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Platform switching: avaliação biomecânica por meio do Método de Elementos Finitos tridimensional

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Co-orientador: Prof. Dr. Edson Antônio Capello de Sousa

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Tabata LF. ***Platform switching*: avaliação biomecânica por meio do método de elementos finitos tridimensional [tese].** Araçatuba: Faculdade de Odontologia da Universidade Estadual Paulista; 2008.

RESUMO GERAL

Introdução e Justificativa. No tratamento com implantes osseointegrados, o tecido ósseo peri-implantar sofre um processo de aposição e reabsorção, durante o primeiro ano após a restauração protética. Tem sido relatado que a *platform switching* reduz a remodelação óssea esperada, muito embora os mecanismos responsáveis por este processo não estejam claramente elucidados.

Objetivo. O objetivo deste trabalho foi avaliar a distribuição de tensões no tecido ósseo peri-implantar, nos implantes e componente protéticos de coroa metalocerâmica implantossuportada, utilizando o conceito de *platform switching* e comparando-o com uma conexão regular *abutment*-implante, por meio do método de elementos finitos tridimensional (MEF-3D).

Material e métodos. Dois modelos 3D reproduziram uma conexão regular entre *abutment*-implante com componentes de mesmo diâmetro (grupo Plataforma Regular - PR) e uma conexão com o conceito de *platform switching* (grupo *Platform Switching* - PS). Um implante regular (plataforma protética de 4.1mm) e um implante largo (plataforma protética de 5.0mm) foram utilizados para representar PR e PS, respectivamente, nos quais um componente protético regular de 4.1mm foi conectado

para simular a coroa protética. Uma carga de 100N foi aplicada utilizando-se o programa ANSYS.

Resultados. PS diminuiu a concentração de tensões no implante quando comparado com PR, alterando a distribuição das tensões na plataforma protética, o que resultou em diminuição das tensões no parafuso e tecido ósseo e aumento das tensões na coroa.

Conclusões. *Platform switching* reduziu as tensões no tecido ósseo peri-implantar, o que pode resultar em uma diminuição da reabsorção óssea marginal. A utilização de componentes protéticos de menor diâmetro que a plataforma protética do implante diminuiu a concentração das tensões nos implantes e no parafuso, podendo resultar em uma diminuição das complicações nas próteses implantossuportadas parafusadas.

Palavras-chave: implantes dentários, análise de elementos finitos, prótese dentária fixada por implantes, biomecânica.

Implicação clínica. A utilização de *platform switching* diminuiu as tensões no tecido ósseo peri-implantar, o que pode resultar em uma diminuição da reabsorção óssea marginal. A diminuição da concentração de tensões no parafuso de retenção e no implante, podem refletir em um menor número de complicações clínicas relacionadas a soltura ou fratura do parafuso, fratura do implante ou ainda falha na osseointegração.

Tabata LF. **Platform switching: biomechanical evaluation using three-dimensional finite element analysis [thesis].** Araçatuba: UNESP - São Paulo State University; 2008.

GENERAL ABSTRACT

Statement of problem. After implant insertion and loading, crestal bone usually undergoes remodeling and resorption during the first year following prosthetic restoration. It has been reported that the platform switching seems to reduce or eliminate the expected postrestoration crestal bone remodeling, although the mechanisms responsible for this process are not yet clearly drawn.

Purpose. The objective of this study was to evaluate the stress distribution in peri-implant bone tissue, implants and prosthetic components of single crown implants-supported with the use of platform switching concept, using three-dimensional Finite Element Analysis (3D- FEA).

Material and methods. Two 3D finite element models reproduced a external hexagonal implant system with peri-implant bone tissue, in which a regular matching diameter connection of abutment-implant (Regular Platform group - RPG) and a platform switching connection (Platform Switching group - PSG) were simulated. A regular implant (prosthetic platform of 4.1mm) and a wide implant (prosthetic platform of 5.0mm) were used to represent the RPG and PSG, respectively, in which a regular prosthetic component of 4.1mm was connected to represent the crown. A load of 100N was applied on the models using ANSYS software.

Results. PSG diminished the stress concentration at the implant when compared to RPG by altering the stress distribution at the prosthetic platform of the implant, which results in a decrease of stress into the screw and supporting bone and an increase of stress in the crown.

Conclusions. Platform switching improved biomechanically the stress distribution in peri-implant bone tissue of implant system, which might result in a reduced marginal bone loss. The use of mismatching prosthetic components in relation to the implant prosthetic platform diameter seems to decrease stress concentration at implant and screw, which might represent less clinical complications.

Keywords: dental implants, platform switching, implant supported prosthesis, finite element analysis, stress distribution, crestal bone loss**.**

Clinical Implications. The use of platform switching concept decreased the stress concentration at the peri-implant bone tissue, which might result in a reduced marginal bone loss. The decreased stress concentration at the screw and implant might diminish clinical complications as screw loosening or fracture, implant fracture or osseointegration failure.

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MEF =	Método de elementos finitos
3D =	Tridimensional
PR =	Plataforma regular
PS =	*Platform switching*
N =	Newton
mm =	Milímetro
Co-Cr =	Cobalto-cromo
σ_{VM} =	Tensões de von Mises
σ_{T} =	Tensões de tração
σ_{C} =	Tensões de compressão
MPa =	Mega Pascal
JAI =	Junção *abutment*-implante

SUMÁRIO

1 INTRODUÇÃO

Desde a introdução da osseointegração, novas alternativas de tratamento protético surgiram para pacientes baseada na colocação de implantes endósseos de titânio em áreas edêntulas. A reposição de dentes através de implantes tem se tornado uma modalidade de tratamento previsível tanto para pacientes parcialmente, como completamente edêntulos.[1,2,3,4] Acompanhamento de próteses fixas sobre dentes naturais por 10 anos revelaram uma taxa de sucesso de aproximadamente 75%.[5] Em contraste, para os implantes osseointegrados essa taxa tem se mostrado maior que 90%,[6,7,8] com opções de tratamento se expandindo para incluir implantes com carga protética imediata, precoce e mediata, além de implantes pós exodontia dentária ou curtos. Entretanto, a técnica cirúrgica de 2 estágios e o carregamento tardio ainda é mais relevante. [9,10]

Um aspecto na terapia com implantes que apresenta grande desafio é a instalação de implantes e a subsequente restauração em áreas estéticas,[6] nas quais o nível do osso peri-implantar e as dimensões do tecido mole são fatores críticos para o resultado estético.[11] Técnicas cirúrgicas que envolvem a manipulação de tecido ósseo e tecido mole foram desenvolvidas com o intuito de favorecer o alcance do resultado ideal para o tratamento com implantes em áreas estéticas. A visão atual é de que a preservação de um tecido peri-implantar saudável a longo prazo é de primeira importância para assegurar função e estética por um período maior.[12]

Entretanto, após a instalação e carregamento do implante, a crista óssea sofre aposição e reabsorção durante o primeiro ano após a restauração protética.[12,13]

Observações radiográficas têm mostrado que após a conexão do *abutment*, inicia uma remodelação óssea, a qual se manifesta pela diminuição das dimensões do osso, tanto horizontalmente (1,3 a 1,4mm)[10,14] como verticalmente (1,5 a 2mm), na face vestibular do implante. Esta reabsorção da crista óssea geralmente coincide com a primeira rosca do implante[11] e pode prejudicar o resultado do tratamento, principalmente em casos estéticos nos quais as deficiências do tecido mole podem criar coroas que aparentam ser maiores que desejadas,[6] já que o suporte da papila gengival depende do osso subjacente.[10]

É crítico também, em áreas onde implantes curtos são usados,[12] principalmente na região posterior da mandíbula, que devido à presença do canal mandibular, muitas vezes associado à pequena quantidade óssea presente nessa região devido à atrofia do rebordo após a perda dos dentes posteriores, não possibilita a instalação de implantes longos. Nesta região, qualquer reabsorção óssea representaria uma diminuição ainda maior na superfície de contato entre osso-implante, podendo ocasionar falha no implante ou na osseointegração.

Os fatores envolvidos no mecanismo de reabsorção e deposição óssea ao redor dos implantes ainda não estão completamente elucidados[15] e diversas teorias existentes tentam explicar as mudanças observadas na altura da crista óssea após a instalação da prótese sobre implante.[16,17] O estabelecimento de um espaço biológico,[12,18,19,20,21] a localização do infiltrado inflamatório,[17,22] a distância da junção *abutment*-implante (JAI) em relação à crista óssea,[21,23,24] o biotipo gengival[25] e a concentração de tensões no tecido ósseo peri-implantar devido a cargas oclusais[7,15,26-36] são algumas dessas hipóteses.[12]

Tem sido relatado que a *platform switching* (PS) parece reduzir ou eliminar a remodelação esperada da crista óssea após a inserção da restauração.[4,6,10,13,17,36,37] O conceito de *platform switching* apresentado por LAZZARA e PORTER (2006) consiste na colocação de componentes protéticos de menor diâmetro em implantes de maior diâmetro e foi baseado em observações radiográficas feitas durante um período de 13 anos. Observações radiográficas sugerem que o processo biológico pós-restauração pode ser alterado quando a borda externa da interface *abutment*-implante é deslocada horizontalmente para o centro e distante da borda externa da plataforma do implante.[6,10,11,17,37] Os resultados de estudos histomorfométricos indicam que PS pode preservar o tecido ósseo peri-implantar e prevenir a reabsorção óssea[13] e pode limitar também o deslocamento apical da barreira epitelial.[4]

A possibilidade de reduzir ou eliminar a perda da crista óssea seria uma grande conquista da implantodontia. Benefícios clínicos como uma estética superior, melhor contato entre implante-osso e aumento da estabilidade primária poderiam ser obtidos com *platform switching*.[37]

2 PROPOSIÇÃO

Dessa forma, o objetivo desse trabalho foi avaliar a distribuição de tensões no tecido ósseo peri-implantar, nos implantes e componentes protéticos de coroas metalocerâmicas implantossuportadas, utilizando o conceito de *platform switching* e comparando-o com uma conexão regular *abutment*-implante, por meio do método de elementos finitos tridimensional (MEF-3D).

3 MATERIAL E MÉTODO

Uma conexão regular entre *abutment*-implante com componentes de mesmo diâmetro (grupo Plataforma Regular - PR) e uma conexão com o conceito de *platform switching* (*Platform Switching* – PS) foram simuladas por dois modelos 3D, os quais reproduziram um sistema de implante de hexágono externo e o tecido ósseo peri-implantar. Um implante regular, com plataforma protética de 4.1mm e 10.0mm de comprimento (SIN, Sistema de Implantes, São Paulo, SP, Brasil) e um implante largo, com plataforma protética de 5.0mm e 10.0mm de comprimento (SIN, Sistema de Implantes, São Paulo, SP, Brasil) foram utilizados para representar PR e PS, respectivamente, nos quais um componente protético regular de 4.1mm tipo UCLA (SIN, Sistema de Implantes, São Paulo, SP, Brasil) foi conectado para simular a coroa protética (Figura 1).

***Design* dos modelos**

A modelagem 3D foi realizada no *software SolidWorks* (SolidWorks Corporation, MA, USA). Uma coroa metalocerâmica em formato tronco-cônica, foi modelada com dimensões de 8mm em altura e 8mm em seu maior diâmetro.[38] O tecido ósseo peri-implantar assumiu 16mm em altura e 11mm em largura, o osso cortical na região da crista com 1,3mm de espessura e o osso trabecular com 13,4mm em altura.[39] Os modelos foram posteriormente exportados para o programa de elementos finitos (Ansys WorkBench 11, Swanson Anlysis System, Houston, Pa, USA), no qual foram atribuídas as propriedades mecânicas das estruturas dos modelos, geradas as malhas de elementos finitos e aplicado o carregamento para realização da análise.

Condições de interface, contorno e carregamento

O implante foi rigidamente ancorado ao tecido ósseo ao longo de toda sua interface. O mesmo tipo de contato foi estabelecido na interface prótese-*abutment*. Todos os materiais foram considerados homogêneos e isotrópicos.[34] As propriedades mecânicas dos materiais (Módulo de Elasticidade e Coeficiente de Poisson) foram baseadas na literatura[40,41,42] (TABELA 1). Em ambos os modelos as condições de contorno foram determinadas na região inferior do tecido ósseo e em suas faces proximais.

Para avaliar a distribuição de tensão no tecido ósseo peri-implantar, nos implantes e componentes protéticos, uma carga vertical de 100N[43] foi aplicada no lado vestibular da superfície oclusal da coroa, compatível com a região de uma cúspide de contenção.

Elementos e nós

Para obtenção dos mapas de tensões, foram geradas as malhas de elementos finitos para os modelos a partir de elementos tetraédricos com dimensão de 0,5mm. Os modelos finais tiveram um total de 158.596 nós e 89.158 elementos para o modelo Plataforma Regular (PR) e 145.212 nós e 80.766 elementos para o modelo *Platform Switching* (PS) representado na figura 2.

Após a atribuição das propriedades mecânicas, geração da malha de elementos finitos e determinação do carregamento, os dados numéricos produziram gráficos coloridos para melhor comparação dos modelos. Os dados obtidos foram avaliados de acordo com Tensões Equivalentes (von Mises, σ_{VM}) e Tensões Principais Máxima (tração, σ_T) e Mínima (compressão, σ_C).

