UNICAMP

*Marcele Jardim Pimentel*

# Biomechanical evaluation of short implants to support complete denture in atrophic mandible

# Avaliação biomecânica de implantes curtos para suporte de próteses totais fixas em mandíbulas atróficas

PIRACICABA
2014

Universidade Estadual de Campinas
Faculdade de Odontologia de Piracicaba

***Marcele Jardim Pimentel***

# Biomechanical evaluation of short implants to support complete denture in atrophic mandible

# Avaliação biomecânica de implantes curtos para suporte de próteses totais fixas em mandíbulas atróficas

Thesis presents to the Piracicaba Dental School of the University of Campinas in partial fulfillment of the requirements for the degree of Doctor in Dentistry, Dental Prosthesis area.

Tese apresentada à Faculdade de Odontologia de Piracicaba, da UNICAMP como parte dos requisitos exigidos para obtenção do Título de Doutora em Clínica Odontológica, na Área de Prótese Dental.

**Orientadora:** Altair Antoninha Del Bel Cury

ESTE EXEMPLAR CORRESPONDE À VERSÃO FINAL DA TESE DEFENDIDA POR MARCELE JARDIM PIMENTEL, E ORIENTADA PELA PROF$^{A}$. DR$^{A}$. ALTAIR ANTONINHA DEL BEL CURY.

______________________________________
Assinatura da orientadora

PIRACICABA
2014

Ficha catalográfica
Universidade Estadual de Campinas
Biblioteca da Faculdade de Odontologia de Piracicaba
Marilene Girello - CRB 8/6159

P649a Pimentel, Marcele Jardim, 1984-
Avaliação biomecânica de implantes curtos para suporte de próteses totais fixas em mandíbulas atróficas / Marcele Jardim Pimentel. – Piracicaba, SP : [s.n.], 2014.

Orientador: Altair Antoninha Del Bel Cury.
Tese (doutorado) – Universidade Estadual de Campinas, Faculdade de Odontologia de Piracicaba.

1. Prótese dentária. 2. Prótese total. 3. Biomecânica. I. Del Bel Cury, Altair Antoninha,1948-. II. Universidade Estadual de Campinas. Faculdade de Odontologia de Piracicaba. III. Título.

Informações para Biblioteca Digital

**Título em outro idioma:** Biomechanical evaluation of short implante to support complete denture in atrophic mandible
**Palavras-chave em inglês:**
Dental prosthesis
Denture, complete
Biomechanics
**Área de concentração:** Prótese Dental
**Titulação:** Doutora em Clínica Odontológica
**Banca examinadora:**
Altair Antoninha Del Bel Cury [Orientador]
Plínio Mendes Senna
Hugo Lemes Carlo
Karina Gonzales Silvério Ruiz
Lourenço Correr Sobrinho
**Data de defesa:** 16-05-2014
**Programa de Pós-Graduação:** Clínica Odontológica

**UNICAMP**

**UNIVERSIDADE ESTADUAL DE CAMPINAS**
**Faculdade de Odontologia de Piracicaba**

A Comissão Julgadora dos trabalhos de Defesa de Tese de Doutorado, em sessão pública realizada em 16 de Maio de 2014, considerou a candidata MARCELE JARDIM PIMENTEL aprovada.

Profa. Dra. ALTAIR ANTONINHA DEL BEL CURY

Prof. Dr. PLÍNIO MENDES SENNA

Prof. Dr. HUGO LEMES CARLO

Profa. Dra. KARINA GONZALES SILVÉRIO RUIZ

Prof. Dr. LOURENÇO CORRER SOBRINHO

**RESUMO**

Este estudo teve como objetivo avaliar o comportamento biomecânico de implantes curtos para suporte de próteses totais fixas em mandíbulas atróficas, assim como avaliar a influência da proporção prótese-implante neste comportamento. Para isto, foi conduzido um estudo *"in vitro"* com a aplicação do método de Fotoelasticidade e *"in silico"*, com auxílio dos softwares *SolidWorks Premium* 2013® e *Ansys Workbench* 14.0®, para aplicação do método de Elementos Finitos. Os grupos foram divididos de acordo com as características dos implantes quanto ao comprimento (11,0; 9,0; 7,0 e 5,0 mm) e diâmetro (Ci = *conventional* 4,0 mm ou Wi = *wide* 5,0 mm) sendo: Ci9 (9,0x4,0 mm), Ci7 (7,0x4,0 mm), Ci5 (5,0x4,0 mm), Wi9 (9,0x5,0 mm), Wi7 (7,0x5,0 mm) e Wi5 (5,0x5,0 mm) comparados ao grupo controle (CG 11,0x4,0 mm). A influência da proporção prótese-implante foi analisada em quatro proporções: 1,2:1; 1,7:1; 2,5:1 e 4,0:1. Foram confeccionados modelos representativos da secção anterior da mandíbula, nos quais foram posicionados quatro implantes de interface cone *Morse* e componentes protéticos (pilar, barra, parafuso de retenção e prótese total - quando aplicável). A extensão do *cantilever* foi igual para todos os grupos, em ambos os experimentos, determinada em 15mm e na extremidade distal foram realizados os carregamentos. Como variável resposta para análise da distribuição de tensão no estudo *"in vitro"* foi obtida a tensão cisalhante em 5 pontos em torno do implante distal (lado de carregamento) e implante subsequente, obtida no software *Fringes®* (carregamento de 0,15 kgf). Já para análise *"in silico"* os valores máximos de tensão para cada corpo avaliado foram obtidos com auxílio do *software Ansys Workbench®* (carregamento de 100 N). Foram obtidos os valores de tensão Máxima Principal para osso e tensão de *von Mises* para implantes e componentes protéticos. Os resultados demonstram que há maior transmissão de forças para região peri-implantar quando implantes de menor área são utilizados. Implantes de 5mm de comprimento mostraram comportamento biomecânico diferente dos demais grupos, com maior níveis de tensão para osso e implantes. O aumento do diâmetro do implantes reduz a concentração de tensão sobre o tecido ósseo, aumentando os níveis de tensão sobre os componentes protéticos. Implantes curtos são responsáveis pelo aumento de tensão nos parafusos de retenção. A proporção prótese-implante aumentada favorece a concentração de tensão no osso cortical, especialmente para proporção extrema de P:I - 4:1 (20:5 mm). Podemos concluir que apesar do aumento de tensão em torno dos implantes e parafusos protéticos implantes curtos representam uma opção para reabilitação de mandíbulas atróficas afim de eliminar procedimentos de enxerto, especialmente quando associados a implantes de largo diâmetro, com ressalva para implantes de 5 mm e proporções P:I extremas.

**Descritores:** Próteses e Implantes; Prótese Dentária; Prótese Total.

**ABSTRACT**

The aim of this study was to evaluate the biomechanical behavior of short implants to support fixed prostheses in atrophic mandible, and assess the influence of prosthesis-implant ratio in this behavior. For this, an "in vitro " study by photoelasticity method, and an "in silico" test, with the aid of software SolidWorks Premium 2013® and Ansys Workbench ® 14.0 for Finite Element Analysis, were conducted. The groups were divided according to the length (11.0, 9.0, 7.0 e 5.0mm) and diameter of the implants (conventional - Ci with 4.0 mm or wide - Wi with 5.0 mm) the groups division was: Ci9 (9.0x4.0mm), Ci7 (7.0x4.0mm ), Ci5 (5.0x4.0mm ), Wi9 (9.0x5.0mm ), Wi7 (7.0x5.0mm ) and Wi5 (5.0x5.0mm ) that was compared to CG (11.0x4.0mm). The influence of prosthesis-implant ratio was analyzed at four levels: 1.2:1; 1.7:1; 2.5:1 and 4.0:1. The models are made representing the anterior section of the mandible, with four cone Morse tape implants and prosthetic components (abutment, bar, retaining screw and dentures - when applicable). The cantilever extension (15mm) was equal for all groups, in both experiments. The load was applied at the end of the cantilever. For the "in vitro" study the shear stress was obtained in 5 peri-implant points around the distal (load side) and the subsequent implant using Fringes® software (load of 0.15 kgf). For the " in silico " test the Maximum Principal Stress was obtained for bone and von Mises stress for implants and prosthetic components using the Ansys Workbench® software (load 100N). The results showed that there is a greater transmission of stress to peri-implant area when smaller implants are used. Implants 5mm long showed different biomechanical behavior when compared to other groups, with higher levels of stress to the bone and implants. Implants with larger diameter decrease the stress in the bone tissue, increasing levels of stress on the prosthetic components. Short implants are responsible for the increase of the stress values in retention screws. The prosthesis-implant ratio favors the increase of stress concentration in the cortical bone, especially for extreme prosthesis-implant ratio (4:1/20:5 mm). Was conclude that despite the increased tension around the implants and prosthetic screws short implants represent an option for rehabilitation of atrophic jaws in order to eliminate grafting procedures, especially when

associated with large-diameter implants, except for 5mm implants associated to extreme P:I ratio.

**Descriptors:** Prostheses and Implants; Prosthodontics; Denture.

**SUMÁRIO**

“O óbvio é aquilo que nunca é visto até

que alguém o manifeste com simplicidade.”

*Kahlil Gibran*

**DEDICATÓRIA**

**À Deus**

Por trilhar meus caminhos, me conduzir sutilmente por eles e por me trazer felicidade em forma de pessoas.

**Aos meus pais**

**Ubirajara Hárlano Oliveira Pimentel** e **Maria do Brasil Jardim Pimentel**

Por acreditarem em minhas escolhas e torná-las realidade. Por todo amor, ensinamentos, exemplo, dedicação e suporte inabalável. Tê-los como porto seguro é o meu maior tesouro.

**À minha família**

A todos os meus familiares (primos, tias, tios) em nome da minha irmã **Manuele Jardim Pimentel**, que torceram e participaram, mesmo que de longe, ao longo desses muitos anos. Minha avó materna **Gilda Pereira Jardim** *(in memoriam)* e meu avô paterno **Severino Ramos Pimentel,** pelo incentivo e carinho dedicados a mim.

# AGRADECIMENTOS

## Agradecimento Especial

À Profª. Drª. **Altair Antoninha Del Bel Cury**, minha orientadora, pela confiança depositada em mim. Agradeço imensamente ter sido convidada a ingressar neste convívio gratificante. Os conhecimentos adquiridos neste período foram de grande importância para minha formação e estar sob sua orientação me desperta para tentar fazer sempre o melhor. Fico feliz pela oportunidade de trabalharmos juntas e me dar liberdade na busca e aplicação do conhecimento. Expresso ainda toda minha admiração por representar a mulher atual, competente e de merecido destaque dentro da árdua missão acadêmica sendo assim, um exemplo a ser seguindo. O ensinamento mais aplicado não é aquele que foi transmitido verbalmente e sim aquele que nos foi mostrado. **Muito Obrigada**.

## Agradecimentos

À Universidade Estadual de Campinas (UNICAMP), na pessoa do Magnífico Reitor, Prof. **Dr. José Thadeu Jorge** e à Faculdade de Odontologia de Piracicaba da Universidade Estadual de Campinas, na pessoa de seu Diretor, **Prof. Dr. Jacks Jorge Júnior** e Diretor Associado**, Prof. Dr. Alexandre Augusto Zaia.**

À Fundação de Amparo a Pesquisa do Estado de São Paulo (FAPESP), pela bolsa de Doutorado concedida a mim, sob o processo #2011/21877-2.

À Coordenadora dos Cursos de Pós-Graduação da Faculdade de Odontologia de Piracicaba da Universidade Estadual de Campinas **Profª. Drª. Renata Cunha Matheus Rodrigues Garcia**, pela sua dedicação plena.

Ao Coordenador do Programa de Pós-Graduação em Clínica Odontológica da Faculdade de Odontologia de Piracicaba – UNICAMP, **Prof. Dr. Márcio de Moraes**, pela representação árdua de suas atividades e pela delicadeza em me prestar atenção especial junto a meu pai.

