, may induce better dissipation of the occlusal load and help to preserve the peri-implant crestal bone. Clinical studies[24,25] support the notion that microthreads at the implant neck provide minimal bone resorption and stable peri-implant marginal bone around implants. The shear stress/strain concentrations were decreased in the thread crest and implant apex in trabecular bone with the EH connection, whereas the shear stress/strain concentrations were increased in these areas with the MT connection, regardless of the implant body shape.

The type of implant body design only influenced stress/strain in the trabecular bone. Cylindrical implants induced lower shear stress and strain than conical implants, although the conical implant presented better primary stability. Some FEA studies have revealed that cylindrical implants are more associated with low stress levels in trabecular bone, which leads to bone preservation.[3,5,12] The highest shear stress/strain concentrations were found in the thread crest and implant apex, especially in conical implants. This finding can be explained by the geometric discontinuities of the thread crest and the small radius of curvature in the apical region of the conical implant.[26]

However, in an FEA study by Huang et al.,[14] the stress was decreased in trabecular bone when a conical body shape was used. The authors attributed this effect to the increased thread depth in the conical body implant, which increased the interface area of the bone-implant contact. In the cylindrical implant, the authors used a lower thread depth. The difference in thread design between the implants could have masked the real effect of the implant body shape on the stress dissipation. In the present study, all of the implants were modeled with a similar thread depth. Therefore, the results were compatible with the real effect of the implant body shape and were not influenced by other implant macro design parameters. Changes in the depth and shape of the threads are important in the biomechanics and bone-implant interface.

FEA methodology has limitations because the biomechanical proprieties of biological tissues cannot reproduce in the cortical and trabecular bone regions considered to be bonded to the implant.[6]

CONCLUSION

The magnitudes of shear stress and strain in the peri-implant region of low-quality bone are improved when an MT connection and cylindrical implant are used, compared to an EH connection and conical implant.

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CONCLUSÃO

A partir dos resultados dos dois estudos, concluiu-se que os parâmetros da macrogeometria do implante que favorecem o comportamento biomecânico no implante e no tecido ósseo peri-implantar de baixa qualidade são colar com microroscas, conexão protética Cone morse, roscas de desenho triangular e formato cilíndrico no corpo do implante.

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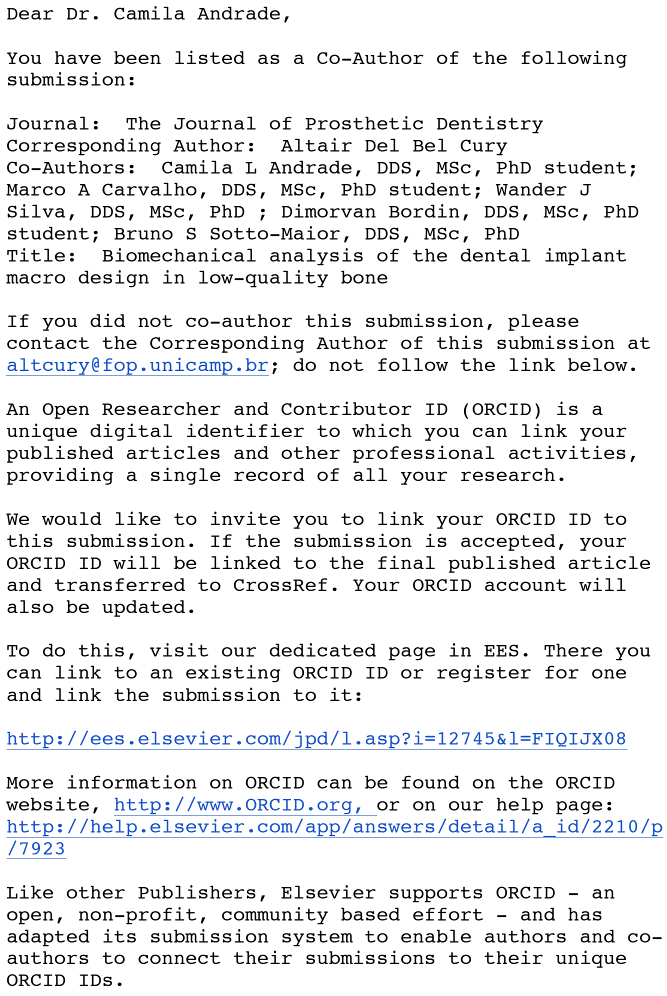
ANEXOS

ANEXO 1. Submissão do Manuscrito 1 para o periódico *The Journal of Prosthetic Dentistry.*



Dear Dr. Camila Andrade,

You have been listed as a Co-Author of the following submission:

Journal: The Journal of Prosthetic Dentistry
Corresponding Author: Altair Del Bel Cury
Co-Authors: Camila L Andrade, DDS, MSc, PhD student; Marco A Carvalho, DDS, MSc, PhD student; Wander J Silva, DDS, MSc, PhD ; Dimorvan Bordin, DDS, MSc, PhD student; Bruno S Sotto-Maior, DDS, MSc, PhD
Title: Biomechanical analysis of the dental implant macro design in low-quality bone

If you did not co-author this submission, please contact the Corresponding Author of this submission at altcury@fop.unicamp.br; do not follow the link below.

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ANEXO 2. Submissão do Manuscrito 2 para o periódico *The International Journal of Oral & Maxillofacial Implants.*

Progress and review history manuscript: 4133

Manuscript title: Biomechanical effect of prosthetic connection and implant body shape in low-quality bone of upper posterior single implant-supported restorations
Manuscript type: Original Article, Implants
All Authors: Camila Lima de Lima Andrade, Marco Aurélio de Carvalho, Altair Del Bel Cury, Bruno Salles Sotto-Maior,
Keywords: dental implant, prosthetic connection, implant body shape, osseointegration, finite element analysis

Submission number: **1**
Date Received: 2014-09-15
Status: **New Submission**

Weeks under review: 0
Requests sent: 0
Reviewers agreed: 0
Reviews completed: 0

Manuscript review document(s)
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Files associated with this submission:

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