4 RESULTADO

Distribuição das tensões nos modelos

Os dados obtidos do programa de elementos finitos produziram os mapas de tensões com escala de cor nos quais é possível comparar a distribuição de tensões nas diferentes estruturas em ambos os modelos (tecido ósseo peri-implantar, implante, parafuso e coroa). Os valores da escala dos mapas de tensão foram padronizados para uma melhor comparação qualitativa (visual) (Figura 3), e os valores de tensão mensurados foram convertidos em gráficos para Tensões Equivalentes (von Mises), Tensões Principais Máxima (tração) e Mínima (compressão), para uma melhor comparação quantitativa (Figuras 4 e 5) da concentração das tensões nas estruturas dos modelos.

As tensões concentraram-se sob o lado da aplicação do carregamento dos modelos. Os implantes apresentaram os maiores valores de tensões em comparação as demais estruturas dos modelos. Analisando os gráficos de tensões equivalentes e principais a dispersão foi semelhante para as tensões de von Mises (σ_{VM}), de tração (σ_T) e de compressão (σ_C), sendo que o uso de *platform switching* diminuiu a concentração das tensões no tecido ósseo, implante e parafuso e aumentou a concentração das tensões na coroa.

Distribuição das tensões no tecido ósseo peri-implantar

Analisando o tecido ósseo peri-implantar os maiores valores de tensões se localizaram na região do osso cortical peri-implantar. Comparando o padrão de distribuição entre os modelos foi possível observar que a transmissão de tensões em PR foi mais intensa e sobre uma maior área quando comparado com o modelo PS, que diminuiu a concentração das tensões no osso cortical (Figura 6).

Distribuição das tensões nos implantes e componentes protéticos

Os valores de tensões foram mais elevados nos implantes do que no tecido ósseo, parafuso e coroa para ambos os modelos. Comparando a distribuição das tensões nos implantes foi possível observar que a concentração das tensões foi maior no modelo PR e localizou-se na periferia da plataforma protética, ao nível do osso cortical e também no pescoço do implante. PS apresentou menores valores de tensões e a concentração das tensões localizou-se mais próxima ao centro da plataforma protética do implante, distante da interface de contato com o osso cortical.

Nos parafusos de retenção as tensões concentraram-se ao longo das roscas e no pescoço dos parafusos, nos quais as tensões de tração foram maiores que as compressivas. PR também apresentou maiores valores de tensões nos parafusos quando comparado com PS. Para a coroa protética, PS apresentou maiores valores de tensões, as quais se localizaram na parte inferior da coroa, na interface de contato com a plataforma protética do implante (Figuras 7 e 8).

5 DISCUSSÃO

Esse estudo avaliou qualitativa e quantitativamente a distribuição das tensões no tecido ósseo peri-implantar, nos implantes e componentes protéticos de uma coroa metalocerâmica implantossuportada, testando o conceito de *platform switching* e seus possíveis efeitos por meio de uma avaliação biomecânica.

Apesar do fato das soluções obtidas por métodos numéricos necessitarem sempre ser cuidadosamente avaliadas sob o ponto de vista dos testes experimentais, parece ser razoável explorar esta abordagem pela possibilidade de avaliar dados que não são mensurareis experimentalmente, a fim de agregar e complementar as informações obtidas de testes *in vivo* e *in vitro*. O desenvolvimento de modelos numéricos possibilita a avaliação do comportamento mecânico do sistema osso-implante-prótese estimando variáveis fundamentais, como a tensão e deformação do tecido ósseo e também investigando um grande número de circunstâncias operacionais.[43]

Entretanto, a lacuna entre o ambiente mecânico que leva a falha do implante e a condição sob a qual o osso se adapta através da reabsorção óssea ainda não está claramente descrita na literatura.[34] Mesmo assim os modelos são úteis para interpretações preliminares da interação implante-*abutment*.[43]

Diversas teorias existem para esclarecer as mudanças observadas na altura da crista óssea após a restauração sobre implante,[17] entretanto isso ainda não foi elucidado.[36] Os níveis da crista óssea são dependentes da localização da JAI em relação à crista óssea,[37] já que foi demonstrado que quando a JAI é posicionada mais profunda no osso, uma maior reabsorção da crista óssea ocorre.[13,21] A razão para a remodelação óssea na presença de um *microgap* não é conhecida, mas pode estar relacionada com a presença de contaminação bacteriana na interface *abutment*-implante ou a micromovimentação nessa interface. Esse espaço entre *abutment*-implante pode ser um reservatório de bactérias, as quais poderiam causar inflamação do tecido mole peri-implantar.[33]

O deslocamento interno da borda da junção *abutment*-implante na configuração PS também desloca o infiltrado inflamatório celular para o centro, distanciando-o da crista óssea. Isso limita a reabsorção óssea ao redor da porção coronal do implante.[10]

Também tem sido reportado na literatura que a reabsorção da crista óssea está relacionada com a sobrecarga e o dano na interface do tecido ósseo peri-implantar.[15] Uma carga excessiva pode provocar reabsorção óssea devido à produção de microdanos com a formação de defeitos ósseos crateriformes laterais aos implantes.[33] Esse microdano ao tecido ósseo também pode ser iniciado pela concentração de tensão e tensão de cisalhamento no pescoço do implante.[27,34,35]

Analisando os resultados obtidos no presente trabalho pode-se observar que esses estão em parte em concordância com os da literatura uma vez que foi possível notar dois fatos interessantes. O primeiro foi que a PS diminui os valores de tensão e também a concentração de tensões no tecido ósseo peri-implantar (FIGURAS 4, 5 e 6) em comparação com a PR. A segunda observação foi que a concentração das tensões sobre a plataforma protética do implante foi deslocada internamente, distanciando-se da interface osso-implante (FIGURA 7). Resultados semelhantes foram encontrados por Maeda et al. (2007) que avaliaram as vantagens biomecânicas da *platform* *switching* usando diferentes diâmetros de componentes protéticos em implantes regulares.

Esta diferença na distribuição das tensões deve ser provavelmente a explicação biomecânica do porque a *platform switching* parece reduzir ou eliminar a reabsorção esperada da crista óssea, observada em estudos clínicos.[6,10,11,17,37] Com uso de um implante mais largo em PS, menores tensões foram verificadas, as quais estavam concentradas distantes da interface osso-implante (FIGURAS 4, 5 e 7). Com isso, uma menor concentração de tensões foi transmitida ao tecido ósseo peri-implantar (FIGURAS 4, 5 e 6), o que pode diminuir microdanos resultando em menor reabsorção óssea.

Outra possível explicação para a eficácia da *platform switching* se baseia na distância entre a superfície óssea e a área de concentração das tensões na plataforma protética do implante, a qual coincide com a região de contato com a coroa protética (FIGURA 7). Como os microrganismos são mais propensos a se deslocar para áreas de grande concentração de energia, é vantajoso ter uma maior distância entre a área de concentração de tensões e o tecido ósseo.[33,36]

Ao avaliar a distribuição das tensões no parafuso de retenção foi possível observar que as tensões concentraram-se no pescoço e ao longo das roscas dos mesmos (FIGURA 8). Analisando os gráficos foi possível observar que os valores das tensões de tração foram maiores que os de compressão, sendo mais elevadas em PR do que em PS (FIGURAS 4 e 5). Maeda et al. (2007) afirmaram que um aumento das tensões no parafuso poderia causar problemas como deformação do componente caso seu limite elástico fosse ultrapassado. Os autores encontraram maiores valores de tensões para os parafusos na configuração de *platform switching*, diferente dos resultados obtidos no presente estudo. Tal diferença pode ser atribuída ao desenho do parafuso de retenção e da coroa protética, que no estudo de Maeda et al. (2007), que foram representados como uma estrutura única, não permitindo a avaliação individual de cada estrutura, como realizado no presente estudo (FIGURAS 7 e 8). Outro fator importante que pode ter diferenciado os resultados reside na representação das roscas dos implantes e dos parafusos, representadas somente neste trabalho, e que, segundo Natali et al. (2006) têm papel de destaque na manutenção da capacidade de assimilação das cargas oclusais pelos implantes. Clinicamente, uma diminuição da concentração das tensões nos parafusos com emprego de *platform switching* é benéfica, pois pode resultar em uma diminuição das complicações nas próteses implantossuportadas parafusadas, como soltura ou fratura do parafuso.

Analisando os mapas de tensões com relação às coroas protéticas, foi verificado que a concentração das tensões em PS foi maior do que em PR, as quais se localizaram na região inferior da infra-estrutura metálica da coroa, na superfície de contato com a plataforma protética do implante (FIGURAS 4, 5 e 7). O uso de *platform switching* aumentou as tensões na coroa provavelmente pela utilização de um implante mais largo, que ofereceu maior resistência estrutural e menor transmissão das tensões as estruturas adjacentes, as quais se concentraram na região inferior da coroa. O aumento das tensões não representaria uma complicação mecânica, uma vez que os valores de tensões (σ_{VM} = 67,9MPa, σ_T = 50,7MPa, σ_C = 86,6MPa) verificados encontram-se muito abaixo do limite de escoamento da liga de Co-Cr (que pode variar de 552 a 1034MPa),[40] utilizada na representação da infra-estrutura metálica da coroa.

Não obstante, como consequência da aplicação de carga, os implantes devem ser capazes de transferir a ação induzida ao tecido ósseo peri-implantar, assegurando a capacidade de resistência do sistema.[43] A funcionalidade das próteses fixas requer o respeito dos limites de resistência dos implantes e dos componentes protéticos,[43] mas também o entendimento de outras propriedades mecânicas relacionadas ao tecido ósseo são necessárias, já que este deve suportar os efeitos das cargas oclusais.[43] Dessa forma, os resultados deste estudo indicam que a *platform switching* parece melhorar a transmissão de carga para o implante, parafuso e para o tecido ósseo peri-implantar.

Bozkaya et al. (2004) avaliaram a característica da transmissão de cargas em 5 diferentes sistemas de implantes e estabeleceram um critério para avaliação da sobrecarga no tecido ósseo baseado nas tensões de escoamento do osso cortical, que tem sido reportado como sendo maior sob compressão (170MPa) do que em tração (100MPa). Neste estudo, a concentração das tensões em ambos os grupos ficou abaixo do valor limite de escoamento do tecido ósseo, sendo maior para PR (σ_C = 54,9MPa e σ_T = 13,6MPa) do que PS (σ_C = 20,3MPa e σ_T = 5,44MPa) (FIGURA 5). Estes resultados têm importante relevância clínica, uma vez que Cullinane e Einhorn (2002) afirmaram que mesmo cargas abaixo dos valores limites de escoamento podem causar falhas no tecido ósseo, nos quais microdanos ao osso não podem ser reparados.

Entretanto, ainda faltam informações para definir as propriedades mecânicas do tecido ósseo e correlacioná-las com seu rearranjo estrutural frente aos estímulos mecânicos-biológicos em função do tempo. A relevância operacional e a confiabilidade dos métodos matemáticos no estudo do comportamento biomecânico dos implantes osseointegráveis, necessitam de uma abordagem mecâno-clínica para um maior aprendizado nessa linha de pesquisa.[43]

Outros trabalhos com MEF-3D avaliando diferentes diâmetros de *abutments* protéticos (regular e largo) em implantes largos devem ser realizados para estudar a influência e o efeito dos implantes largos na distribuição das tensões na configuração de *platform switching*. Além disso, o desenvolvimento de experimentos em animais e triagens clínicas longitudinais é necessário para validar os achados biomecânicos deste estudo.

6 CONCLUSÃO

Baseado nos resultados obtidos e dentro das limitações desse estudo foi possível concluir que:

- *Platform switching* reduziu as tensões no tecido ósseo peri-implantar, o que pode resultar em uma diminuição da reabsorção óssea marginal.
- A utilização de componentes protéticos de menor diâmetro que a plataforma protética do implante diminuiu a concentração das tensões nos implantes e no parafuso, podendo resultar em uma diminuição das complicações nas próteses implantossuportadas parafusadas, como soltura ou fratura do parafuso, ou ainda fratura do implante.

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TABELA

Tabela 1. Estruturas e propriedades dos materiais usados nos modelos.