Aos docentes **Prof. Lourenço Correr Sobrinho**, **Prof. Karina Gonzales Silvério Ruiz**, **Prof. Hugo Lemes Carlo**, **Prof. Plínio Mendes Senna**, por aceitarem, prontamente, o convite para compor a banca de defesa, dentre as muitas atividades que realizam. Assim como os membros suplentes desta comissão: a **Profª. Dalva Cruz Laganá**, **Profª. Fernanda Faot** e **Prof. Carlos José Soares**. Obrigada.

À Faculdade de Odontologia da Universidade do Federal da Paraíba (UFPB) pelos primeiros conhecimentos recebidos e pelas amizades construídas. Às **Prof$^{as}$. Dr$^{as}$. Sueli Marques Soares, Marise Diniz da Rosa e Prof. Dr. Lino João da Costa** pelos ensinamentos nas iniciações científicas e aos **Profs. André Ulisses, Fabiano e Tânia Rodrigues, Leonardo Marconi e Solange Félix**, em nome dos demais docentes.

As **Prof$^{as}$. Dr$^{as}$. Célia Marisa Rizzatti Barbosa**, **Renata Cunha Matheus Rodrigues Garcia** e **Prof. Dr. Wander José da Silva** por compartilharem suas experiências, conhecimentos e principalmente pela atenção dispensada a mim no laboratório de Prótese Parcial Removível da Faculdade de Odontologia de Piracicaba – UNICAMP, sempre muito atenciosos e dispostos a ajudar.

Aos docentes do Departamento de Prótese e Periodontia, da área de concentração de Prótese Dentária da Faculdade de Odontologia de Piracicaba – UNICAMP **Prof. Dr. Marcelo Ferraz Mesquita, Prof. Dr. Mauro Antônio de Arruda Nóbilo, Prof. Dr. Rafael Leonardo Xediek Consani, Prof. Dr. Valentim Adelino Ricardo Barão** pela atenção dada prontamente a mim em todos os momentos que os solicitei, pelo convívio harmonioso, pelas experiências compartilhadas em momentos dentro de sala ou fora dela, pelos ensinamentos transmitidos e pelo espaço concedido a mim, sempre que necessário, dentro do laboratório de Prótese Total da Faculdade de Odontologia de Piracicaba – UNICAMP, muito obrigada.

Aos engenheiros mecânicos **Pedro Noritomi** e **Daniel Takanori** pelos cursos de grande valia assistidos, por toda transmissão de conhecimento e pelo contato fácil para elucidação de questionamentos metodológicos, muito obrigada.

Aos parceiros do laboratório de Prótese Parcial Removível: **Andréa Araújo, Antônio Pedro, Indira Cavalcante, Giancarlo De la Torre, Kelly Andrade, Larissa Vilanova, Lívia Forster, Luiz Carlos** pelo ótimo convívio no dia-a-dia do laboratório. À **Edmara Tatiely, Fernando Rigolin, Letícia Gonçalves, Paula Furlan, Thaís Gonçalves** pela oportunidade de aprendizado. À **Aline Sampaio, Bruna Alferes**, **Camilla Lima** e **Samilly Souza**, pelos momentos de descontração. À **Camila Heitor e Plínio Senna** por toda ajuda e atenção presta a mim. Ao **Yuri Carvalcanti** pelo carinho e amizade. Aos queridos parceiros que compartilham conhecimentos dentro de uma metodologia em comum **Germana Camargos**, **Marco Aurélio** e **Bruno Sotto-Maior** muito obrigada por tudo que me ensinaram. Agradeço em especial a **Priscilla Lazarri e Dimorvan Bordin** que estão sempre muito dispostos a compartilhar, ajudar e realizar qualquer trabalho com muita alegria. Aos que já foram **Arcelino Farias, Carol Meloto, Lis Meireles, Sheila Rodrigues, Willian Custódio**, pelas experiências trocadas.

À **Gislaine Piton**, **Eliete Aparecida** e **Ana Paula** funcionárias competentes e dedicadas, por toda ajuda e convivência no dia-a-dia.

Aos queridos **Alfonso Sánchez, Danilo Gonzaga, João Lyra, João Silva, Monokuame Petelo** por todo conhecimento transmitido a mim e pelos momentos compartilhados. A **Ataís Bacchi** pela parceria imensa e amizade, muito obrigada. À **Laíse Lima** e **Naiara de Paula Nóbilo** pela amizade prazerosa. À **Karina Morais** por toda amizade, ajuda e pela alegria que é a **Malu**. À **Caroline Odo, Cindy Goes e Izabella Pereira** pelo tempo que partilhamos. As minhas amigas **Gabriela Cassaro** e **Giselle Rodrigues Ribeiro,** por tudo que vivemos e que fizeram por mim. A **Micaela Cardoso**, amiga querida, pelo cuidado delicado que tem comigo, muito obrigada por cuidar de mim.

A todos os amigos conquistados ao longo dos anos de minha vida que não se perderam com a distância e passar dos anos, em especial **Helen Queiroz, Isabelle Graziella, Gustavo Dália, Juan Pablo, Karina Guatreaux, Mário Márcio Filho, Marcos Dantas, Marina Lavor, Miguel Martinez, Rafaela Cid** dentre tantas pessoas muito queridas para mim**.** Às mais antigas **Marcia Soares, Paula Duarte** e **Thais Barcia** ter vocês é uma felicidade para mim.

Ao meu noivo **Pedro Neto** por todo o amor que me transmite, por todo carinho, por cuidar de mim e me por como prioridade em sua vida.

A todos aqueles que de uma forma ou de outra colaboraram para a realização deste trabalho, que participaram junto comigo ou estiveram presentes em minha vida ao longo desses anos de formação.

**LISTA DE ABREVIATURAS E SIGLAS**

CG – Control Group = implantes com 11 mm comprimento  e 4 mm de diâmetro

Ci – “Conventional Implant” = implante com 4 mm de diâmetro

Wi – “Wide Implant” = implante com 5 mm de diâmetro

Ci9 – “Conventional Implant” com 9 mm de comprimento

Ci7 – “Conventional Implant” com 7 mm de comprimento

Ci5– “Conventional Implant” com 5 mm de comprimento

Wi9– “Wide Implant” com 9 mm de comprimento

Wi7– “Wide Implant” com 7 mm de comprimento

Wi5– “Wide Implant” com 5 mm de comprimento

$\sigma_{vM}$ – von Mises Stress

$\sigma_{max}$ – Maximum Principal Stress

P:I – Prosthesis-Implant (ratio)

## INTRODUÇÃO

A ausência dentária e de estímulo funcional para manutenção do osso, culmina em um processo de reabsorção e remodelagem óssea fisiológica e irreversível. A necessidade de reabilitações cada dia mais estéticas e eficientes faz com que as próteses implanto-suportadas ganhem preferência dentro das diversas opções da odontologia restauradora. Pacientes com reabsorção severa da mandíbula, usuários de próteses totais removíveis, comumente se queixam da função deficiente alcançada com esta modalidade de tratamento. A perda da estabilidade e retenção é responsável por grande parte das reclamações, sendo esta condição mais expressiva na mandíbula (Stellingsma K. *et al.,* 2004). As próteses sobre implantes representam uma solução efetiva para eliminação desta condição. Entretanto, a redução severa do remanescente ósseo limita a utilização de implantes de comprimento longo e está associada a incidência de fraturas de mandíbula, mesmo que baixas (< 0,05% em 27 anos de avaliação) (Soehardi *et al.,* 2011).

Implantes curtos surgiram como uma tentativa de alcançar as vantagens oferecidas pelas próteses suportadas por implantes osseointegrados, sem a necessidade implícita dos processos reconstrutivos, que visam compensar a reabsorção óssea fisiológica, viabilizando a inserção de implantes de maior comprimento. Inicialmente, implantes curtos de 10mm (*Standart Branemark* - 3.75mm de diâmetro) foram introduzidos para este contexto e com o passar dos anos o comprimento dos implantes foi reduzindo, com a finalidade de aumentar o número de casos que poderiam ser reabilitados com esta opção de tratamento, sendo introduzidos assim, implantes de 7mm de comprimento (Karthikeyan *et al.*, 2012). Atualmente a definição exata de implantes curtos não se mostra consensual na literatura, mas de uma maneira geral, implantes iguais ou menores que 10 mm são considerados curtos (Atieh *et al.,* 2012) e essa é a medida limite mais usada para a esta definição (Atieh *et al*., 2012; Elangovan *et al.*, 2013; Jiansheng *et al.*, 2012; Lops *et al.*, 2012; Menchero-Cantalejo *et al.*, 2011; Monje *et al.*, 2013; Telleman *et al.*, 2011).

A opção por implantes curtos simplifica substancialmente a reabilitação minimizando a incidência de complicações associadas às intervenções reconstrutivas, prévias ou imediatas à instalação de implantes mais longos (Esposito *et al.*, 2011 (a);

Jiansheng *et al.*, 2012; Maestre-Ferrín *et al.,* 2009). As vantagens associadas às reabilitações com implantes de menor comprimento estão quase sempre vinculadas à redução ou eliminação de cirurgias preliminares de maior complexidade, diminuindo assim o risco cirúrgico, o tempo de tratamento, custos e desconforto do tratamento (Atieh *et al.*, 2012; Felice *et al.,* 2010; Grant *et al.,* 2009).

Apesar dos índices de sucesso (60 a 100%) (Chiapasco *et al.,* 2009, 2006), os procedimentos de enxertia geralmente estão associados a taxas significativamente maiores de falhas e complicações (Chiapasco *et al.*, 2009, 2006; Esposito et al., 2011 (a); Felice *et al.*, 2009; Maestre-Ferrín *et al.*, 2009; Mertens *et al.*, 2012; Stellingsma K. *et al.*, 2004). Em comparação com implantes curtos (6.5 mm) foram observadas cerca de vinte e duas complicações para trinta pacientes enxertados contra cinco em trinta pacientes tratados com implantes curtos, em um período de 3 anos de observação (Esposito *et al*., 2011 (a)). Pacientes submetidos à cirurgia de enxerto podem permanecer hospitalizados cerca de 3 a 9 dias, enquanto pacientes tratados com implantes curtos não são submetidos a essa experiência, além de apresentarem menor incidência de complicações e perda de implantes (Keller & Tolman, 1992; Stellingsma K. *et al.*, 2004). Deslocamento e reabsorção do enxerto também são citados na literatura como complicações em pacientes enxertados (Maestre-Ferrín *et al.,* 2009). Outro ponto a ser considerado nesta comparação é que implantes curtos são fixados em osso nativo tornando o procedimento mais previsível (Esposito *et al.*, 2006; Esposito *et al.,* 2011(b), 2011(a); Felice *et al.*, 2009, 2012). A indicação de implantes curtos pode livrar o paciente de procedimentos mais agressivos, de maneira segura e previsível aumentando assim, o número de indicações e a aceitação, por parte do paciente em ser submetido à terapia com implantes osseointegrados (Lai *et al.,* 2013).

As vantagens alcançadas com implantes curtos seriam irrelevantes se a sobrevida destes implantes fosse significativamente menor, quando comparado aos implantes longos (Atieh *et al.,* 2012). Inicialmente, os casos de falhas observadas nos implantes curtos *standarts* (3.75 de diâmetro) eram considerados mais frequentes do que em implantes longos (Jemt, 1991; Lekholm *et al.,* 1999). A proporção coroa-implante desfavorável foi apontada como uma possível causa para baixa taxa de sobrevida dos implantes curtos já que esta relação poderia influenciar no comportamento biomecânico da prótese. A redução da área de contato entre osso/implante poderia estar relacionada às mudanças negativas no comportamento biomecânico, provocadas por um braço de alavanca aumentado, na relação suporte-restauração (Misch *et al.*, 2006; Romeo *et al.,* 2006). Princípios da proporção coroa-raiz, determinados para dentes naturais, foram inicialmente aplicados em reabilitações implanto-suportadas (Birdi *et al.,* 2010), entretanto, os implantes osseointegrados parecem não seguir fielmente os parâmetros determinados para dentição natural. Estudos clínicos recentes afirmam que a proporção, inicialmente considerada desfavorável, entre o tamanho da coroa e o comprimento dos implantes curtos parece não inferir qualquer influência negativa para o sucesso do tratamento em próteses parciais e unitárias (Atieh *et al.*, 2012; Birdi *et al.*, 2010; Blanes *et al.*, 2007; Menchero-Cantalejo *et al.*, 2011; Mertens *et al.*, 2012). Essa teoria é reforçada por estudo clínico retrospectivo onde a proporção coroa-implante variou de 0,9 a 3,2 mm e não afetou o sucesso dos implantes curtos (Birdi *et al.,* 2010).

Mesmo com índices baixos de falha, em acompanhamentos de 10 a 20 anos em função, (Lai *et al.,* 2013; Lops *et al.,* 2012; Mertens *et al.,* 2012) estudos clínicos mostram que mais de 70% dessas falhas acontecem antes do carregamento, abstendo a razão da falha à ação mecânica do conjunto coroa-implante (Atieh *et al.,* 2012; Felice *et al.,* 2012; Menchero-cantalejo *et al.,* 2011). Implantes curtos (≤ 8 mm) foram considerados suficientes para suportar forças oclusais, sem perda óssea marginal, mesmo quando não esplintados e restaurados com coras unitárias (Lai *et al.,* 2013). Casos de perda do parafuso de retenção (5,6%), fratura do pilar (0,4%), perda de retenção em coroas cimentadas (3,9%) e fratura da porcelana (2,6%) são consideradas comuns, para o número de implantes colocados em um período de 5 a 10 anos de avaliação, mas, apesar disto, a complicação mais comum neste período foram quadros de peri-implantite, que culminaram na perda dos implantes e redução da taxa de sobrevida a longo prazo (Lai *et al.,* 2013). Causa esta, também citada como fator relevante para perda tardia destes implantes (Lops *et al.,* 2012).

Estudos clínicos atuais demonstram que as taxas de sobrevida de implantes curtos são semelhantes às taxas encontradas com implantes longos variando de 94 a 100% com períodos de acompanhamento de 1 a 10 anos (De Santis *et al.,* 2011; Griffin e Cheung, 2004; Guljé *et al.*, 2013; Jiansheng *et al.*, 2012; Lai *et al.*, 2013; Maló *et al.*, 2007, 2011; Nedir *et al.,* 2004). Adicionalmente estudos clínicos comparando implantes curtos aos implantes longos associados à procedimentos reconstrutivos, reforçam os baixos índices de falhas e complicações (Esposito *et al.*, 2011 (b), 2001 (a); Felice *et al.*, 2012), validando sua indicação como alternativa às técnicas reconstrutivas, com resultados positivos mesmo para implantes extremamente curtos (5 mm) (Felice *et al.*, 2012). Os resultados apontados na literatura sugerem que os implantes curtos parecem não ser tão frágeis, biomecanicamente, como se pensava anteriormente (Glantz e Nilner, 1998; Rangert *et al.*, 1997).

Fatores como tratamento de superfície e aumento do diâmetro dos implantes curtos parecem estar relacionados com a melhora dos índices alcançados (Menchero-Cantalejo *et al.*, 2011; Pommer *et al.*, 2011). A associação entre implantes curtos e de maior diâmetro tem o intuito de buscar um aumento na área de contato entre o implante e o tecido ósseo circunjacente. A redução do comprimento implica, necessariamente, na redução desta área de contato e o aumento do diâmetro compensaria essa redução. Estudo clínico (Jiansheng *et al.,* 2012) relata 162 casos de implantes curtos e largos para reabilitação de elementos isolados em região posterior com sobrevida de 99,4% em um período médio de 24 meses de observação, após carregamento. O aumento do diâmetro, além de ajudar a minimizar complicações, (das Neves *et al.*, 2006; Renouard e Nisand, 2006) pode tornar o índice de sucesso dos implantes curtos semelhantes aos longos de menor diâmetro (Mertens *et al.,* 2012). Apesar disto, revisões sistemáticas recentes apontam uma associação entre redução comprimento do implante (5 a 8.5mm) e índice de falhas (Atieh *et al.,* 2012; Pommer *et al.,* 2011; Telleman *et al.,* 2011) com aumento destes índices para implantes menores que 7mm (das Neves *et al.,* 2006; Pommer *et al.,* 2011; Telleman *et al.,* 2011). É relatado ainda, que o aumento do diâmetro não compensaria a redução do comprimento (Pommer *et al.,* 2011), tornando o assunto não consensual.

O uso de implantes curtos é muito difundido para tratamento de casos de edentulismo parcial e perdas unitárias, entretanto o comportamento biomecânico desta opção para casos de pacientes totalmente desdentados ainda não foi investigado. É apontada na literatura a necessidade de trabalhos que se direcionem a responder a partir de qual comprimento o risco de falha dos implantes aumenta (Pommer *et al.,* 2011), bem como é vista a necessidade de aumentar o número de informações a respeito comportamento das tensões presentes nesta opção de tratamento. Assim, este trabalho tem o objetivo avaliar do comportamento biomecânico de implantes curtos para suporte de próteses totais fixas em mandíbulas atróficas, assim como avaliar a influência do aumento do diâmetro destes implantes e da proporção prótese-implante neste comportamento, no intuito de ampliar o uso dos implantes curtos, de maneira mais previsível, para pacientes com mandíbulas severamente reabsorvidas.

**Formato da Tese**

Esta tese foi escrita no formato alternativo, conforme deliberação número 228/2013 da Comissão Central de Pós-Graduação (CCPG) da UNICAMP, que prevê a inclusão de artigos já publicados ou submetidos para publicação em revistas científicas como capítulos da tese.

O artigo descrito no capítulo 1 foi submetido ao periódico Clinical Implant Dentistry and Related Research (vide comprovante no Anexo 1). Os artigos apresentados nos capítulos seguintes encontram-se em fase de pré-submissão.

CAPÍTULO 1

## *Short implants to support fixed prosthesis in atrophic mandible – Photoelastic Testing*

Marcele Jardim PIMENTEL; Wander José da Silva; Altair Antoninha DEL BEL CURY

**Abstract**

**Background:** Previous studies evaluated the use of short implants for single or partial replacement however, their application in edentulous arch was not observed yet. **Objective:** This study evaluates the stress behaviour around short implants for edentulous atrophic mandibles. **Methodology:** The groups were composed by implants with two diameters (conventional 4.0 mm and wide 5.0 mm) and three lengths: Ci9 (9.0 x 4.0 mm), Ci7 (7.0 x 4.0 mm), Ci5 (5.0 x 4.0 mm), Wi9 (9.0 x 5.0 mm), Wi7 (7.0 x 5.0 mm) and Wi5 (5.0x5.0 mm) that were compared to a control group (CG 11.0 x 4.0 mm). The analysis was performed thought photoelasticity method ($n = 6$). Each model comprised 4 implants with same length and diameter, connected by a chromium-cobalt bar. A 0.15kgf were applied at the end of the cantilever (15 mm) and the maximum shear stress was recorded around the distal and subsequent implant. The stress values were determined and the quantitative data (Fringes®) were submitted to statistical analysis one-way ANOVA/Dunnet ($p < 0.05$). **Results:** The reduction in the implant length increased stress values with significant different from the CG to Ci5, while the association with wide diameter reduced the stress values without difference between short and long implants. **Conclusion:** Short implants increase stress around the implant, however, implants with 7 and 9 mm showed similar behaviour to long, especially when associated with large diameter.

**Key words**: Short Implants Photoelasticity, Biomechanical.
**Descriptors:** Dental Implantation, Dental Prosthesis, and Mandible.

## Introduction

Severe alveolar resorption represents a limiting situation in oral rehabilitation. [1,2] The progressive bone loss can restrict the use of implants, and there are many different surgical approaches to overcome this condition. [3,4] Short implants have been proposed as an alternative for surgical treatments in an attempt to exclude or reduce the need of bone grafts. In addition, they also reduce the morbidity, treatment time, costs and complications rates. [5–10]

Short implants were introduced with a standard diameter (3.75 mm) and lack of a superficial treatment. Initially, the survival rates of short implants are doubtful as showed by some studies, which reported a preponderance of failures when this type of implant was used. [11–13] Meanwhile recent studies have shown positive results with short implants [1,8,14–16] even when shorter than 7 mm of length was indicated. [7–9,17] Clinical studies have also appointed that short implants are a good choice especially if compared with longer implants, which are associated with extensive reconstructive procedures. [7,9,10,18] Patients submitted to the vertically augmented, in order to receive longer implants, experienced a higher implant failure and significant more complications compared with those patients that received short implants. [7,9,17,19] Additionally, a study of 20 years of follow up [15] showed that no implant fractures or more complications were found to shorter implants (8 mm).

Systematic reviews also appoint that short implants can be placed successfully in the partially edentulous patient [13,20–23], and implants shorter than 10 mm are sufficient to support occlusal forces without undesirable crestal bone resorption, even when restored with unsplinted single-crown. [8] Currently the increasing survival rates of the short implants are associated with improvement of surface of implants. The cumulative success of rough-surface implants is greater than machined-surface implants, especially for short implants. [21,23,24] Moreover, the increase of the diameter could help minimize complications [12,25,26] since that a large implant diameter results in more homogeneous stress distribution and less stress concentration on the implants. [27]

The majority of studies with short implants are conducted in single tooth restorations or partial edentulous. Few authors report cases with short implants in totally edentulous jaw. [15,28] These patients present a progressive bone resorption, and many times a conventional removable denture not achieves stability and satisfactory results. The implant-supported prosthesis represents an attractive option in theses cases, meantime that the bone friability, in cases of severely atrophic mandible, is a challenge due any increase of stress in this fragile bone, requires caution. Thus the knowledge of the biomechanics of dentures supported by short implants is necessary to increase the predictability of this treatment and avoid complications.[29] The encouraging results achieved by short implants conduced us to test the biomechanical behaviour of short implants to support fixed prosthesis in totally edentulous patient, trying to extend this rehabilitation option for cases of jaw severely atrophic with greater predictability, in an attempt to reduce large bone reconstructions. Thus, the aim of this study investigated stress levels in the peri-implant area when short implants are used to support a fixed prosthesis in atrophic mandible.

## Methodology

This in vitro study was conducted using the photoelastic analysis. The groups were composed according to lengths and diameters of the implants (Table 1). Each group contained four Morse taper implants (Titamax CM or Titamax WS, Neodent®, Curitiba - Brazil) with their respective abutments (1.5 mm of length). The implants were named A, B, C, D from the loaded to the non-loaded side. A chromium-cobalt bar with a bilateral cantilever of 15 mm was attached to the implants.

Table 1: Groups distribution according to length and diameter of implants

| Group | Length (mm) | Diameter (mm) |
|---|---|---|
| CG | 11.0 | 4.0 |
| Ci9 | 9.0 | 4.0 |
| Ci7 | 7.0 | 4.0 |
| Ci5 | 5.0 | 4.0 |
| Wi9 | 9.0 | 5.0 |
| Wi7 | 7.0 | 5.0 |
| Wi5 | 5.0 | 5.0 |

CG: Control Group; Ci: Conventional Implant (4.0 mm of diameter); Wi: Wide Implant (5.0 mm of diameter)

*Photoelastic model development*

a) <u>Matrix development</u>

Phoelastic plane models were fabricated considering an average interforame distance of 40.35 mm obtained from a metric analysis involving twenty-three dissected resorbed mandibles. Such distance mean value was used to determine the spatial distribution of implants using computer software (SolidWorks, Dassault Systemes Solid Works Corp., Concord, MA, USA) (Figure 1). This distance value was set in the software (Figure 1A - red line) and a mandible image was imported to limit the anterior anatomy of the arch. The dimensions used to obtain the plane model were then determined (Figure 1 - blue line) following the curvature of the arc and the interforame distance. Based on these dimensions, a glass matrix for the photoelastic model was made with two plane arms (50 mm long each), with an angle of approximately 130°, a height of 20 mm, and a thickness of 10 mm.