Materiais	Módulo de Elasticidade (GPA)	Coeficiente de Poisson	Referências
Osso Cortical	13.70	0.30	Sevimay et al., 2005
Osso Trabecular	1.37	0.30	Sevimay et al., 2005
Titânio (Ti-6Al-4V)	103.40	0.35	Sertgoz e Gunever, 1996
Liga de Co-Cr	218.00	0.33	Sevimay et al., 2005
Porcelana Feldspática	64.00	0.25	Yi e Kelly, 2008

FIGURAS

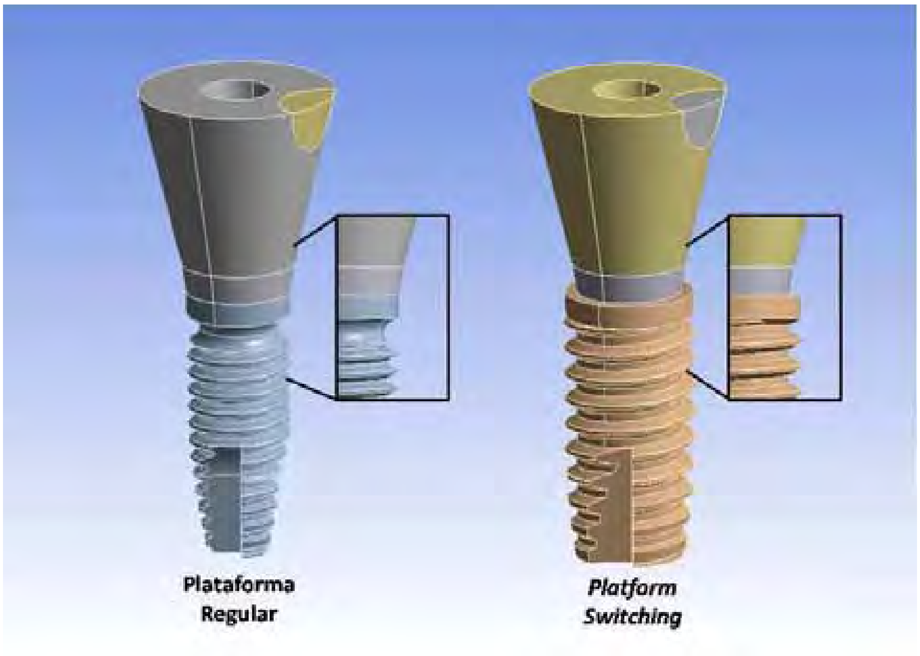

Figura 1. Modelos 3D da junção *abutment*-implante dos grupos PR e PS.

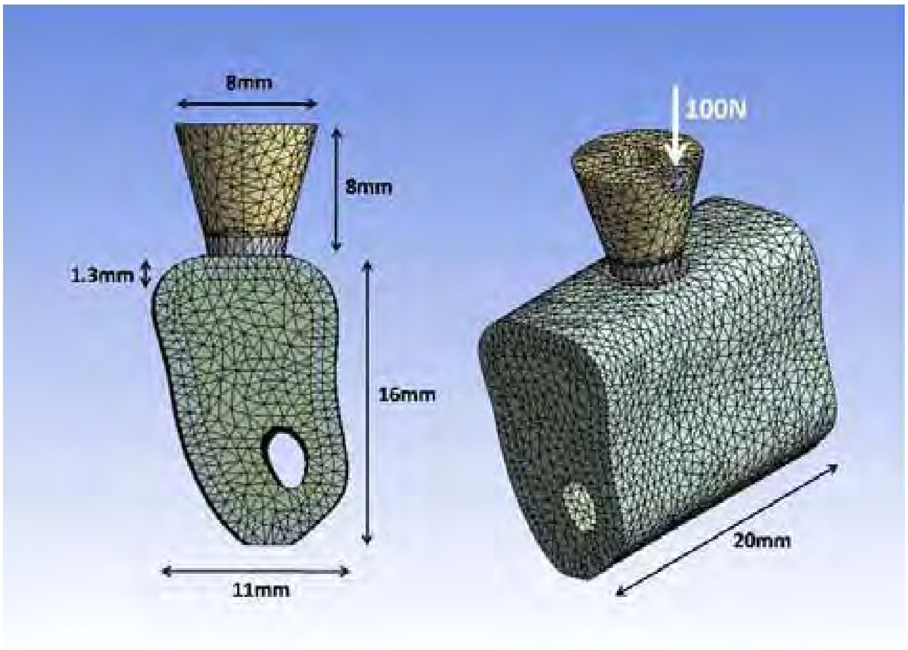

Figura 2. Vista frontal e obliqua da malha de elementos finitos do modelo PS (158.596 nós e 89.158 elementos).

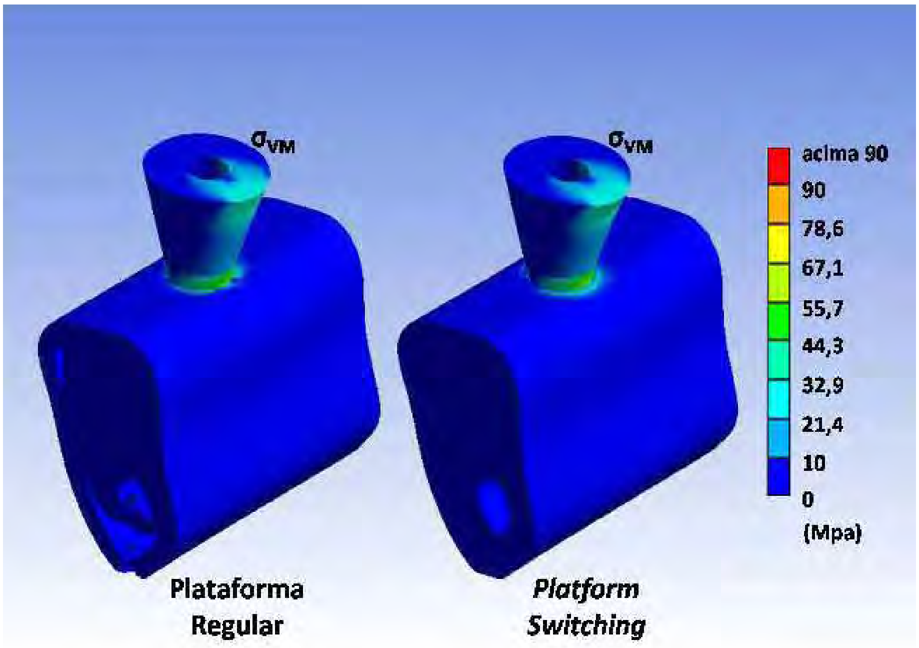

Figura 3. Distribuição das tensões de von Mises (σ_{VM}) nos modelos PR e PS.

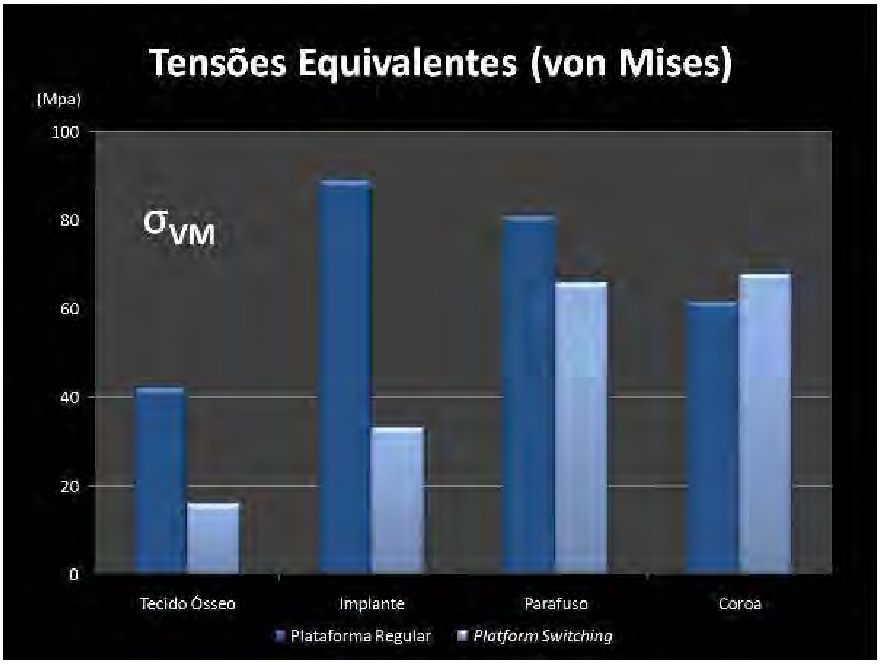

Figura 4. Valores de tensões de von Mises (σ_{VM}) no tecido ósseo, implante, parafuso e coroa para os modelos PR e PS.

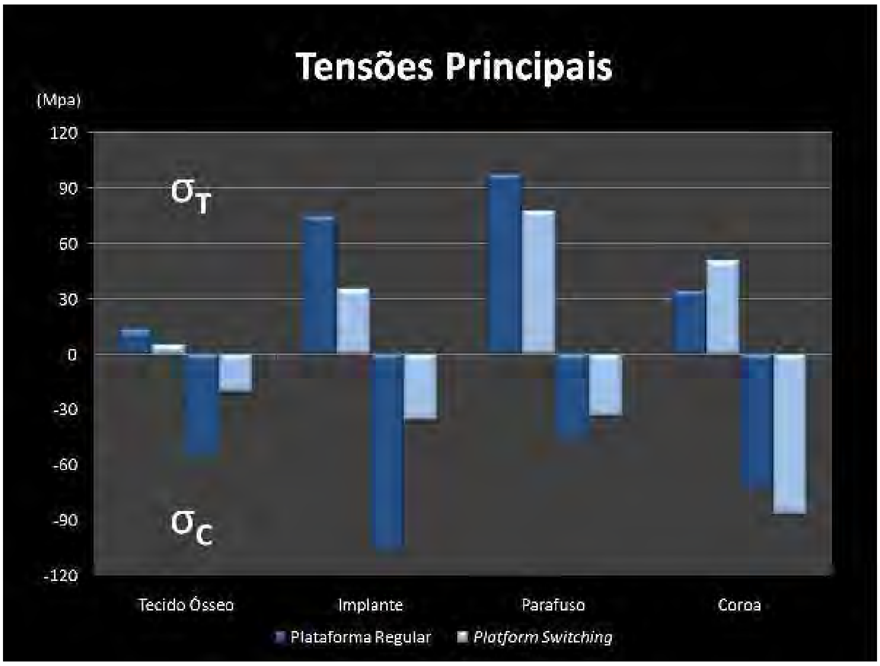

Figura 5. Valores de tensões principais máxima (σ_T, tração) e mínima (σ_C, compressão) no tecido ósseo, implante, parafuso e coroa para os modelos PR e PS.

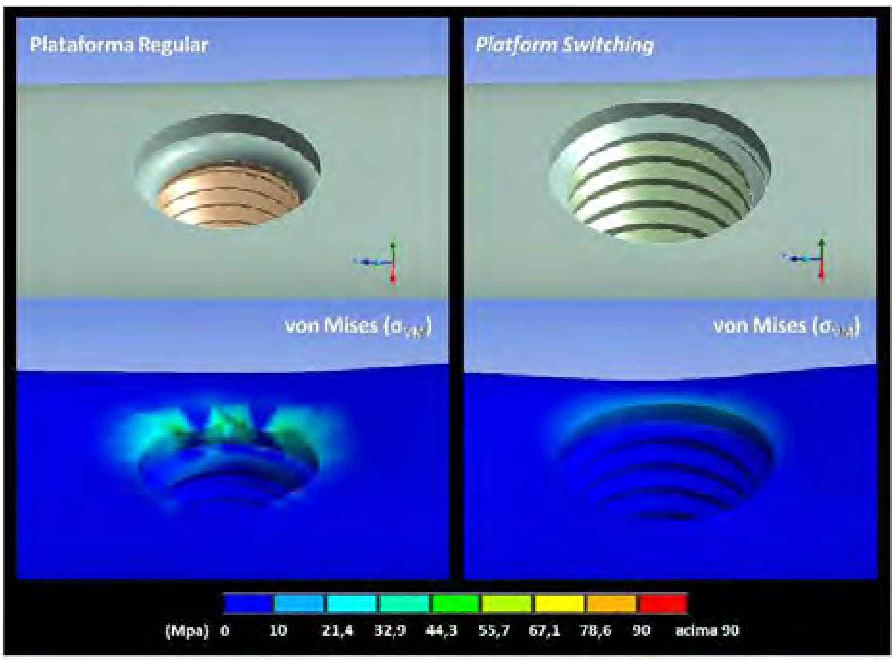

Figura 6. Distribuição das tensões de von Mises (σ_{VM}) no tecido ósseo dos modelos PR e PS.

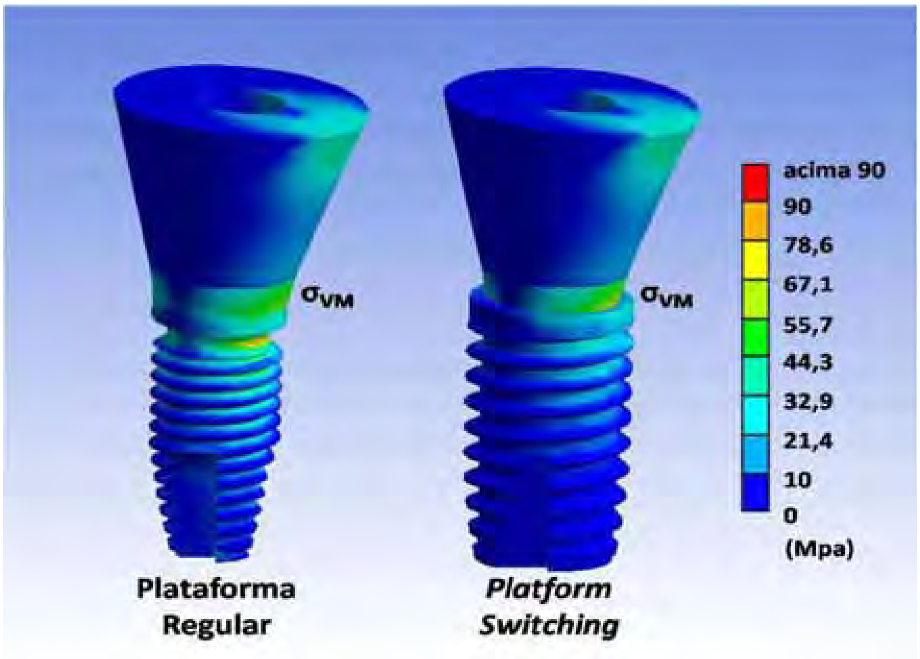

Figura 7. Distribuição das tensões de von Mises (σ_{VM}) nos implantes e coroas dos modelos PR e PS.