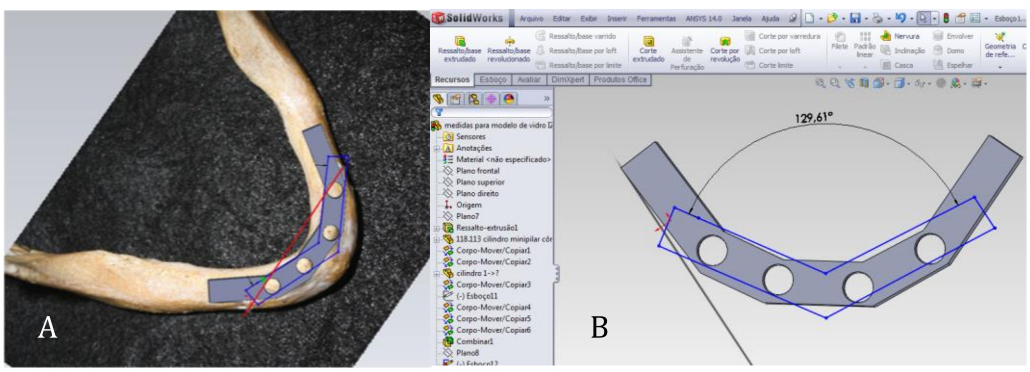



Figure 1: A) Interforame Distance (40.35mm) represented by red line. B) Spatial distribution of the implants considering the mean values of the distance between alveolar foramen.

b) Master casts

A polyvinyl siloxane impression was taken from a mandible (Figure 2A) and, based on the implant position defined in the software, an index was created to standardize the position of each analogous abutment (Figure 2B). One master cast was built with type IV stone (Figure 2C) and used to fabricate the cobalt-chromium frameworks.

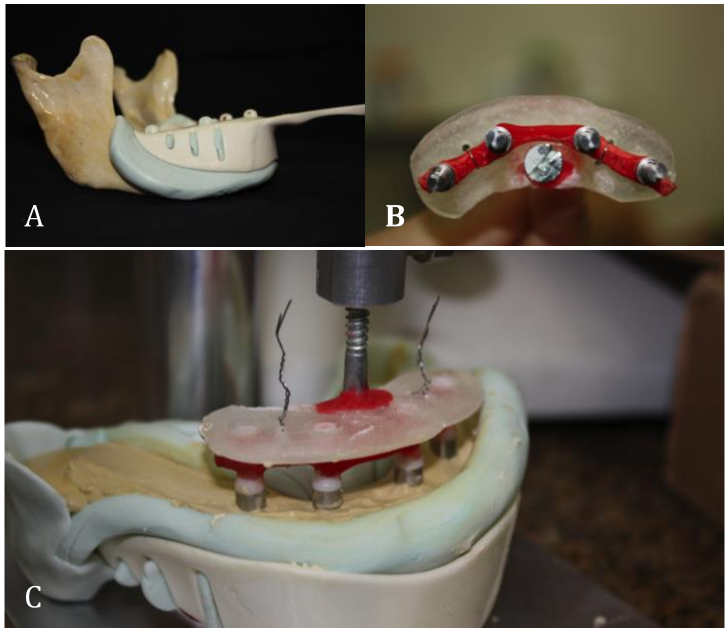



Figure 2: A) Jaw shaped, B) Analogous distribution, C) Plaster models cure.

c) Photoelastic model manufacture

The glass matrix was immersed in silicone (ABS blue – Polipox/Sao Paulo/SP/Brazil) and after 4 hours the mold was obtained. The abutments and the bar were installed in the implants (Figure 3A). This set was fixed in an acrylic platform with steel wire, and positioned in a device fabricated to allow the suspension of the set (Figure 3B) within a pressure chamber. The vertical rod was manipulated to insert the implants in the exactly position into the mold (Figure 3C). The photoelastic resin (GIV - Polipox/Sao Paulo/SP/Brazil) was insert with a syringe until achieves the implant platform. This set was submitted to the air pressure (60 psi/10 minutes) to eliminate air molecules, and waiting 48 hour achieving the final shape (Figure 3D). The final model presented smooth and transparent appearance and also, were analysed in the polariscope to confirm the absence of residual stresses. A slit was made, at the end of cantilever, to ensure that the load exerted was held in the same position for all bars.

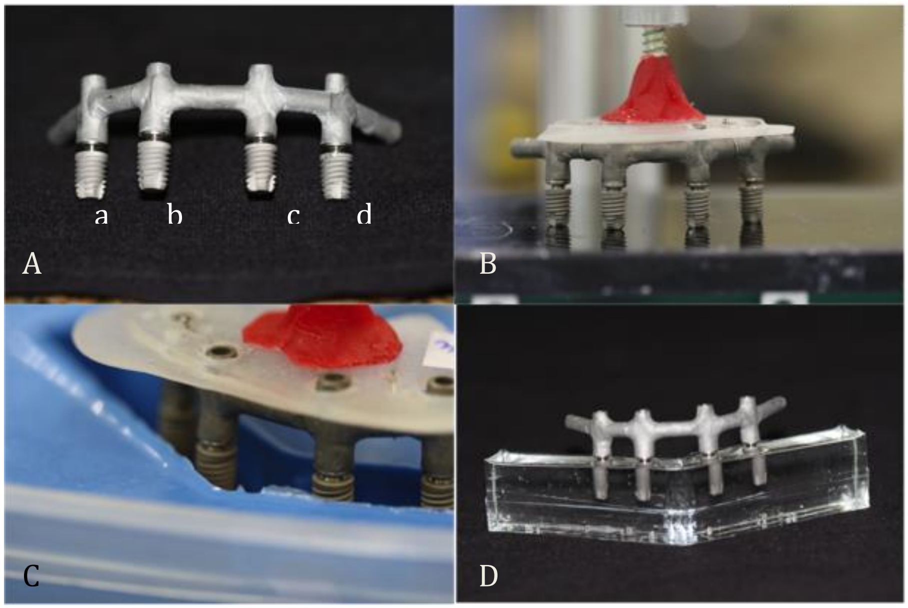



Figure 3: Photoelastic model: A) Implants (a, b, abutments and bar. B) Parallelism between the implants. C) The set inserted in the mold. D) Final model.

*Loading and Analysis Characteristic*

A load of 0.15 kgf was applied at the end of the cantilever, unilaterally. The load value was determined in a pilot study, in order to restrict the fringes formation until order 4, which allows the determination of the shear stress values (n = 6).

The quantitative analysis was performed by Fringes® software (Federal University of Uberlandia – UFU). Five-point readings were pre-determined in the Fringes® software (two cervical and three apical), in which values of shear stress were obtained (Figure 4). Data were subjected to One-way ANOVA followed by Dunnett's for comparison to the CG ($P < 0.05$) (SAS - *Statistical Analysis System,* North Carolina USA).

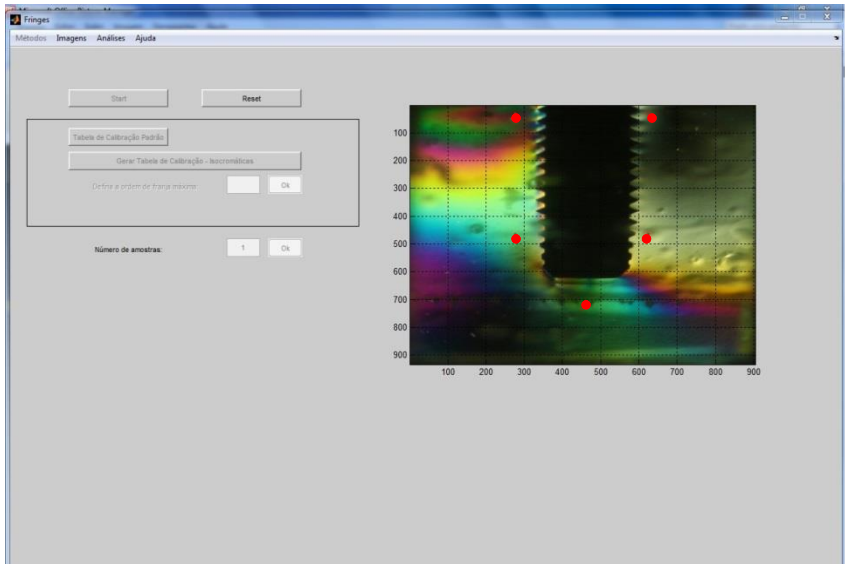



Figure 4: The Fringes Software platform, whit pre-determinate points of analysis (red points)

**Results**

Qualitative analysis showed that the fringes were present mainly in the implant closer to the load side (*implant A*) and in the subsequent implant (*implant B*). For this reason only this two implants were analysed in the software (Table 2).

Analysing the stress behaviour in cervical area was observed that, regarding the smaller diameter groups (4 mm of diameter), only implants with 9mm of length (Ci9) had a similar shear stress values compared to the CG. When associated with the large diameter, it was observed a reduction on the stress values in the cervical region without significant differences between short implants and CG. For apical area implants with 5 mm of length showed significantly different stress behaviour, with more stress concentration. The association with short and increased diameter reduced stress values without statistical differences compared to the CG (Figure 5).

The length or increase in the diameter does not interfere with the stress behaviour for cervical areas for implant B, however showed difference of the stress behaviour for apical stress concentration (Figure 6).

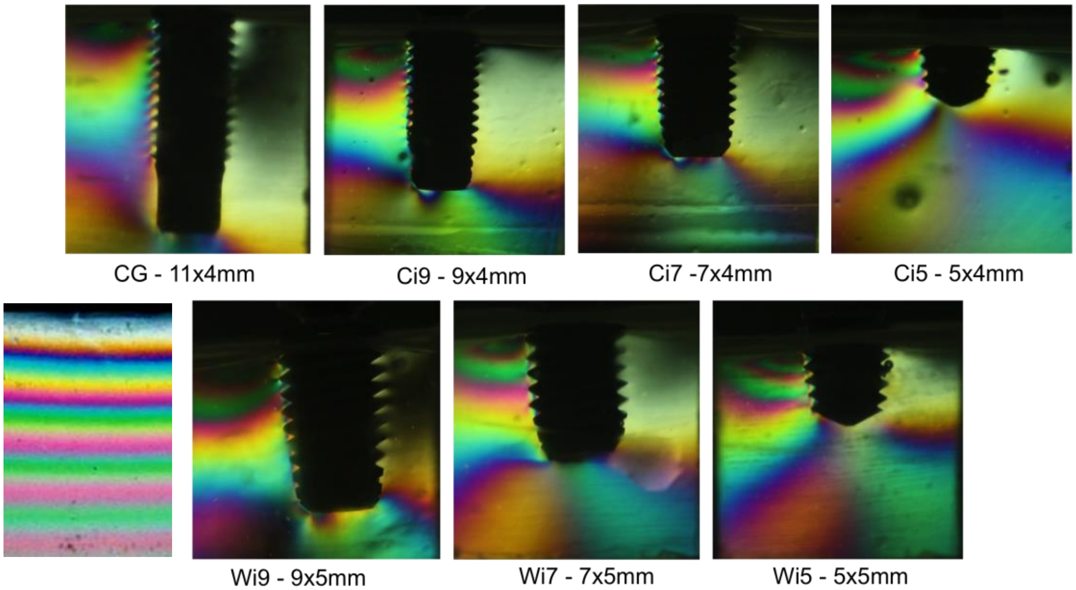



Figure 5: Illustration of the fringe behaviour in the groups to implant A.

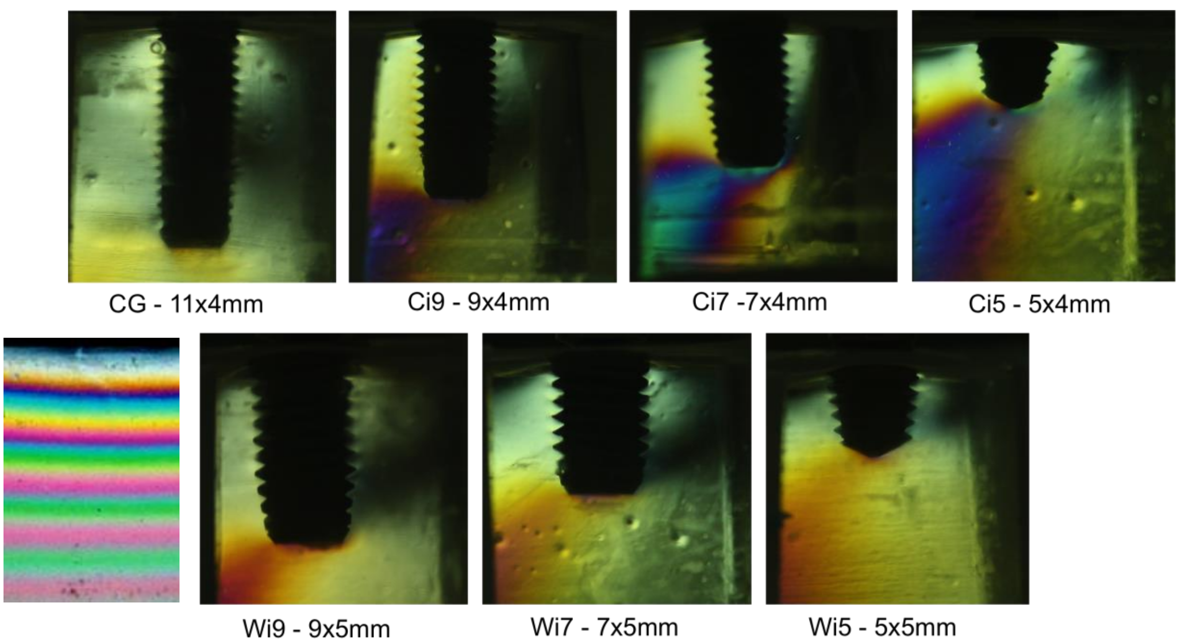



Figure 6: Illustration of the fringe behaviour in the groups to implant B.

Table 2: Shear stress values to implant A (closer to the load side) and implant B (subsequent implant).

| | **Shear Stress Values** (MPa) | | | | | |
|---|---|---|---|---|---|---|
| | *Implant A* | | | *Implant B* | | |
| **Groups** | *Total Stress* | *Cervical Stress* | *Apical Stress* | *Total Stress* | *Cervical Stress* | *Apical Stress* |
| **CG** | 97,84 ± 15,68 | 46.31 ± 9.13 | 51.53 ± 7.12 | 50,94 ± 1,59 | 19.90 ± 0.88 | 31.04 ± 1.75 |
| **Ci9** | 118,80 ± 9,63 | 59.02 ± 9.18 | 59.79 ± 7.98 | 52,26 ± 8,02 | 17.96 ± 0.67 | 34.30 ± 8.02 |
| **Ci7** | 118,93 ± 13,10 | 64.58 ± 9.04* | 54.34± 7.70 | 54,57 ± 5,14 | 19.46 ± 1.45 | 35.11 ± 5.12 |
| **Ci5** | 143,98 ± 21,87* | 68.11 ± 11.74* | 75.87 ± 10.27* | 61,21 ± 8,36 * | 20.32 ± 1.99 | 40.89± 7.73* |
| **Wi9** | 110,74 ±11,76 | 54.26 ± 6.53 | 56.48 ± 6.74 | 52,55 ±1,94 | 20.28 ± 1.05 | 32.27± 1.02 |
| **Wi7** | 113,90 ± 9,76 | 57.41± 8.89 | 56.49 ± 2.42 | 46,62 ± 4,85 | 18.96 ± 2.01 | 27.66 ± 3.32 |
| **Wi5** | 118,32 ± 22,47 | 61.00 ± 9.56 | 57.33 ± 4.58 | 18,44 ± 3,69 | 18.44 ± 3.69 | 30.46 ± 6.38 |

Symbol (*) indicates different behavior compared to CG. Comparisons significant $p < 0.05$.

## Discussion

The hypothesis that short implants increase stress levels in the peri-implants area when used to support a fixed prosthesis in atrophic mandible was accepted. However, the stress behaviour was not similar for all the short implants. The definition of short implants has not reached absolute consensus, and for the most published study implants of 10mm or shorter have generally been considered “short”. [20,22] The implant length in the groups was based in this concept. There are few studies to evaluate the extra-short implants effectiveness. [7,13,30] Thus, implants with 5 mm was insert to simulated an extreme condition.

Annibali and colleagues[21] report in a systematic review that the biomechanical rationale behind the use of short implants is that the crestal portion concentrate the increased stress, whereas very little stress is transferred to the apical portion. In the present study considering the implant A (next to the load side) the results showed significant more stress on cervical area for Ci5 and Ci7. The shear stress values were higher in the cervical portion and the images clearly show more fringes formation to shorter implants. The stress concentration in the implant A may be due the loading in the cantilever extension; the stress was concentrated especially in the cervical portion at the closet load implant, in the same side of load. Analysing the subsequent implant (B), the behaviour is different; the stress was more concentrated in the apical region. This may resulted from the splint arrangement, since that the splints between the implants change the biomechanical behaviour. [8,31,32] The other implants (C and D) did not show fringes formation, and for this reason, they were not included in the analyses.

Initially, it was suggested that the length of the implants were directly related the implants failures rates. [11,12] However the survival rates of short implants must be compared with the success rate of standard implants associated with advanced surgical techniques of graft in resorbed regions. [9,17,21] Thus, the short implants should be considered an alterative to eliminated grafts procedures. Under these circumstances, the survival of standard implants decreases to maxilla or mandible, and being recommended to prioritize simpler approaches. [3,4] The current study found similar stress behaviour to total stress when implants with 11, 9 and 7 mm of length was compared. The improvement of the stress distribution and reduction in the shear stress values when the increased diameter was associated, confirm that the contact area between bone-implant is relevant to improve the mechanical behaviour. However, the reduction in length not results in statistical differences between them. A clinical retrospective study affirms that factors involving the survival rates seen to be independent of the implant length, and the prognosis of short implants is consistent to partial and single-crowns.[15] However, this retrospective study compare implants with 8 and 10 mm of length, meanwhile some authors consider implants with 10 mm, as a short implant.[23]

Stress levels in the bone tissue surrounding splinted implants showed markedly lower values when compared with single implants. [33] Previous clinical study showed 100% of survival to implants and prosthesis supported by short implants (< 10 mm) even after 10 years of follow up, and the authors report that this very good outcome could be a result of splinting implants. [1] Reflecting about the high successful reports with short implants, even to single crowns, and considering that to a fixed complete prosthesis the implants are splinted, we believe that short implants can be used to atrophic full edentulous jaw without system biomechanical damage. It is interesting when Lai and colleagues [8] affirm that short implants (shorter than 8 mm) are sufficient to support occlusal forces (without difference between 6 or 8 mm) even when restored with unsplinted single crowns, because this reinforce the hypotheses that splinted implants can show even better results. Despite this, was reported that the most failures process with short implants happens before the loading, exempting biomechanical factors of blame for this failure. [21–23]

Many studies report the use short implants (≤10 mm) with a considerable success, however the literature regarding survival rate of ≤ 7 mm is sparce. [13] Despite this, a recent systematic review affirms that short (≤ 7 mm) can be placed successfully, in mandibular or maxilla. The majority of the studies included in this review associate short and wide implants. [13] Biomechanical test showed that an increase of the implant diameter result in more homogeneous stress distribution and less stress concentration on the implants, [27] besides minimize complications[25,26], and might guarantee the conservation of marginal peri-implant bone level. [34] Previous recent study affirms that short-wide implants provides an increased implant-bone contact area, suggesting that this increased area could make a short implant comparable to a longer implant with a smaller diameter. [1] In addition, previous clinical trials suggested that the potential role of the implant diameter for short implants should be investigated, since clinicians tend to compensate for the lack of height by using implants with a wider diameter. [17] The present study brings some valuable information regarding this discussion showing that the association of short and wide diameter resulted in better performance in the stress distribution around the short implants (9, 7 and 5 mm) and approximates the biomechanical behaviour to those found with long implants. Considering the adjacent implant (B), shorter-wide implants (7 and 5 mm) concentrated less stress in the peri-implant area than longer implant. This biomechanical testing proves that has a comparable behaviour between the short-wide implants and the long implants regarding the concentration of stress in the peri-implant area.

Interesting point to discuss is the possibility of a large diameter implant being compatible with bone-resorbed shape. Although considered large, implants with 5 and 6mm of diameter were considered sufficiently small to allow rehabilitation of posterior jaw in severe resorbed cases. [7,17] Short implant with 4.8 mm of diameter were reported to support fixed complete dentures without fractures or more complications.[15] Although, this, some patients are successfully rehabilitated even with short-lower diameter implants (3.0 to 4.5). [1,13]

Few study reported results with 6 or 5mm implants length. Systematic review affirms that this point limits conclusions about their clinical outcomes, that should be drawn with caution. [21] The results of the present study reinforce the caution needed, since the groups with 5mm show different stress behaviour even when they were splinted. Nevertheless, clinical studies conduced with extra short implants (5x5 mm) concluded that, clinically, the short implants are similar, if not better, to the longer implants into the appropriated comparison where the longer implants are associated with reconstructive procedures, to single crown or partial restoration in short term follow up. [7,9,17]

Although there are surprising results with short implants, there are some precautions not yet discussed, such as the cantilevers avoidance. [35] The success rate of implants restored with single crown and cantilevers restorations are lower than splinted fixed partial prosthesis. [36] The present study produced a 15mm of cantilever, and even in this condition the results of short implants were similar to long implants. This may be due the splinting multiple implants, that is considered is favourable to improve the biomechanical behaviour [33,35] and survival [36] of the implants.

The predictable use of short implants could expand the range of indications and increase patient acceptance of the implant therapy. [8] However, there are relevant points were not included in this study, such as the behaviour of the prosthetics components (abutments, bar and retention screw), the stress concentration on implant body and the quality or friability conditions of remain bone in severe atrophic process. The bone quality is a factor that can influence the survival rates [1], and it was not considered in this study, however concern that the bone type seems similar to long implants, short implants had a better prognosis in the mandible [20], as well in the bone type I –III [8] witch specially caution to bone type IV[25,37], that is no frequently observed in mandible.

**Conclusion**

Short implants increase stress concentration in the peri-implant area. Implants with 7 and 9 mm of length showed similar behaviour to the long implants, especially when associated with an increased diameter. Extra short implants (5 mm) increased the stress levels with large differences to the long implant.

**Acknowledgments**

The authors would like to thank the Neodent for the granting of the material, to the professor Mauro A. A. Nobilo to allow use of polariscope for this study, and the professor Marcelo F. Mesquita to allow the use of the prosthesis laboratory, Piracicaba Dental School. This study was supported by FAPESP with study scholarships awarded to the first named author #2011/21877-2.

**References**

1. Mertens C, Meyer-Bäumer A, Kappel H, Hoffmann J, Steveling HG. Use of 8-mm and 9-mm implants in atrophic alveolar ridges: 10-year results. Int J Oral Maxillofac Implants 2012; 27(6):1501–8.

2. Yi YS, Emanuel KM, Chuang S-K. Short (5.0 × 5.0 mm) implant placements and restoration with integrated abutment crowns. Implant Dent 2011; 20(2):125–30.

3. Chiapasco M, Casentini P, Zaniboni M. Bone augmentation procedures in implant dentistry. Int J Oral Maxillofac Implants 2009;24 Suppl(1):237–59.

4. Chiapasco M, Zaniboni M, Boisco M. Augmentation procedures for the rehabilitation of deficient edentulous ridges with oral implants. Clin Oral Implants Res. 2006;17 Suppl 2(c):136–59.

5. Gulje F. Implants of 6 mm vs . 11 mm lengths in the posterior maxilla and mandible : a 1-year multicenter randomized controlled trial. Clin Oral Implants Res 2013; 24(12):1325-31.

6. Arlin ML. Short dental implants as a treatment option: results from an observational study in a single private practice. Int J Oral Maxillofac Implants 2006; 21(5):769–76.

7. Felice P, Pistilli R, Piattelli M, Soardi E, Corvino V, Esposito M. Posterior atrophic jaws rehabilitated with prostheses supported by 5 × 5 mm implants with a novel nanostructured calcium-incorporated titanium surface or by longer implants in augmented bone . Preliminary results from a randomised controlled trial. Eur J of implantology 2012; 5(2):149–61.

8. Lai H, Si M, Zhuang L, Liu Y. Long-term outcomes of short dental implants supporting single crowns in posterior region : a clinical retrospective study of 5 – 10 years. Clin Oral Impl Res 2013; (2011):230–7.