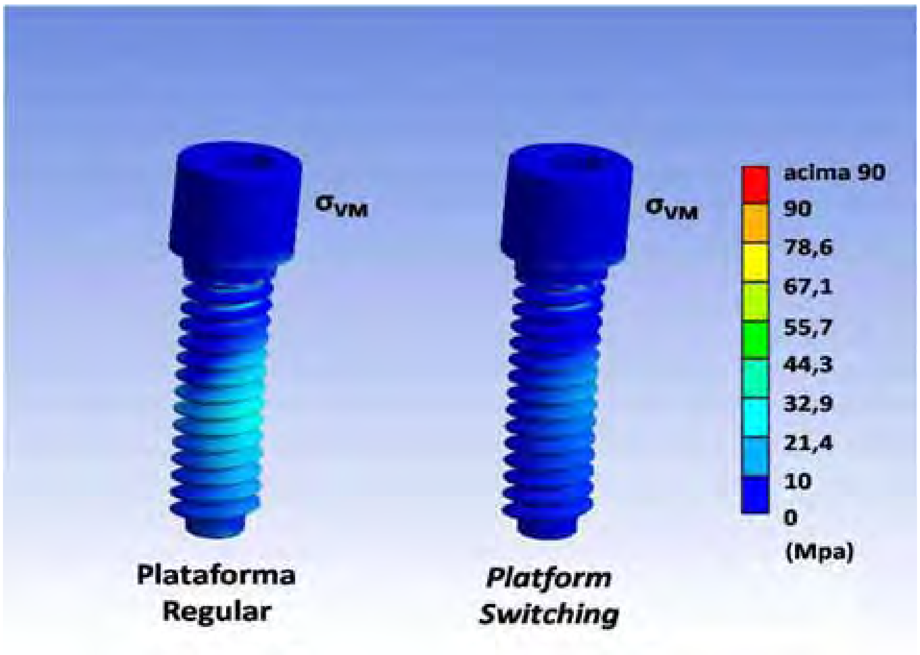

Figura 8. Distribuição das tensões de von Mises (σ_{VM}) nos parafusos dos modelos PR e PS.

ANEXOS

ANEXO A – Normas da revista selecionada para publicação do artigo.

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Authors must adhere to the following guidelines, which are provided to ensure the expeditious processing of manuscripts. Failure to follow these guidelines may result in the rejection of manuscripts or delays in the review process and publication.

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MANUSCRIPT PREPARATION

To submit a manuscript, please follow the instructions below.

- Submit 1 **typed, double-spaced** manuscript with 1-inch margins. Also submit a CD with a label identifying the computer system and word processing program used. CD format is preferred.
- Manuscripts should not exceed **10 to 12 pages** (excluding references, legends, and tables). All pages must be numbered. **The text must conform to acceptable English usage.**
- Use generic drug names (trade names may be listed in parentheses at point of first mention).
- Use a generic term to describe a product, then provide the **product trade name**, manufacturer, city, and state/country in parentheses following the generic term.
- Authors must use current dental nomenclature. Consult the 8th edition of The Glossary of Prosthodontic Terms for accepted terminology. This can be downloaded free of charge on the Elsevier Web site: www.journals.elsevierhealth.com/periodicals/ympr/home.
- Identify teeth by name (e.g., maxillary right central incisor) rather than by number.
- The primary author must justify the number of authors if the list exceeds four.

Title page:

- No abbreviations should be used in the title. **The title should be as concise as possible and yet define the study's scope, content, and clinical significance.**
- Include each author's full name, title, academic degrees(s), institutional affiliation(s), and location(s).
- If the manuscript was presented before an organized group, specify the name of the organization, the location, and inclusive dates of the event at which the manuscript was presented.
- **List any grant or other financial support** by citing the name of the supporting organization and/or the grant number.
- List the mailing address, business and home telephone numbers, fax number, and e-mail address of the author who will receive correspondence.

Abstract:

- **A structured abstract is required for all research articles.** It should include the following sections: (1) statement of the problem, (2) purpose of study, (3) material and methods, (4) results, (5) conclusion, and (6) clinical implications. The abstract should be limited to 250 words and typed double-spaced on a separate page. It should contain no abbreviations.
- **Tip articles** do not require abstracts. The abstract of a **clinical report** or a **dental technique** article should summarize the article and the procedure's advantages in one brief paragraph.

Text - types of articles:

- Articles in the Journal can be classified as follows: clinical reports, research studies, technical procedures, systematic reviews, articles on other professional subjects, and tips. All submissions are evaluated by peer review.

- All research manuscripts must include a brief statement of the clinical significance of the material presented.
- **The clinical report** (1) describes the author's methods for meeting a patient treatment challenge, (2) makes appropriate reference to other treatment methods considered and provides a rationale for the selection of the chosen method, and (3) includes a brief summary. It should be no longer than 4-5 pages and accompanied by no more than 8 quality descriptive illustrations. Please note: The Editor may approve the publication of additional figures if they significantly contribute to the value of the article.
- **The research report** (1) clearly states the problem and objective of the research in the form of a research hypothesis, (2) summarizes relevant literature in the introduction, (3) identifies the limitations of the study, (4) describes the research method so that it can be duplicated and judged for validity, (5) reports the results accurately and briefly, (6) provides a discussion of the findings, and (7) lists the conclusions that may be drawn from the research.
- **The technical procedure** (1) states the objective of the technique, (2) describes the procedure, (3) makes appropriate reference to alternate techniques, (4) discusses the advantages and disadvantages of the technique presented, and (5) is written in a step-by-step "cookbook" manner. **The technique section must be in command form.**
- **The systematic review** accurately records the sequence of development of a particular phase of dentistry, and provides documentation by references. The Journal is transitioning away from literature reviews to systematic reviews. The systematic review should be developed in the Cochrane style and format. For more information on systematic reviews, please see www.cochrane.org. An example of a systematic review in the Journal is

  Fitzpatrick B. Standard of care for the edentulous mandible: a systematic review. J Prosthet Dent 2006 Jan;95(1):71-8.

  Briefly, the systematic review consists of the following:
  An abstract - using a structured format.
  The text of the review - consisting of an introduction (background and objective), methods (selection criteria, search methods, data collection, and data analysis), results (description of studies, methodological quality, and results of analyses), discussion, authors' conclusions, acknowledgments, and conflicts of interest.

  Tables and figures, if necessary showing characteristics of the included studies, specification of the interventions that were compared, the results of the included studies, a log of the studies that were excluded, and additional tables and figures relevant to the review.

- **Tips from our readers** are reports of helpful or timesaving procedures. They should be limited to 2 authors, no longer than 250 words, and accompanied by no more than 2 illustrations. **The procedure section must be in command form.**

References:

- References must be identified in the text by superscript Arabic numbers and **numbered in the order that they are cited in the text.**
- All references, except those requiring discussion of new evidence-based information resulting from the study at hand, should be cited in the introduction and/or material and methods section(s).
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For journal articles: Jones ER, Smith IM, Doe JQ. Occlusion. J Prosthet Dent 1985;53:120-9.

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ANEXO B – Artigo em Inglês, nas normas da revista.

Platform switching: biomechanical evaluation using three-dimensional finite element analysis

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Statement of problem. After implant insertion and loading, crestal bone usually undergoes remodeling and resorption during the first year following prosthetic restoration. It has been reported that the platform switching seems to reduce or eliminate the expected postrestoration crestal bone remodeling, although the mechanisms responsible for this process are not yet clearly drawn.

Purpose. The objective of this study was to evaluate the stress distribution in peri-implant bone tissue, implants and prosthetic components of single crown implants-supported with the use of platform switching concept, using three-dimensional Finite Element Analysis (3D- FEA).

Material and methods. Two 3D finite element models reproduced a external hexagonal implant system with peri-implant bone tissue, in which a regular matching diameter connection of abutment-implant (Regular Platform group - RPG) and a platform switching connection (Platform Switching group - PSG) were simulated. A regular implant (prosthetic platform of 4.1mm) and a wide implant (prosthetic platform of 5.0mm) were used to represent the RPG and PSG, respectively, in which a regular prosthetic component of 4.1mm was connected to represent the crown. A load of 100N was applied on the models using ANSYS software.

Results. PSG diminished the stress concentration at the implant when compared to RPG by altering the stress distribution at the prosthetic platform of the implant, which results in a decrease of stress into the screw and supporting bone and an increase of stress in the crown.

Conclusions. platform switching improved biomechanically the stress distribution in peri-implant bone tissue of implant system, which might result in a reduced marginal bone loss. The use of mismatching prosthetic components in relation to the implant prosthetic platform diameter seems to decrease stress concentration at implant and screw, which might represent less clinical complications.

Keywords: dental implants, platform switching, implant supported prosthesis, finite element analysis, stress distribution, crestal bone loss**.**

Clinical Implications. The use of platform switching concept decreased the stress concentration at the peri-implant bone tissue, which might result in a reduced marginal bone loss. The decreased stress concentration at the screw and implant might diminish clinical complications as screw loosening or fracture, implant fracture or osseointegration failure.

INTRODUCTION

Since the introduction of osseointegration, new alternatives of prosthetic treatment were available to patients based on the placement of endosseous titanium implants in edentulous areas. The replacement of missing teeth by means of implants has become a predictable treatment modality for both complete and partial edentulous patients.[1,2,3,4] Ten-year surveys of fixed prostheses on natural teeth reveal a survival rate of approximately 75%.[5] In contrast, success rates for endosseous implants have been shown to be greater than 90%.[6,7,8] As these success rates have been achieved, treatment options have expanded to include immediate and early delayed implant placement and loading after tooth extraction. However conventional 2-step surgical and delayed loading techniques are still more relevant.[9,10]

One aspect of implant therapy that can be most challenging is the placement and subsequent restoration in the esthetic zone,[6] in which the level of peri-implant bone support and the soft tissue dimensions are factors suggested to be critical for the esthetic outcome.[11] Numerous techniques within surgical hard-tissue and soft-tissue management are available today to assist in achieving an ideal aesthetic treatment result. The current view is that the long-term preservation of healthy peri-implant tissues is of primary importance for ensuring function and esthetics over an extended period.[12]

Nevertheless, after implant insertion and loading, crestal bone usually undergoes remodeling and resorption during the first year following prosthetic restoration in implants.[12,13] Radiographic observation have shown that after abutment connection, remodeling of bone takes place, which is manifested in diminished bone dimensions, both horizontally (1,3 to 1,4mm)[10,14] and vertically (1,5 to 2mm), at the facial aspect of the implant. This crestal bone loss generally coincides with the level of the first thread of the implants[11] and can jeopardize the treatment outcome, especially in aesthetic cases in which facial soft tissue deficiencies create a crown that appears longer than desired,[6] since the gingival papillae support depends on the crestal bone level underneath.[10]

It is also critical in areas where short implants are used,[12] especially in the posterior region of the mandible, due to the presence of the mandibular canal, generally associated with the alveolar ridge atrophy after tooth extraction, resulting in a small amount of bone volume, in which the use of short implants are the only alternative. In areas like this, any bone resorption would represent a decrease of bone to implant contact surface that could lead to implant or osseointegration failure.

The factors involved in the mechanisms of the bone resorption and deposition around dental implants are not yet completely known[15] and several theories try to explain the changes observed in crestal bone height following implant restoration.[16,17] The establishment of a biologic width,[12,18,19,20,21] the location of the inflammatory cell infiltrate,[17,22] the distance of implant-abutment junction (IAJ) from crestal,[21,23,24] gingival biotype[25] and stress concentration due to occlusal loading[7,15,26-36] are some of those hypothesis.[12]

It has been reported that the platform switching (PS) seems to reduce or eliminate the expected postrestoration crestal bone remodeling.[4,6,10,13,17,36,37] The concept of platform switching presented by Lazzara & Porter (2006) consists in the placement of smaller-diameter prosthetic components on wider-diameter implants and was based on a description of radiographic observations made over a 13-year period. These observations suggests that the resulting postrestorative biologic process can be altered when the outer edge of the implant-abutment interface is horizontally repositioned inwardly and away from the outer edge of the implant platform.[6,10,11,17,37] The results of histomorphometric studies indicate that PS can protect the peri-implant mineralized tissue and prevent bone resorption, since it was verified the presence of cortical bone around the implant shoulder in PS configuration[13] and also that PS limited the apical down-growth of the epithelium barrier.[4]

The ability to reduce or eliminate crestal bone loss would be a major achievement in implant dentistry. Clinical benefits such as superior esthetics, better bone-to-implant contact, and improved primary stability, could be obtained with platform switching.[37]

So, the objective of this study was to evaluate the stress distribution in peri-implant bone tissue, implants and prosthetic components of single crown implants-supported with the use of platform switching concept, using three dimensional Finite Element Analysis (3D- FEA).

MATERIALS AND METHODS

A regular matching diameter connection of abutment-implant (Regular Platform group - RPG) and a platform switching connection (Platform Switching group - PSG) were simulated by two 3D finite element models that reproduced a external hexagonal implant system with peri-implant bone tissue. A regular implant (prosthetic platform of

4.1mm and 10.0mm in length) (SIN, Implant Systems, Sao Paulo, SP, Brazil) and a wide implant (prosthetic platform of 5.0mm and 10.0mm in length) (SIN, Implant Systems, Sao Paulo, SP, Brazil) were used to represent the RPG and PSG, respectively, in which a regular prosthetic component (UCLA) of 4.1mm (SIN, Implant Systems, Sao Paulo, SP, Brazil) was connected to represent the crown (Figure 1).

Model Design

The 3D modeling was performed in SolidWorks software (SolidWorks Corporation, MA, USA). The crown was modeled with dimension of 8mm in height and 8mm in the major diameter.[38] The peri-implant bone tissue model assumed 16mm in height, 11mm in width, cortical bone at the crestal region with 1,3mm in thickness and trabecular bone with 13,4mm in height.[39] The models were then imported into the finite element software (Ansys WorkBench 11, Swanson Anlysis System, Houston, Pa, USA), in which the mechanical properties were determined for all structures of the models, the finite element mesh were generated and the load applied to evaluate stress distribution.

Interface Conditions, Constrains and Loading

The implant was rigidly anchored in the bone model along its entire interface. The same type of contact was provided at the prosthesis-abutment interface. Every material was assumed to be homogeneous and isotropic.[34] Mechanical properties of the materials were taken from the literature[40,41,42] (Table 1). Boundary conditions were modeled to fix the inferior region of bone tissue and also the mesial and distal faces of the mandibular section.

To assess the stress distribution into the peri-implant bone tissue, the implants and the prosthetic components, a vertical 100N load[43] was applied on the vestibular side of the occlusal surface of the crown.

Elements and Nodes

The finite element mesh was generated with tetrahedral elements of 0.5mm. The final models had a total number of 158,596 nodes and 89,158 elements for the Regular Platform model and 145,212 nodes and 80,766 elements for the Platform Switching model (Figure 2).

After pre-processing of finite element analysis, numerical data produced color graphics for better comparison of the models. The obtained data was evaluated according to Equivalent Stress (von Mises), Maximum (tensile) and Minimum Principal Stress (compressive).

RESULTS

Stress distribution in the models

The processed data obtained from Finite Element software provided stress maps with a colorful scale in which is possible to compare the stress distribution in the different structures of both models (peri-implant bone tissue, implants, screw and prosthesis). The values of the maps scales were standardized for better qualitative (visual) comparison (Figure 3), and stress measures were presented in graphics for Equivalent Stress (von Mises), Maximum (tensile) and Minimum Principal Stress (compressive) (Figures 4 and 5) for better quantitative comparison of stress concentration among the structures of the models.

The stress concentration was located under the applied load side of the models. The implants presented the highest stress measurements in relation to the other structures of the models. Analyzing the graphics for Equivalent Stress and Principal Stress, the dispersion of von Mises (σ_{VM}), Maximum (σ_T) and Minimum stress (σ_C) were similar, in which the use of platform switching produced a decrease of stress concentration for bone tissue, implant and screw and an increase of stress concentration for the prosthesis.

Stress distribution on peri-implant bone tissue

When analyzing peri-implant bone tissue, the highest stress values were concentrated at the cortical bone. When comparing the pattern of stress distribution between the models, it is possible to observe that the stress distribution of RPG was done over a wider area at the peri-implant bone tissue with a higher stress concentration, while the PSG diminished the stress distribution and concentration (Figure 6).

Stress distribution on implants and prosthetic components

Stress measurements were higher at the implants when compared with bone tissue, screw and prosthesis for both models. When comparing the stress distribution at the implants, it was possible to observe that for RPG model the stress concentration presented higher measurements and was located in the outer edge of the prosthetic platform at the cortical bone level and also at the implant neck. PSG presented less stress measurements and stress concentration was located inwardly over the prosthetic platform, away from the outer edge.

For the retention screw, the stress was concentrated along the threads and neck for both models, in which tensile stress was higher than compressive stress. RPG also presented higher stress measurements for retention screw when compared with PSG. For the prosthesis, PSG presented higher stress values in which the stress was concentrated at the bottom part of the crown, at the interface with the prosthetic platform of the implant. (Figures 7 and 8).

DISCUSSION

This study aimed to evaluate the stress distribution on peri-implant bone tissue and also in the implants and prosthetic components of single-tooth restoration over implants, testing the concept of platform switching and its possible effects on crestal bone loss through a biomechanical approach.

In spite of the fact that solutions arising from numerical methods must always be carefully evaluated in the light of experimental testing, it seems reasonable to exploit this approach for the possibility of evaluating data that are experimentally not measurable, such as strain or stress in the bone tissue, thus completing and extending information obtained from *in vivo* and *in vitro* tests. The development of numerical models makes it possible to evaluate the mechanical behavior of the bone-implant compound by estimating fundamental variables, such as strain and stress in the bone tissue and also to investigate a large number of operational conditions.[43]

However, the border between the mechanical environment that leads to implant failure and that under which bone adapts through bone resorption is not yet clearly drawn.[34] Even though, the models are definitely useful for a preliminary interpretation of implant-abutment interaction.[43]

Several theories exist as to the reason for the observed changes in crestal bone height following implant restoration[17] however, this is not yet clarified.[36] These crestal bone levels are dependent on the location of the IAJ in relation to the bone crest,[37] since it was demonstrated that when the IAJ is positioned deeper within the bone, the resulting loss of crestal bone height increases.[13,21] The reason for the reaction to the presence of a microgap is not known, but it could be related to the presence of a bacterial contamination at the implant-abutment interface or to micromovements of the implant abutment interface. These hollow spaces can be a trap for bacteria, which might cause inflammation in the peri-implant soft tissues.[33]

The inward movement of the IAJ in the PS configuration also shifts the inflammatory cell infiltrate inward and away from crestal bone. This limits bone resorption around the coronal aspect of the implant.[10]

It has also been reported in the literature that crestal bone resorption is related to overload and to damage of the supporting interfacial bone.[15] Excessive load can trigger bone resorption due to the production of bone microdamage with the creation of craterlike bone defects lateral to the implants.[33] This microdamage to the bone tissue can also be initiated by stress concentration and stress shielding at the implant neck.[27,34,35]

When analyzing the obtained data, the findings in the present study were partially in agreement with those in the literature since it was possible to observe two interesting things. The first one was that the PSG decreased the amount of stress value and also the stress distribution over the peri-implant bone tissue (Figure 6) in comparison to RPG. The second observation was that the stress concentration on the implants over the prosthetic platform, was shifted inwardly away from the bone surface (Figure 7). Same results were found for the implants by Maeda et al (2007) that evaluated the biomechanical advantages of PS using different diameter dimensions of abutments for regular implants.

This difference in stress distribution could probably be the biomechanical explanation on why platform switching seems to reduce or eliminate the expected postrestoration crestal bone remodeling, observed in the clinical studies.[6,10,11,17,37] With the use of a wider implant in the PSG, a lower incidence of stress was found, that was also concentrated away from the peri-implant bone surface (Figures 4, 5 and 7). This resulted on a lower concentration of stress in peri-implant bone tissue (Figures 4, 5 and 6), what would cause less microdamage in the bone resulting in a minimal crestal bone loss.

Another possible reason to explain the efficacy of the PS configuration is also based on the distance between the bone surfaces to the stress-concentrated area on the implant surface (Figure 7). As microorganisms are likely to move toward the high-energy area or by the mechanism such as interface micromovements that allow the microorganism move that area, it is advantageous to have a large distance between the stress concentration area and bone surface.[33,36]

In relation to retention screw, it was observed that stress concentration was located at the neck and through the threads of the screw (Figure 8). Analyzing the graphics it was verified that tensile stress was higher than compressive, being higher for RPG than PSG (Figures 4 and 5). Maeda et al. (2007) stated that a increase of stress may cause problems such as abutment screw deformation if over the elastic limit. However, these authors found higher values for PS configuration differently from the results of the present study. Such difference may rely on the design of the retention screw and the abutment, that in the study of Maeda et al. (2007) were represented as a single structure, not allowing the separated evaluation of each prosthetic components (Figures 7 and 8). Another important factor that might lead to different results was that the threads of the implants and the screw were represented only in the present study, which have a main role in the maintaining the load-bearing capacity of implants.[43] Clinically, the decreased stress concentration at the screw with platform switching is mechanically advantageous, because it could represent a fewer number of complications in implant-supported prosthesis, as screw loosening or fracture.

When analyzing the stress maps for prosthesis, it was verified that the amount of stress in the PSG was higher for the crown, when comparing with RPG. The stress concentration at the crowns was located at the bottom part of the abutment, in the contact surface that fits the prosthetic platform of the implant (Figures 4, 5 and 7) . The use of a wider implant would offer greater resistance and lower stress distribution to bone tissue resulting in higher stress for PSG due to the implant thickness. The increased stress concentration may not lead to a mechanical complication since the stress measurements verified (σ_{VM} = 67.9MPa, σ_T = 50.7MPa, σ_C = 86.6MPa) were lower than the yield strength of the Co-Cr alloy (552 to 1034MPa),[40] used in the super-structure of the crown.

Nevertheless, as consequence of the load application, implants must be capable of transferring the action induced to the peri-implant bone tissue, thus ensuring the bearing capacity of the system.[43] The functionality of fixed prostheses requires the respect of strength limits for implants and prosthetic components,[43] but also further mechanical requirements must be retained with reference to bone tissue as a material that must support the loads effects.[43] In this way, the PS configuration seems to improve the load transmission to implant , screw and peri-implant bone tissue.

Bozkaya et al. (2004) evaluated the load transfer characteristics of 5 different implant systems in compact bone and established a criterion to evaluate bone overload based on the ultimate stress of the cortical bone, which has been reported to be higher in compression (170MPa) than in tension (100MPa). The stress concentration in both groups were below the ultimate stress, being higher for RPG (σ_C = 54,9MPa and σ_T = 13,6MPa) than PSG (σ_C = 20,3MPa and σ_T = 5,44MPa). These obtained data seems to be clinically relevant since Cullinane and Einhorn (2002) stated that even loads below the ultimate stress can cause bone failure, as in the case of fatigue failures, in which the microdamage of the bone can no longer be repaired.

However, there is still lack of information in defining the mechanical properties of the bone tissue with regard to the time-dependent process of structural re-arrangement according to permanent mechano-biological stimuli.[43] The operational relevance and the reliability of numerical methods in defining the biomechanics of dental implants and to confirm the necessity of an integrated clinical-mechanical approach must be pointed out for a deeper insight to this field research.[43]

Other FEA studies with wide implants associated with different diameter of prosthetic components (regular and wide) must be done to evaluate the influence and effect of a wider implant in stress distribution. Besides that, the development animal experiments and longitudinal clinical trials are also necessary to validate these biomechanical findings.

CONCLUSION

Based on the obtained data and within the limitations of this study, the following conclusions were draw:

- Platform switching improved biomechanically the stress distribution in peri-implant bone tissue of implant system, which might result in a reduced marginal bone loss.
- The use of mismatching prosthetic components in relation to the implant prosthetic platform diameter seems to decrease stress concentration at implant and screw, which might represent less clinical complications, as screw loosening or fracture, implant fracture or osseointegration failure.

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REFERENCE LIST

TABLE

FIGURES

TABLE

Table 1. Structures and materials properties used in the models.