9. Esposito M, Cannizarro G, Soardi E, Pellegrino G, Pistilli R, Felice P. A 3-year post-loading report of a randomised controlled trial on the rehabilitation of posterior atrophic mandibles: short implants or longer implants in vertically augmented bone? Eur J Oral Implantol 2011; 4(4):301–11.

10. Felice P, Pellegrino G, Checchi L, Pistilli R, Esposito M. Vertical augmentation with interpositional blocks of anorganic bovine bone vs. 7-mm-long implants in posterior mandibles: 1-year results of a randomized clinical trial. Clin Oral Implants Res 2010; 21(12):1394–403.

11. Jemt T. Failures and complications in 391 consecutively inserted fixed prostheses supported by Brånemark implants in edentulous jaws: a study of treatment from the time of prosthesis placement to the first annual checkup. Int J Oral Maxillofac Implants 1991;6(3):270–6.

12. Lekholm U, Gunne J, Henry P, Higuchi K, Lindén U, Bergström C, et al. Survival of the Brånemark implant in partially edentulous jaws: a 10-year prospective multicenter study. Int J Oral Maxillofac Implants 1999; 14(5):639–45.

13. Karthikeyan I, Desai SR, Singh R. short implants : A systematic review. J Indian Soc Periodontol 2012; 16(3).

14. Perelli M. Short ( 5 and 7 mm long ) porous implants in the posterior atrophic mandible : a 5-year report of a prospective study. Euro J Oral Implantol 2011; 4(4):363–8.

15. Lops D, Bressan E, Pisoni G, Corazza B, Romeo E. Short Implants in Partially Edentulous Maxillae and Mandibles : A 10 to 20 Years Retrospective Evaluation. Int J Dent 2012; 2012:351793.

16. Jiansheng H, Dongying X, Xianfeng W, Baoyi X, Qiong L, Jincai Z. Clinical evaluation of short and wide-diameter implants immediately placed into extraction sockets of posterior areas: a 2-year retrospective study. J Oral Implantol 2012; 38(6):729–37.

17. Esposito M, Pellegrino G, Pistilli R, Felice P. Rehabilitation of posterior atrophic edentulous jaws : prostheses supported by 5 mm short implants or by longer implants in augmented bone ? One-year results from a pilot randomised clinical trial. Euro J Oral Implantal 2011; 4(1):21–30.

18. Felice P, Checchi V, Pistilli R, Scarano A, Pellegrino G, Esposito M. Bone augmentation versus 5-mm dental implants in posterior atrophic jaws. Four-month post-loading results from a randomised controlled clinical trial. Eur J Oral Implantol 2009; 2(4):267–81.

19. Stellingsma K, Raghoebar GM, Meijer HJ a, Stegenga B. The extremely resorbed mandible: a comparative prospective study of 2-year results with 3 treatment strategies. Int J Oral Maxillofac Implants 2004; 19(4):563–77.

20. Telleman G, Raghoebar GM, Vissink A, den Hartog L, Huddleston Slater JJR, Meijer HJ a. A systematic review of the prognosis of short (<10 mm) dental implants placed in the partially edentulous patient. J Clin Periodontol 2011; 38(7):667–76.

21. Annibali S, Cristalli MP, Dell'Aquila D, Bignozzi I, La Monaca G, Pilloni a. Short dental implants: a systematic review. J Dent Res 2012; 91(1):25–32.

22. Atieh M a, Zadeh H, Stanford CM, Cooper LF. Survival of short dental implants for treatment of posterior partial edentulism: a systematic review. Int J Oral Maxillofac Implants 2012; 27(6):1323–31.

23. Menchero-cantalejo E, Barona-dorado C, Cantero-álvarez M, Fernández-cáliz F. Meta-analysis on the survival of short implants. Med Oral Patol Oral Cir Bucal 2011; 16(4):546-51.

24. Feldman S, Boitel N, Weng D, Kohles SS, Stach RM. Five-year survival distributions of short-length (10 mm or less) machined-surfaced and Osseotite implants. Clin Implant Dent Relat Res 2004; 6(1):16–23.

25. Renouard F, Nisand D. Impact of implant length and diameter on survival rates. Clin Oral Implants Res 2006; 17 Suppl 2:35–51.

26. Das Neves FD, Fones D, Bernardes SR, do Prado CJ, Neto AJF. Short implants--an analysis of longitudinal studies. Int J Oral Maxillofac Implants 2006; 21(1):86–93.

27. De Paula GA, da Mota AS, Moreira AN, de Magahlães CS, Cornacchia TPM, Cimini CA. The effect of prosthesis length and implant diameter on the stress distribution in tooth-implant-supported prostheses: a finite element analysis. Int J Oral Maxillofac Implants 2012; 27(3):19–28.

28. Stellingsma C, Vissink a., Meijer HJ a., Kuiper C, Raghoebar GM. Implantology and the Severely Resorbed Edentulous Mandible. Crit Rev Oral Biol Med. 2004; 15(4):240–8.

29. Soehardi A, Meijer GJ, Manders R, Stoelnga PJW. An inventory of mandibular fractures associated with implants in atrophic edentulous mandibles: a survey of Dutch oral and maxillofacial surgeons. Int J Oral Maxillofac Implants 2011; 26(5):1087–93.

30. Bressan E, Sivolella S, Urrutia ZA, Salata LA, Lang NP, Botticelli D. Short implants (6 mm) installed immediately into extraction sockets: an experimental study in dogs. Clin Oral Implants Res 2012; 23(5):536–41.

31. Pjetursson BE, Tan K, Lang NP, Brägger U, Egger M, Zwahlen M. A systematic review of the survival and complication rates of fixed partial dentures (FPDs) after an observation period of at least 5 years. Clin Oral Implants Res 2004;15(6):667–76.

32. Nissan J, Ghelfan O, Gross M, Chaushu G. Analysis of load transfer and stress distribution by splinted and unsplinted implant-supported fixed cemented restorations. J Oral Rehabil 2010; 37(9):658–62.

33. Bergkvist G, Simonsson K, Rydberg K, Johansson F, Dérand T. A finite element analysis of stress distribution in bone tissue surrounding uncoupled or splinted dental implants. Clin Implant Dent Relat Res 2008; 10(1):40–6.

34. Sbordone C, Toti P, Ramaglia L, Guidetti F, Sbordone L, Martuscelli R. A 5-year clinical and computerized tomographic implant follow-up in sinus-lifted maxillae and native bone. Clin Oral Implants Res 2013;1–9.

35. Misch CE, Steignga J, Barboza E, Misch-Dietsh F, Cianciola LJ, Kazor C. Short dental implants in posterior partial edentulism: a multicenter retrospective 6-year case series study. J Periodontol 2006; 77(8):1340–7.

36. De Santis D, Cucchi A, Longhi C, Vincenzo B. Short threaded implants with an oxidized surface to restore posterior teeth: 1- to 3-year results of a prospective study. Int J Oral Maxillofac Implants. 2011;26(2):393–403.

37. Nedir R, Bischof M, Briaux J-M, Beyer S, Szmukler-Moncler S, Bernard J-P. A 7-year life table analysis from a prospective study on ITI implants with special emphasis on the use of short implants. Clin Oral Implants Res. 2004; 15(2):150–7.

CAPÍTULO 2

***Short implants to support fixed prosthesis in atrophic mandible: influence on bone and prosthetic components – Finite Element Analyses***

Marcele Jardim PIMENTEL; Dimorvan BORDIN; Altair Antoninha DEL BEL CURY

**Abstract**

**Objective**: The aim of this study was to evaluate the biomechanical behavior of short implants to support a complete denture in mimicking severely atrophic mandibles, using a finite elements analysis. **Method**: The virtual models consisted of the anterior section of mandibular, four implants, abutments, bar and retention screws. The control group (CG 4.0x11.0 mm) was compared to implants with three lengths and two diameters (conventional 4.0 or wide 5.0): Ci9 (4.0x9.0 mm), Ci7 (4.0x7.0 mm), Ci5 (4.0x5.0 mm), Wi9 (5.0x9.0 mm), Wi7 (5.0x7.0 mm), Wi5 (5.0x5.0 mm). For all groups an axial load (100 N) was applied in the end of cantilever (15mm) using the Ansys Workbench 14.0. The values of von Mises stress were obtained for implants and prosthetic components, and maximum principal stress for bone tissue. **Result**: Short implants (Ci) increased the stress in the cancelous bone until 37.44% (Ci7) compared to CG. The highest value of stress to the implants was observed to Ci5 (162.91 MPa) followed by Ci7 (126.15 MPa). The large diameter decreased the stress concentration in the bone and implants for all lengths. Concerning the abutment, wide implants had higher values of stress compared to Ci. Short implants increase the stress values in the retention screw. **Conclusion**: The Ci7, Ci5 and Wi5 result in more stress in the implant and bone. Short implants associated with a larger diameter reduced the stress values in the tissue bone and implants while increase stress concentration in abutment and screw.

**Key Words:** Biomechanical, Short Implants, Edentulous and Fixed Prosthesis.

**Descriptors:** Dental Implantation, Dental Prosthesis and Mandible.

## Introduction

After complete teeth loss, the alveolar portion of the jaws starts a resorption process that evolves to atrophy; this is a chronic process, and is known as residual ridge resorption. The reduction of the edentulous alveolar crest, and the degree to which it changes, is correlated to many factors that contribute to determine the speed and evolution of this process. [1,2] This often leads to a situation where there is no longer sufficient bone support for the proper functioning of removable complete dentures. This problem is worse in the mandible [3,4] and becomes a challenge to achieve stability and retention of the mandibular denture, [5] besides work around load intolerance of the mucosa, pain, difficulties to eat, speech and facial changes. [4] The era of dental implants is an important milestone with excellent resolution for these mandibular edentulous cases. However, rehabilitation in atrophic bone condition is still considered a challenge due to anatomic limitations, extreme low quantity and quality of bone. [1,4,6]

Bone grafting and alveolar distraction osteogenesis seems to be a good alternative in an attempt to restore the bone loss, and allow the implant insertion. [7,8] Despite the low predictability, with multiple complications at and after grafting process, [5,9] and reports of graft lost or providing insufficient bone (with graft resorption), [10] a high success index is achieved, with more than 90% of survival rates for theses technics [8,10]. However, surgical procedures increase time for treatment, cost, risk of infections and morbidity. [5,9,11,12] Thus, short implant has been proposed to avoid surgical reconstruction [5,9,11–16] and it has been demonstrated to be a safe alternative to bone graft, increasing patients acceptance towards implant support prosthesis, [9,11,16–22] even to cases with severe resorbed mandible (height mean 9.7 ± 1.4 mm). [5]

Nevertheless, some concerns regarding the biomechanical behaviour raise doubts as to its effectiveness. Short implants reduces the support area due to the smaller contact area between bone and implants. Systematic review appoints that there was a significant negative association between implant length (5 to 8.5 mm) and failure rate or a tendency towards an increasing survival rate per implants length. [21] It was assumed that longer implants would offer great predictability than short, especially before the emergence of rough implant surface. [17] However the vast majority of the failure of short implants occurs before the loading application for different reasons. [9,11,18,19,23]

Meantime the fail rates of short implant is similar to long implants [9,14,15,17,24–26] previous study affirm that the length of the implants seems not influence the survival rates, however another factors such as the surface topography, surface treatment, and surgical protocols might be more relevant. [17] The majority of studies with short implants was conduced with partial edentulous subjects and, despite the short implant having been cited as a treatment option for severely atrophic jaws, furthermore, this option is not widely used.[4,27–30] Some reports cited the use of short implants as indication to rehabilitate edentulous jaw with fixed prosthesis support [4,5,17,27,28] however, nothing exist about the biomechanical behaviour of this treatment option.

This study was conduced to enlarge the security and clarify the biomechanical of short full edentulous jaw, in order to expand the benefits of implants for patients with severe resorption, without bone graft procedures. This study aimed to test short implants to support a complete denture in atrophic mandible and evaluated the benefit of the association between short and wide implants to improve the results of short implants to this clinical indication.

## Methodology

*Groups*

An experimental "*in silico*" study was performed and seven groups composed the study. The experimental groups were tested with two diameters (4.0 mm - conventional/Ci and 5.0 mm - wide/Wi) and three different length (5.0 mm, 7.0 mm, 9.0 mm) compared to control group (11.0 x 4.0 mm). The groups are described at Table 1.

Table 1: Groups distribution

| | Length (mm) | Diameter (mm) |
|---|---|---|
| CG | 11.0 | 4.0 |
| Ci9 | 9.0 | 4.0 |
| Ci7 | 7.0 | 4.0 |
| Ci5 | 5.0 | 4.0 |
| Wi9 | 9.0 | 5.0 |
| Wi7 | 7.0 | 5.0 |
| Wi5 | 5.0 | 5.0 |

Ci – Conventional Implant (4 mm of diameter); Wi – Wide Implant (5 mm of diameter)

*Model Construction*

The models were constructed with SolidWorks software 2013® (Dassault Systèmes SolidWorks Corp, Concord, MA, EUA). All groups consisted of a fragment for mimicking the anterior region of the mandible that was obtained from dissected resorbed jaw characteristics. The distributions of implants followed the arrangement previously described (Pimentel and Del Bel Cury, 2014 – Chapper 1). The bone fragment has 8 mm of width and different height between the groups (13 and 10 mm) in order to approaching of the clinical indication for short implants. The cortical portion has 1mm of thickness for all groups. The different implants, from each group, were positioned and subtracted from mandibular by Boolean operations.

The Morse taper implants and respective abutments (1.5 mm of length) were chosen for all groups. The implants and prosthetic components CAD were obtained from the manufacturer (Neodent System®, Curitiba, Parana, Brazil), respecting the exactly implants and components design. The archives were exported to SolidWorks for geometry simplification and design refinement. Boolean operations were required to ensure a perfect fit between pieces during assembly of the groups. The implants were insert vertically with the same depth, at bone level, and were distributed equidistantly between the foramen distances (40 mm), equal for all groups.

The implants were splinted with a chromo-cobalt bar that was constructed following the arch shape and connected to the cylinders by Boolean operation in the software. The bar was the same to all groups with 3 mm of height, 5 mm of thickness and 15 mm of cantilever. The retention screws were also the same to all groups. The abutments have the same tridimensional shape to (Ci11, Ci9, Ci7, Wi9 and Wi7). The Ci5 and Wi5 differed from them due to the anatomic internal cone of implant with 5 mm. The distance from the bone level to the bar was constant for all groups (5 mm). The load area was design in the end of cantilever, simulating the load at the first molar, and has the same position for all groups (Figure 1 – A).

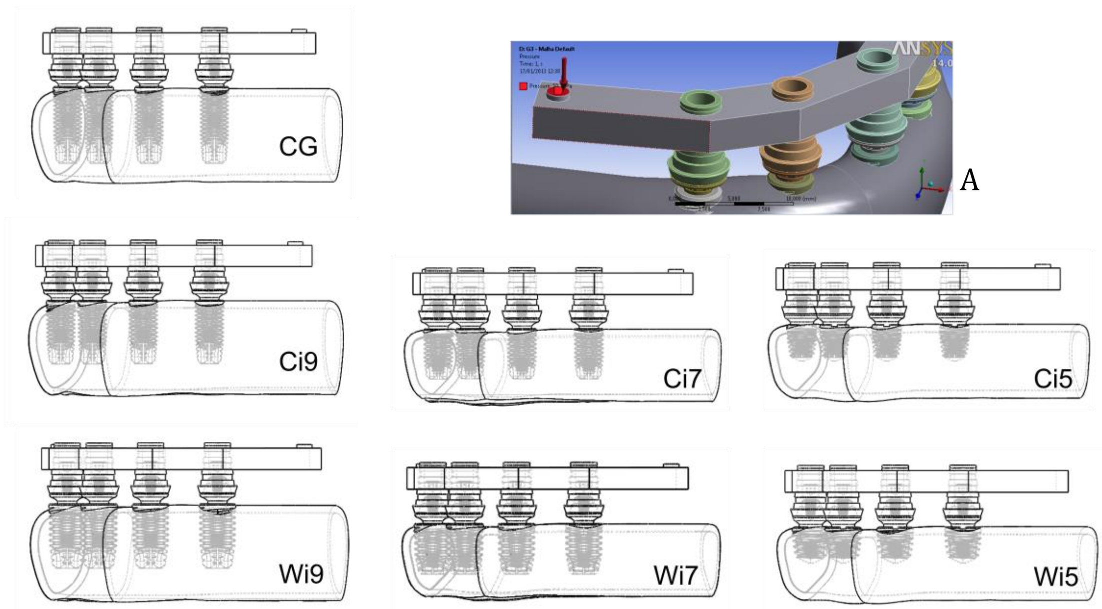



Figure 1: Lateral view of the models for all groups. The load model was at the bar cantilever in Ansys Software (A) and was represented by the read area. Boundary condition includes fixed support bilaterally at the distal faces and the inferior border of the mandible.

*Finite Element Analysis*

All groups were assembled at SolidWorks 2013 and the CAD models were exported to the Ansys Workbench 14.0 FEA software (Swanson Analysis Inc, Houston, PA, USA) as .SLDASM files. The mechanical properties such as elastic modulus and Poisson's ratio were obtained from the literature (Table 2). The mesh was constructed through convergence of analysis. Different element size were tested until does not alter more than 5% to the maximum stress values to all components (elements sizes tested: 1.8; 1.6; 1.4; 1.2; 1.0; 0.8; 0.6; 0.4mm). Thus, that was determined a tetrahedral element of 1 mm size, used in all models. The number of elements and nodes in each group were: 275,290 and

447,538 (CG); 208,234 and 346947 (Ci9); 269,930 and 439,547 (Ci7); 145,162 and 250,073 (Ci5); 269,930 and 439,547 (Wi9); 200,240 and 338923 (Wi7); 201,009 and 332,169 (Wi5).

All structures were considered isotropic, homogeneous and linear elastic. [6] The boundary condition was defined by fixing the distal surfaces bilaterally of the bone segment, and the inferior border, limiting body movement in all directions. The models were loaded in the cantilever extension (unilaterally) with unilateral axial loading of 100 N, based on the average bite force considering conventional denture as opposed to overdentures (mean 88.1 ± 61.20 N).[31] The maximum principal stress ($\sigma_{max}$) for the bone segment and the von Mises stress ($\sigma_{vM}$) for the prosthetic components and implants were obtained. The data of the groups were compared to the CG.

Table 2: Mechanical properties of bone and dental materials.

| Material | Elastic Modulus (*E*) GPa | Poisson Ration (*v*) | References |
|---|---|---|---|
| Cortical Bone | 13.7 | 0.30 | Cruz et al., 2009[32] |
| Cancellous Bone | 1.37 | 0.30 | Cruz et al., 2009[32] |
| Titanium | 110.0 | 0.33 | Cruz et al., 2009[32] |
| Chromo-Cobalt | 218 | 0.33 | Geng et al., 2001[33] |

**Results**

To compare seven different implant treatment configurations (CG x Ci9, Ci7, Ci5, Wi9, Wi7, Wi5) proposed for atrophic mandible, five variables were investigated. The maximum values of stress for group and the trend behaviour for short and wide implants are described in Table 3. Analysing the bone behaviour for short implants associated with a smaller diameter (4.0mm), the maximum principal stress ( $\sigma_{max}$) in cortical bone was highest in Ci5 (45.04 MPa), followed by the CG (37.99 MPa). The maximum values of stress to Ci9 and Ci7 were lower than CG (-11.39% and -32.08% respectively). The association of short implants with a large diameter (Wi9, Wi7 and Wi5) reduced the maximum values of stress in cortical bone, when compared to CG or Ci9, Ci7, Ci5 groups

(Figure 2). Nonetheless in cancellous bone, the $\sigma_{max}$ values have increased to Ci9 (+2.02%), Ci7 (+37.44%) and Ci5 (+26.05%). The wide implant also reduced stress values in cancellous bone compared to Ci9, Ci7, Ci5 groups. The $\sigma_{max}$ in cancellous bone was highest for Ci7 (8.81 Mpa) and Ci5 (8.08 MPa) with close values of stress between short-wide implants and CG (Table 3; Figure 3).

The implants were submitted to von Mises criteria ($\sigma_{vM}$) and the maximum values for each model were visualized in the distal implant, next to the load side (Figure 4). The highest values of stress were found for the shortest implants Ci5 (162.91 MPa), Ci7 (126.15 MPa) and Wi5 (120.9 MPa). The use of short-wide implants reduced the stress values in the implants. The lower stress values were observed in Wi7 (80.06 MPa), Wi9 (82.72 MPa) even compared with CG (Table 3). The opposite happened for the abutment, the $\sigma_{vM}$ stress was highest for Wi7 (199.99 MPa) followed by Wi9 (190.79 MPa), and lower values were found for Ci5 (65.83 MPa) and Ci7 (168.72 MPa) (Table 3; Figure 5).

Considering the $\sigma_{vM}$ stress in the bar was observed that the stress was concentrated in the last pillar between the cantilever and the distal implant, on the load side. The highest stress value was for the CG (492.25 MPa), while for the short implants the values of stress in the bar reduced for all experimental groups, ranging from 0.55% (Ci5) to 13.31% (Wi9). The screw presented lower values for the CG (74 MPa). Short implants, regardless of the length or diameter, resulted in increased stress in the retention screw. Comparing with all variables, the increase of stress in the screw was the most significant, increasing up to twice compared to the CG (Table 3, Figure 6).

Table 3: Stress Values (MPa) in bone, implants and prosthetic components after distal loading. Difference of percentage values between the experimental groups (Ci9, Ci7, Ci5, Wi9, Wi7, Wi5) and the control (CG).

| | **Cortical Bone** | | **Cancelous Bone** | | **Implants** | | **Abutment** | | **Bar** | | **Screw** | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | **MPa** | **%** | **MPa** | **%** | **MPa** | **%** | **MPa** | **%** | **MPa** | **%** | **MPa** | **%** |
| **CG** | **37.99** | | **6.41** | | **112.14** | | **184.55** | | **492.25** | | **74.22** | |
| **Ci9** | 33.66 | -11.39% | 6.54 | +2.02% | 99.88 | -10.93% | 189.51 | +2.68% | 429.49 | - 12.74% | 164.0 | +120.96% |
| **Ci7** | 25.80 | - 32.08% | 8.81 | +37.44% | 126.15 | + 12.49% | 168.72 | -8.57% | 439.1 | - 10.79% | 149.8 | + 101.83% |
| **Ci5** | 45.04 | +18.55% | 8.08 | +26.05% | 162.91 | +45.27% | 65.83 | -64.32% | 489.54 | - 0.55% | 107.98 | + 45.48% |
| **Wi9** | 21.65 | -43.01% | 5.44 | -15.13% | 82.72 | - 26.23% | 190.79 | + 3.38% | 426.71 | - 13.31% | 159.12 | +114.38% |
| **Wi7** | 18.51 | -51.27% | 6.86 | +7.02% | 80.06 | - 28.60% | 199.99 | + 8.36% | 431.15 | - 12.41% | 160.18 | + 115.81% |
| **Wi5** | 26.11 | -31.27% | 5.88 | -8.26% | 120.9 | +7.81% | 116.98 | -36.61% | 434.8 | -11.67% | 121.35 | +63.50% |

Ci – Conventional Implant (4 mm of diameter); Wi – Wide Implant (5 mm of diameter). The Maximum Principal Stress ($\sigma_{max}$) was adopted for bone and von Mises Stress ($\sigma_{vM}$) was adopted for implant and prosthetic components

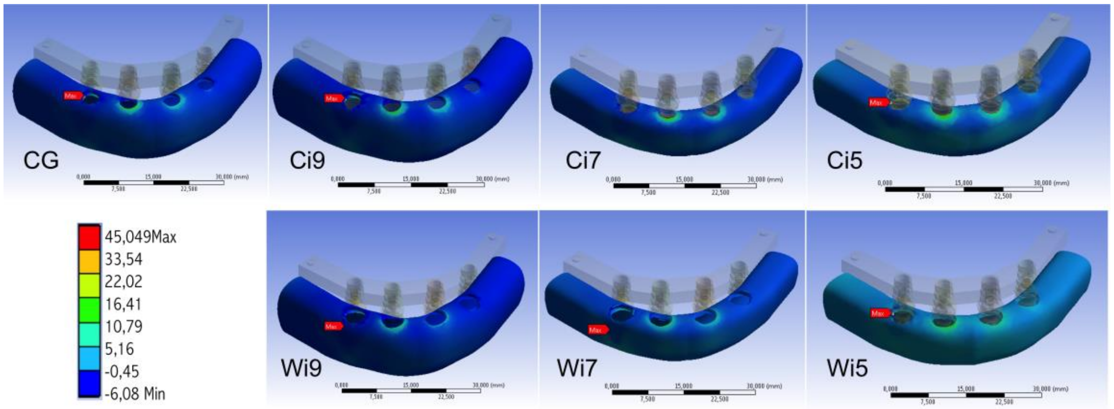



Figure 2: Occlusal view of the cortical bone. The red point identifies the peak stress to the Maximum Principal Stress ($\sigma_{max}$) criteria. The scale was standardized to the maximum value (Ci5 - 45.04 MPa) for comparison of stress distribution between the groups.