Materials	Young's modulus (GPA)	Poisson's ratio	References
Cortical bone	13.70	0.30	Sevimay et al., 2005
Trabecular bone	1.37	0.30	Sevimay et al., 2005
Titanium (Ti-6Al-4V)	103.40	0.35	Sertgoz and Gunever, 1996
Co-Cr alloy	218.00	0.33	Sevimay et al., 2005
Feldspathic porcelain	64.00	0.25	Yi and Kelly, 2008

FIGURES

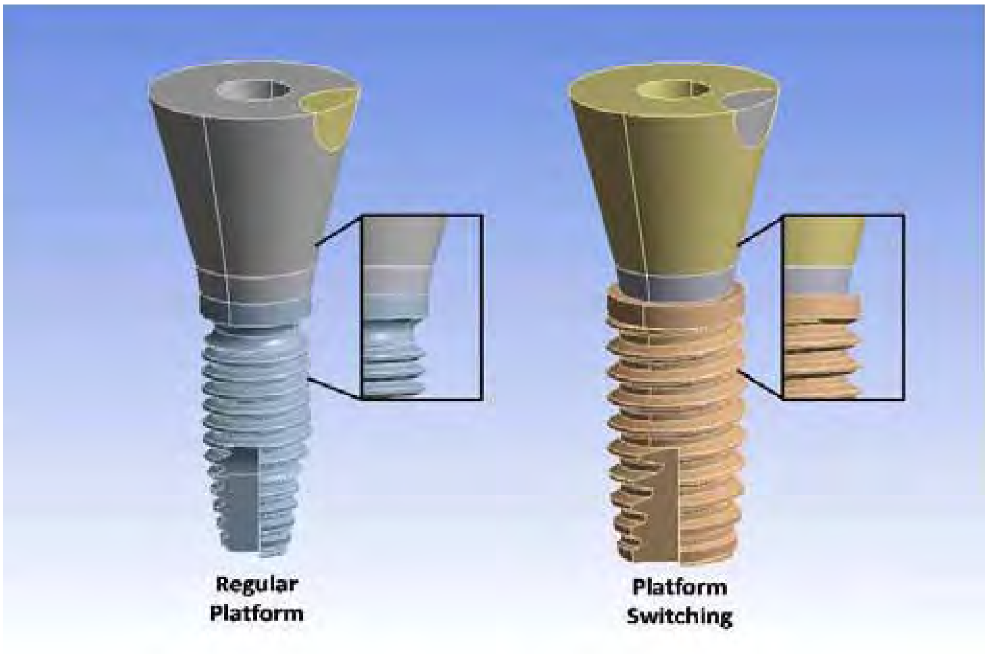

Fig 1. Three-dimensional models of implant-abutment connection of RPG and PSG.

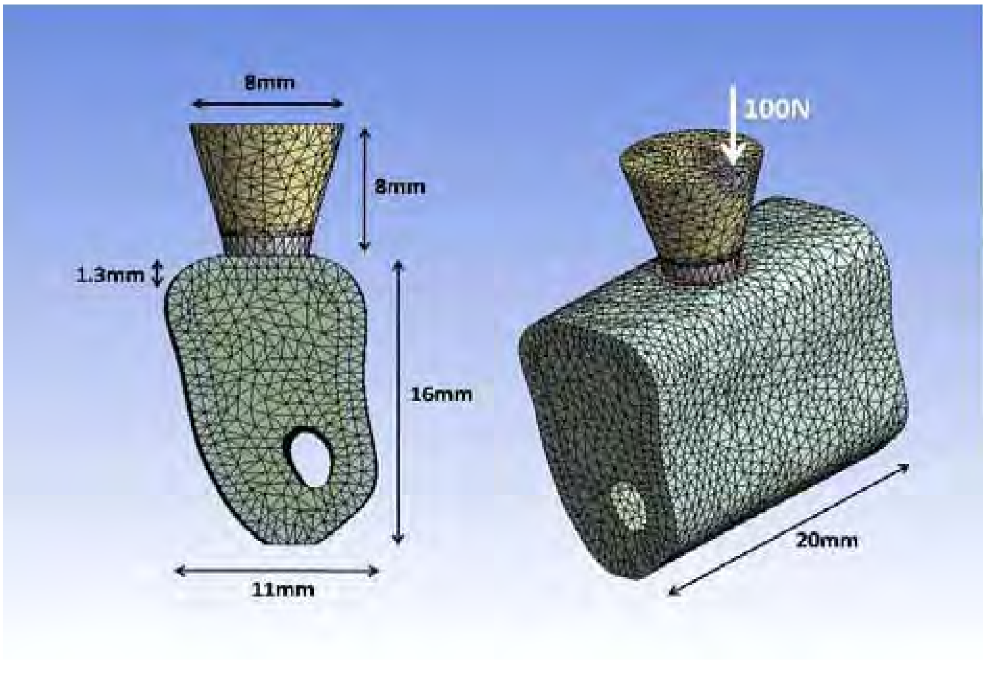

Fig 2. Frontal and oblique view of the finite element mesh of PSG (158,596 nodes and 89,158 elements).

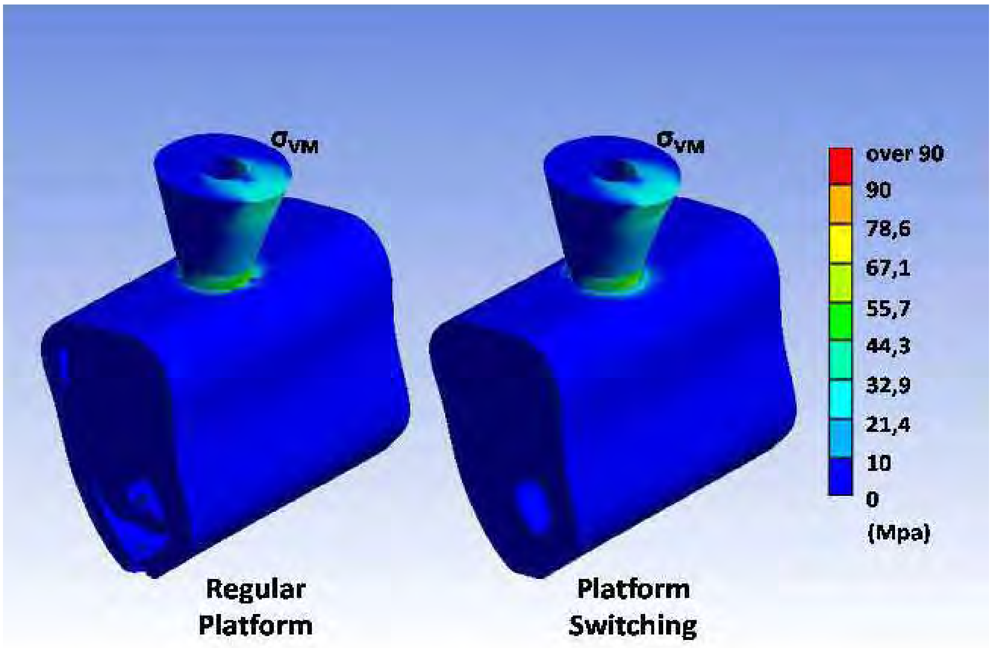

Fig 3. von Mises (σ_{VM}) stress distribution for RPG and PSG models.

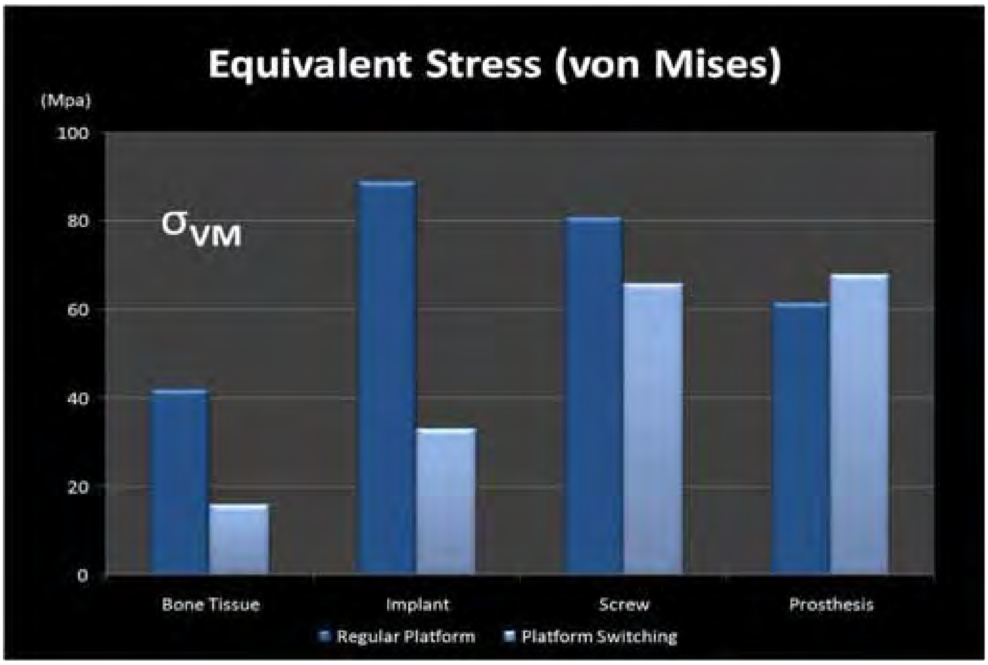

Fig 4. von Mises (σ_{VM}) stress measures at bone tissue, implant, screw and prosthesis for RPG and PSG models.

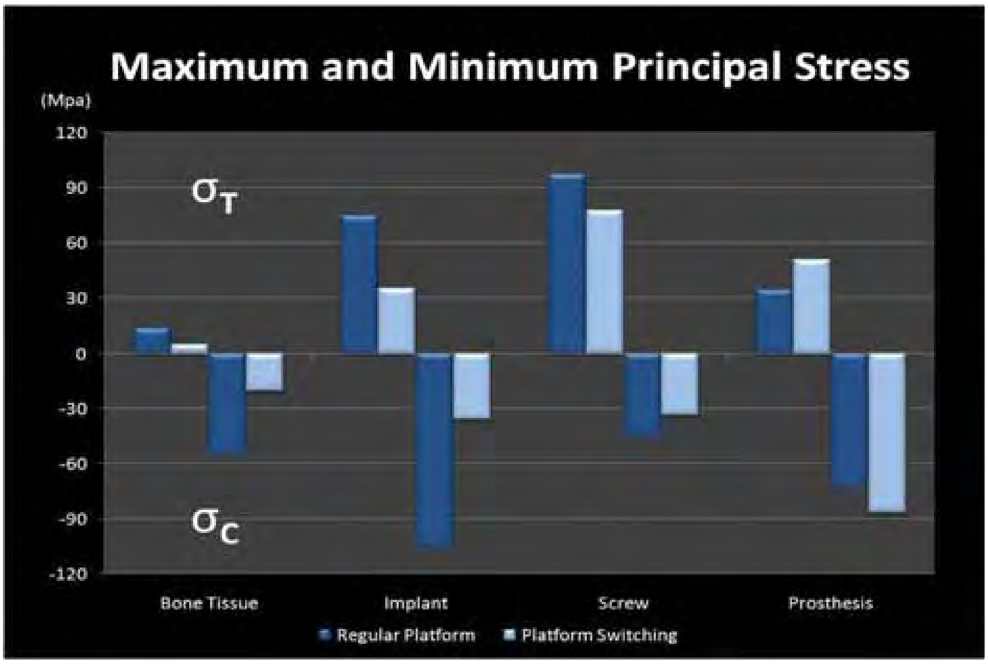

Fig 5. Maximum (σ_T, tensile) and Minimum Principal (σ_C, compressive) stress measures at bone tissue, implant, screw and prosthesis for RPG and PSG models.

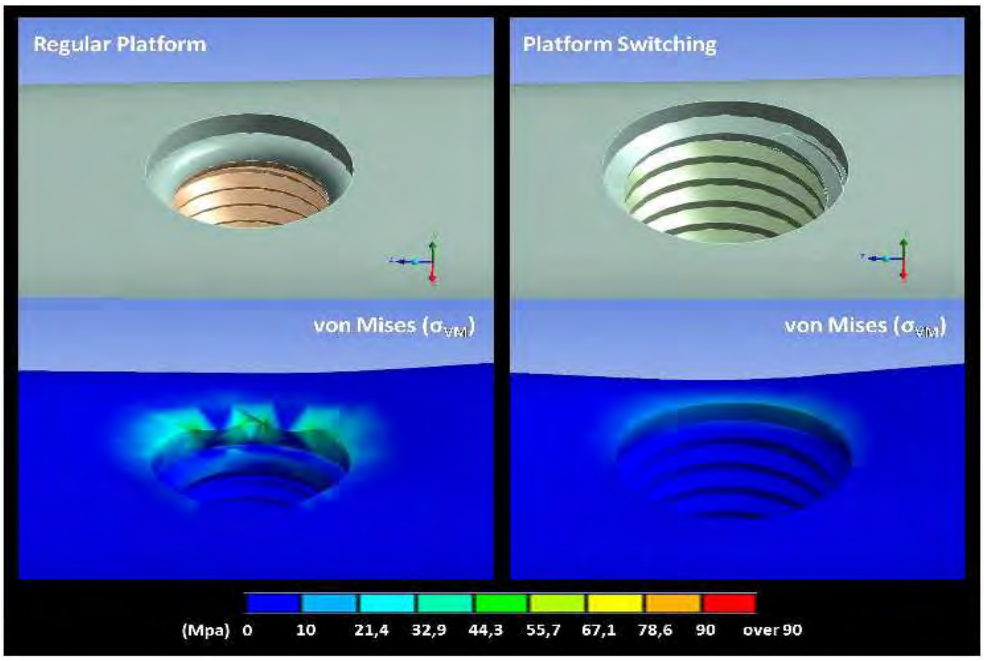

Fig 6. von Mises (σ_{VM}) stress measures at bone tissue for RPG and PSG.

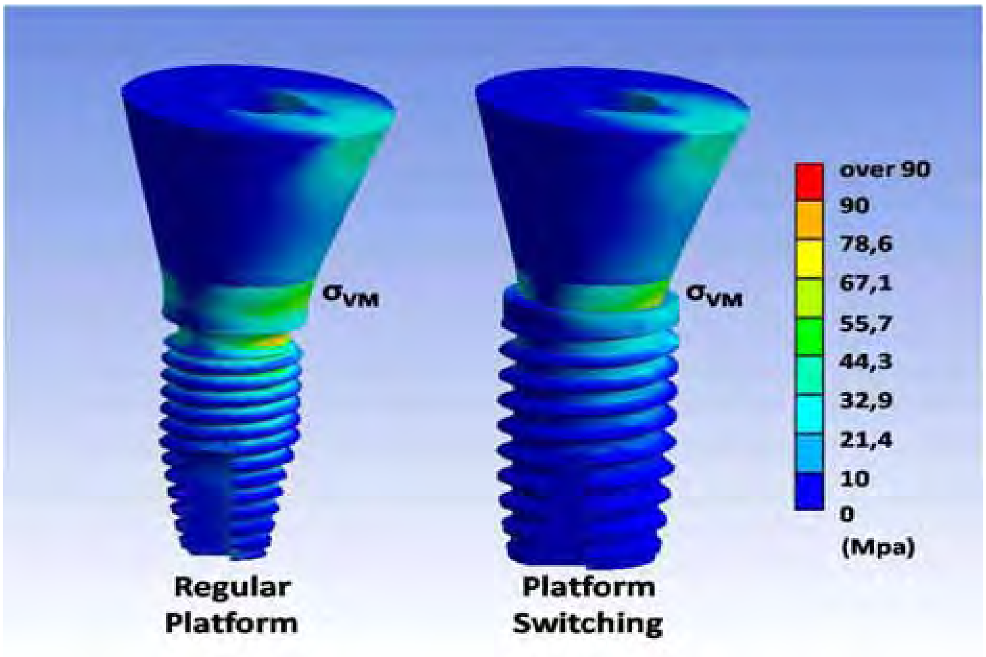

Fig 7. von Mises (σ_{VM}) stress measures at the implants and prosthesis for RPG and PSG.

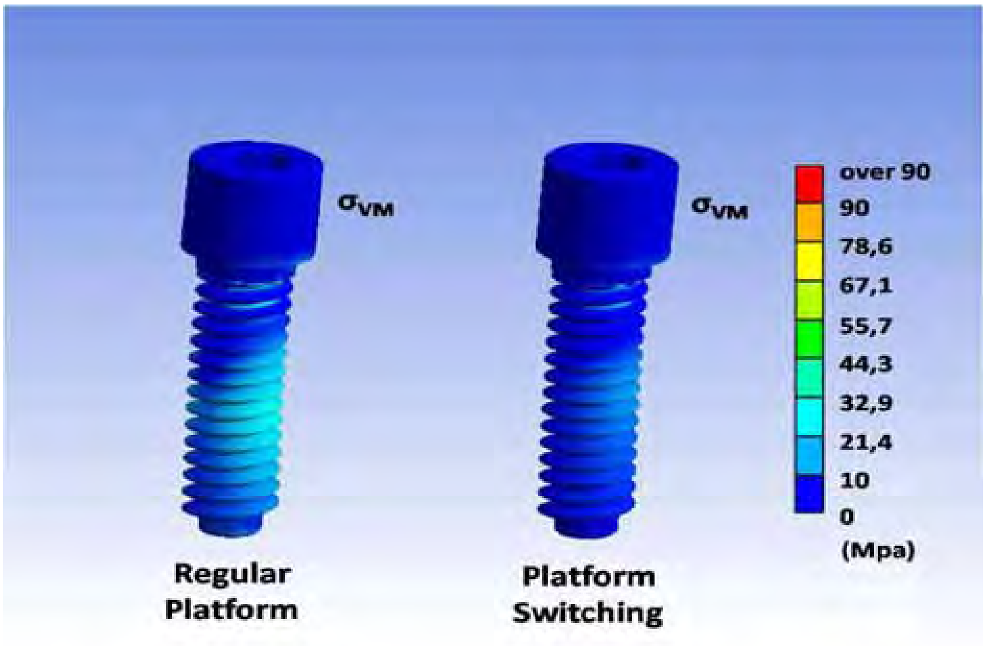

Fig 8. von Mises (σ_{VM}) stress measures at the screw for RPG and PSG.

ANEXO C – Figuras adicionais.

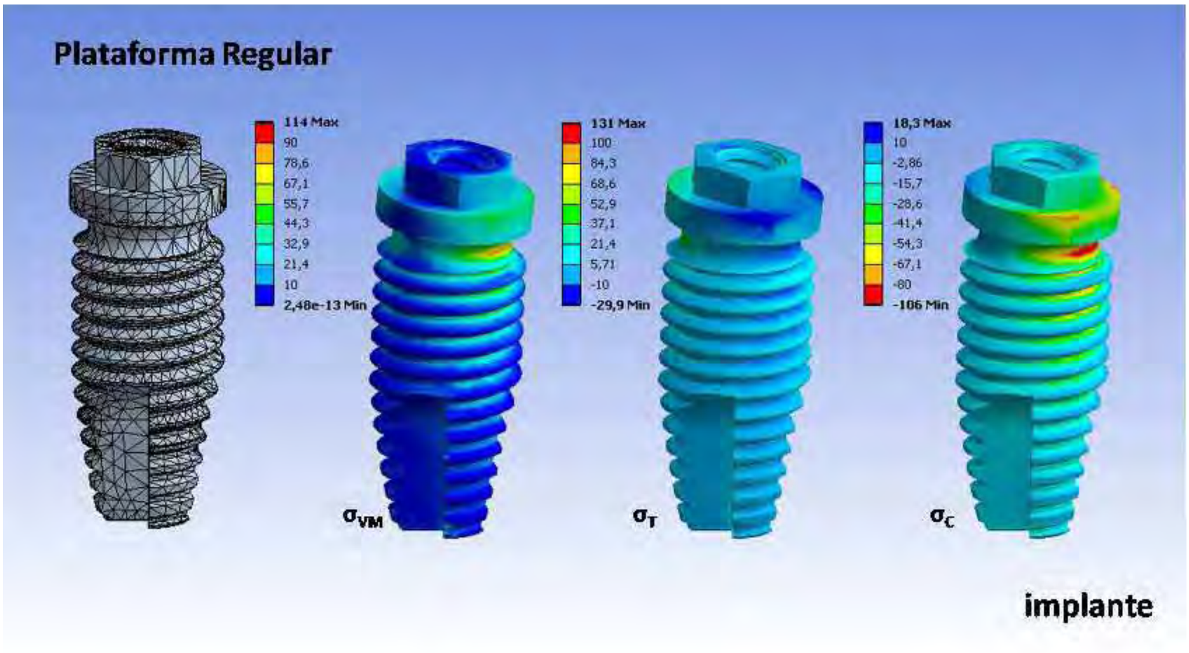

Figura 9. Modelo 3D do implante do grupo PR. Malha de elementos finitos, tensões de von Mises (σ_{VM}), tensões de tração (σ_T) e tensões de compressão (σ_C).

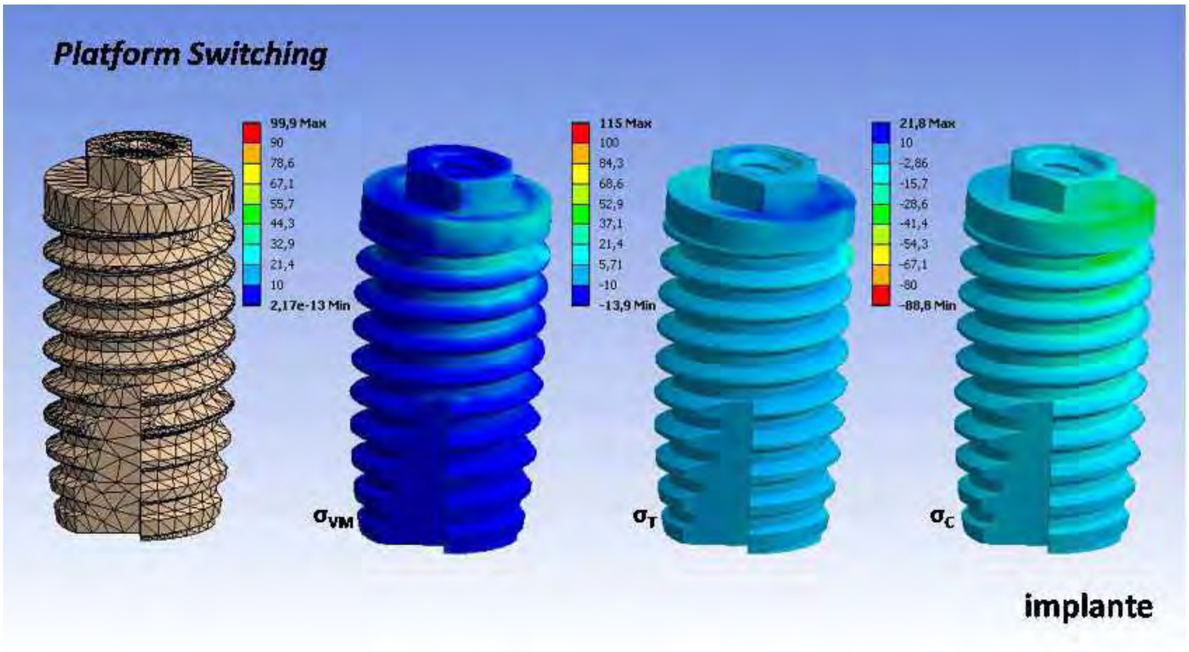

Figura 10. Modelo 3D do implante do grupo PS. Malha de elementos finitos, tensões de von Mises (σ_{VM}), tensões de tração (σ_T) e tensões de compressão (σ_C).

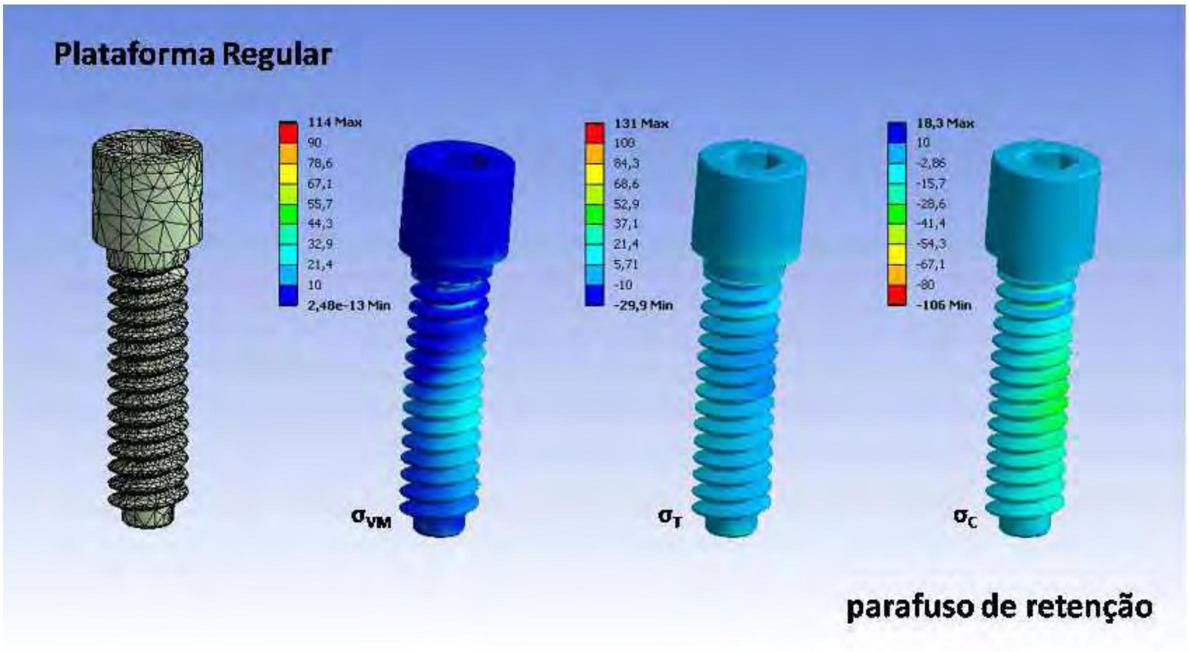

Figura 11. Modelo 3D do parafuso de retenção do grupo PR. Malha de elementos finitos, tensões de von Mises (σ_{VM}), tensões de tração (σ_T) e tensões de compressão (σ_C).

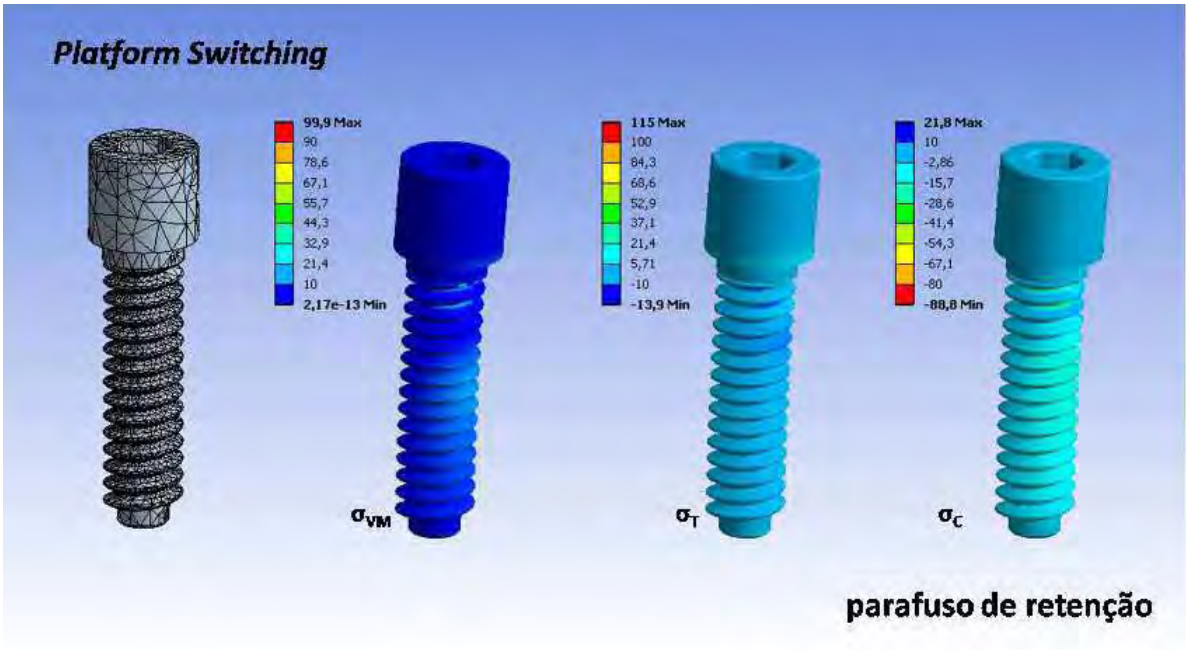

Figura 12. Modelo 3D do parafuso de retenção do grupo PS. Malha de elementos finitos, tensões de von Mises (σ_{VM}), tensões de tração (σ_T) e tensões de compressão (σ_C).

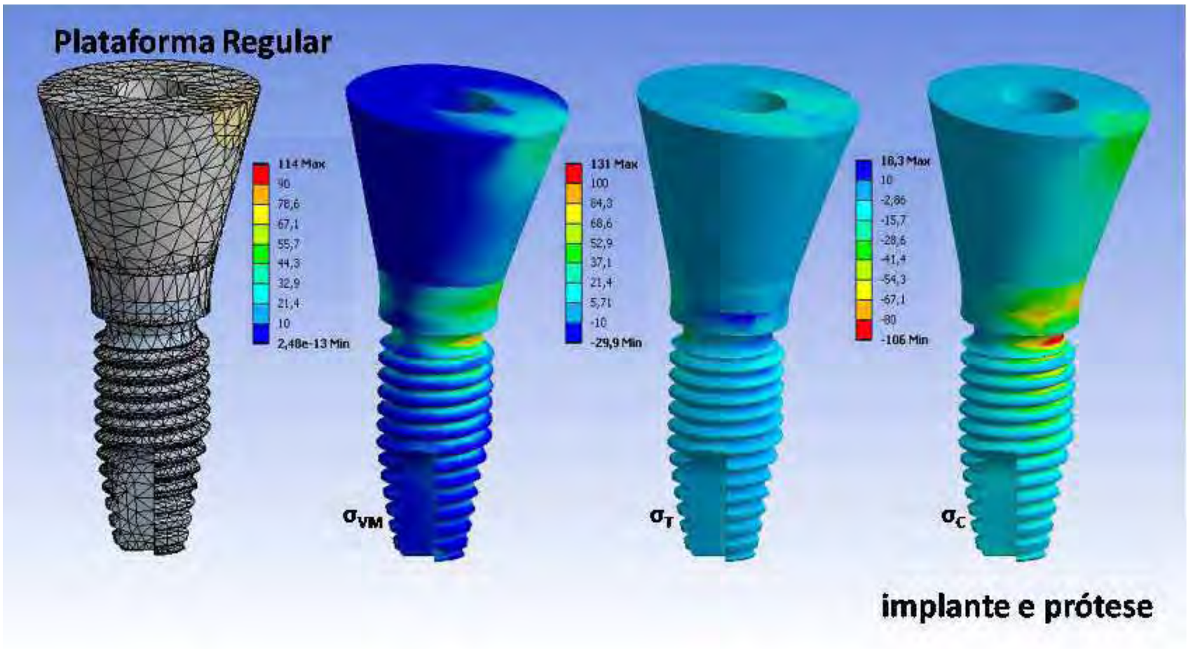

Figura 13. Modelo 3D do implante e da prótese do grupo PR. Malha de elementos finitos, tensões de von Mises (σ_{VM}), tensões de tração (σ_T) e tensões de compressão (σ_C).

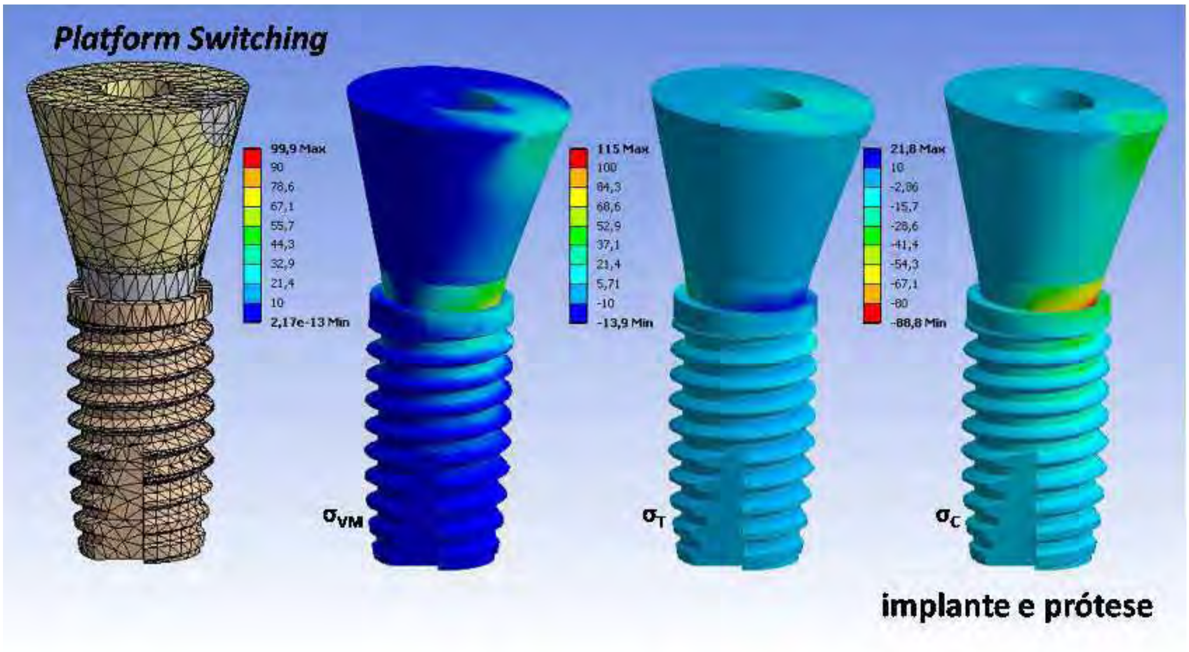

Figura 14. Modelo 3D do implante do grupo PS. Malha de elementos finitos, tensões de von Mises (σ_{VM}), tensões de tração (σ_T) e tensões de compressão (σ_C).

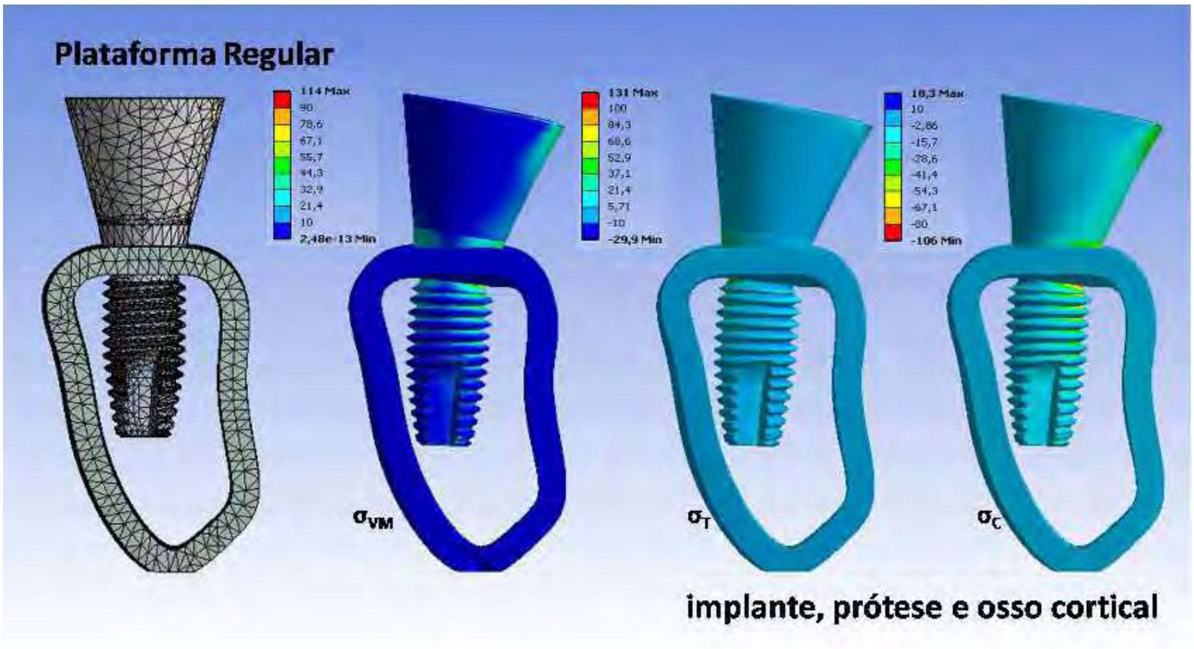

Figura 15. Modelo 3D do implante, da prótese e do osso cortical do grupo PR. Malha de elementos finitos, tensões de von Mises (σ_{VM}), tensões de tração (σ_T) e tensões de compressão (σ_C).

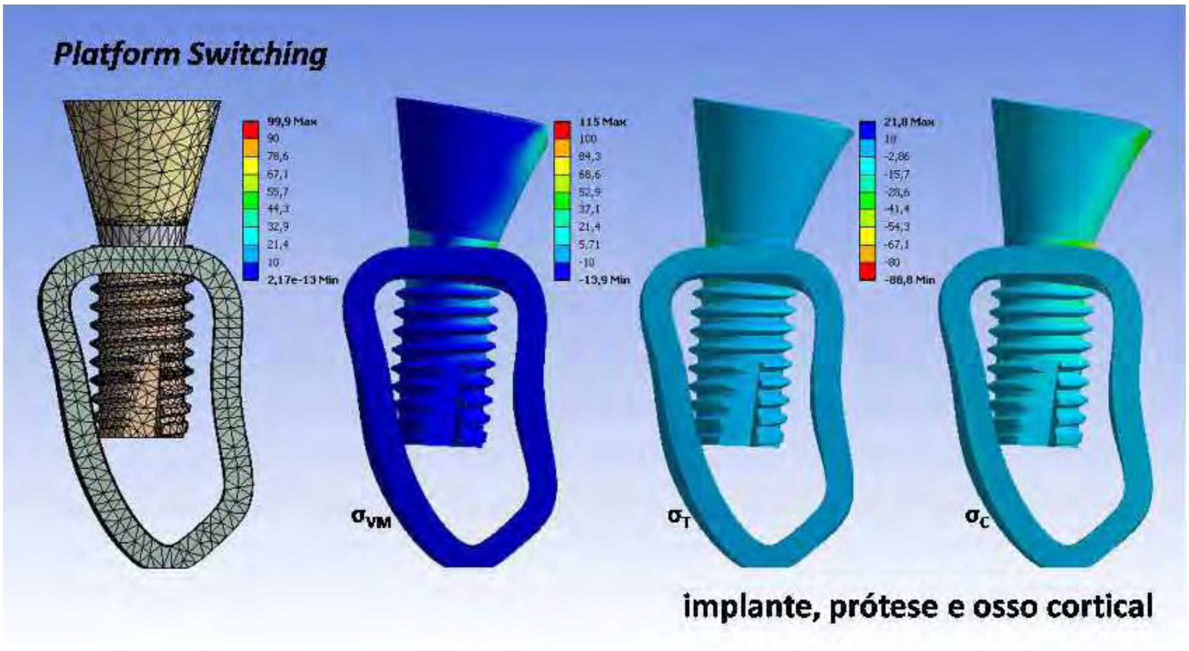

Figura 16. Modelo 3D do implante, da prótese e do osso cortical do grupo PS. Malha de elementos finitos, tensões de von Mises (σ_{VM}), tensões de tração (σ_T) e tensões de compressão (σ_C).