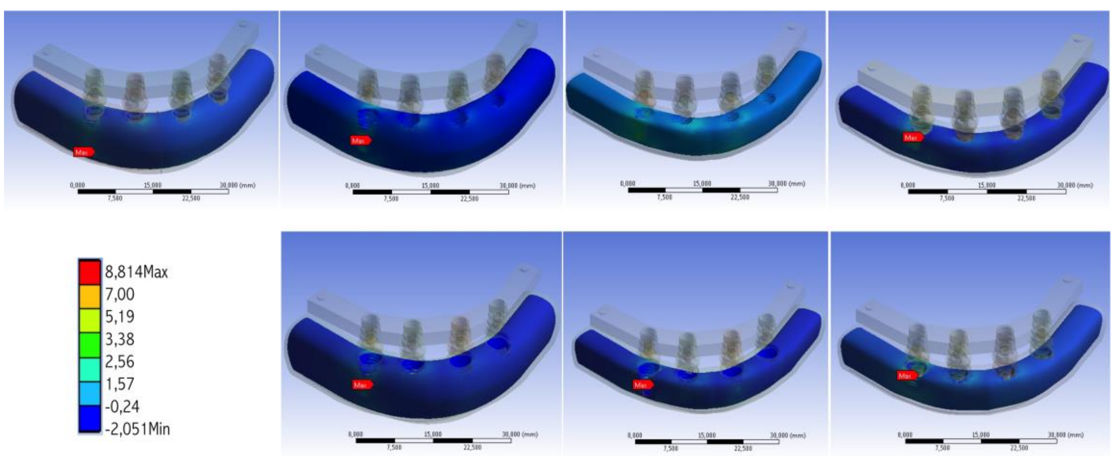



Figure 3: Occlusal view of the cancelous bone. The red point identifies the peak stress to the Maximum Principal Stress ($\sigma_{max}$) criteria. The scale was standardized to the maximum principal stress value (Ci7 -8.81 MPa) for comparison of stress distribution between groups

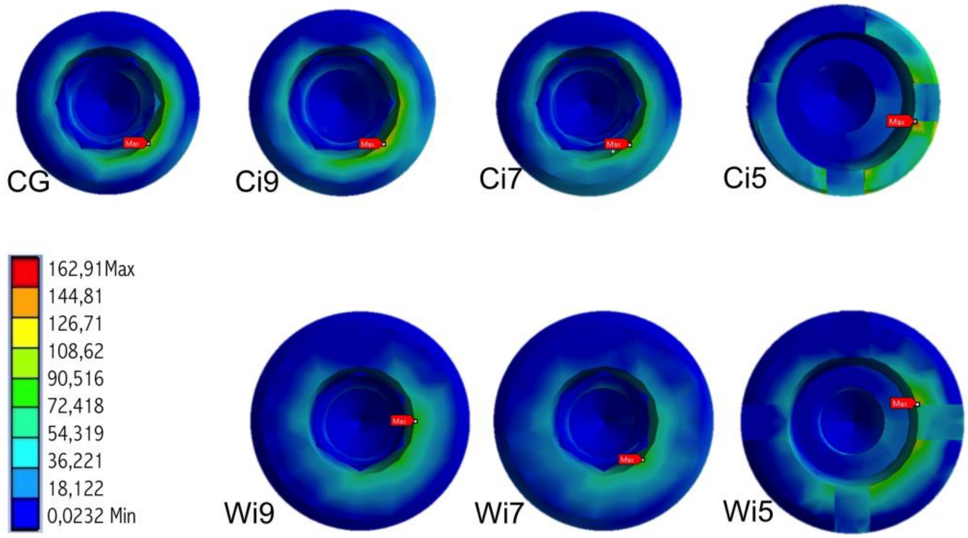



Figure 4: Occlusal views of the platform implant. The red point identifies the peak stress to von Mises Stress ($\sigma_{vM}$) criteria. The scale was standardized to the maximum stress value (Ci7 - 162.91 MPa) for comparison of stress distribution between groups.

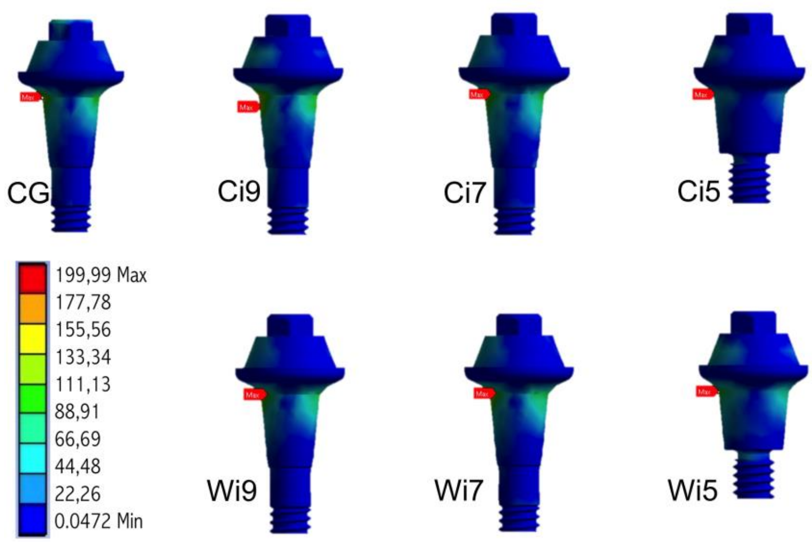



Figure 5: Front views of the abutment. The red point identifies the peak stress to von Mises Stress ($\sigma_{vM}$) criteria. The scale was standardized to the maximum stress value (Wi7 - 199.99 MPa) for comparison of stress distribution between groups.

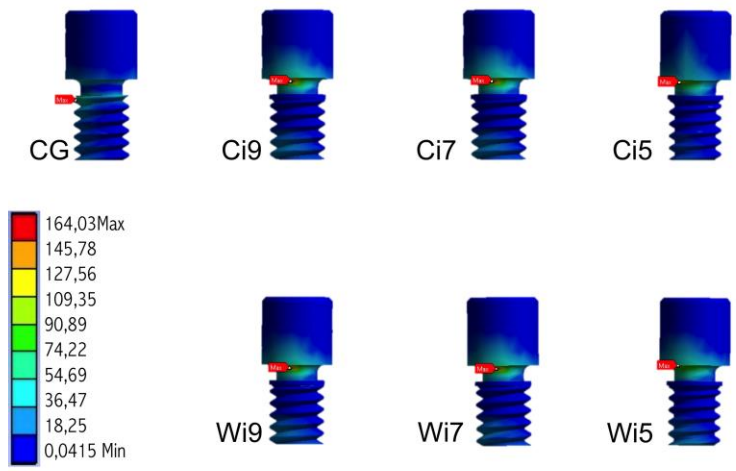



Figure 6: Front views of the screw. The red point identifies the peak stress to von Mises Stress ($\sigma_{vM}$) criteria. The scale was standardized to the maximum stress value (Ci9 - 164.0 MPa) for comparison of stress distribution between groups.

**Discussion**

Finite element analysis (FEA) has been used extensively to predict the biomechanical performance of complex geometries, as well as the effect of clinical factors of success.[33] The aim of this study was to evaluate the biomechanical behavior of short implants to support a fixed prosthesis in atrophic mandible and the bone fracture is the main concern regarding atrophic mandible. Reduced contact area (implant-bone), to support an extensive prosthesis, and the bone fragility, due the reduced thickness of residual ridge, are the main points to weaken indicate this treatment option. The knowledge of the bone behavior and the determination of stress concentration area are important to foresee the clinical success.

The highest Maximum Principal Stress ($\sigma_{max}$) in cortical bone was observed in Ci5 (45.04 MPa), which represents the group with the smallest contact area (bone-implants) between the experimental groups, this value is closely to the ultimate strengths value of humane bone (51 MPa).[34] This behaviour was expected since it was assumed that longer implants offer great predictability than short ones. [17] Extra-short implants (4.0 x 5.0 mm) presented the highest value of stress, with more than 18% increment in stress when compared to the long implant. Previous study affirms that implants with 4.0 x 5.0 mm has 50% more stress in cortical bone than longer implants (13 and 11 mm) in partial edentulous jaw. [35] Meantime, this previous study evaluated unsplinted crowns, with different height, and implants positioned in different bone levels, which could be responsible for high value, since that in this conditions their biomechanical behaviour is most required. Despite the differences, both studies observed a same behaviour trends. Contradicting these findings, the others groups showed lower stress values when compared to CG. Therefore, it can be suggested that extreme reductions in the bone-implant contact area can result in increased stress in cortical bone for short splinted implants, however, short implants with increased length can achieve better behaviour. Some clinical studies found similar results for short and long implants, [28,36–41] without bone complications.

A biomechanical study affirms that the increase of the diameter is clearly more significant for reduce stress levels in the bone than the effect of implant length, [42] and the present results corroborate with this finding. The increase in contact area represented by the association of short and large implants (Wi9, Wi7 and Wi5), reduced the maximum values of stress in cortical bone, when compared to CG or Ci9, Ci7, Ci5 groups. Wide implant associated with 9 and 7mm of length reduced 43.01% and 51.27% of the stress in cortical bone compared to the CG. This finding is in agreement with already reported study, which described that, the magnitude of the stress in cortical bone decreases when the implant diameter is increased. [43] Previous studies comparing implants with 15 and 7 mm of implant length reported more stress for short implants in cortical bone, however splinted configuration was not considered. [44]

Nonetheless, in cancellous bone, the use of short implants increase the stress values in 2.02% (Ci9), 37.44% (Ci7) and 26.05% (Ci5) compared to CG. The increase of the stress values in cancellous bone was also reported for extra-short implants (5.0 x 4.0 mm). [35] The influence of implant length was more evident for cancellous bone compared to cortical, which was also previously reported. [44] The increase of implants diameter reduced the stress values in cancellous bone, compared to Ci9, Ci7 and Ci5. Wide implants presented little change in the amount of stress from the CG with close values between them. [17,45] The support provided by the implant interferes with the amount of tension concentrated on the cancellous bone, in an inversely proportional relationship.

The increase of stress in a severe resorbed bone requires caution. The present study appoints that bone stress values not excess the bone physiological limit (ranged by 51 to 193 MPa), despite Ci5 is closest them. [34] However, it is interesting to notice that the atrophic mandible is not characterized solely by resorption phenomena; in fact, some parts of the mandible are subject to "new bone formation" [1]. This may represent the reaction of mandibular bone tissue to a request for greater resistance from the remaining bone. If, for other reasons, the height of the mandibular body is progressively reduced, the residual bone is necessarily strengthened with new bone apposition if its levels of resistance are to remain constant. [1] The use of short implants can help the maintenance of a greater bone thickness, bringing benefits and improving the mandible resistance to fracture. The incidence of edentulous mandible fracture is less than 0.05% in 27 years, [46] but the implant insertion closest to inferior edge, for any jaw size, generates bone fragility and increases the chance of fracture. [46,47]

The implants were submitted to von Mises criteria ($\sigma_{vM}$) and the maximum values for each model were visualized in the distal implant, next to the load side. Short implants demonstrated different behaviours. The highest values of stress were found for groups with less bone-implant contact area Ci5 (162.91MPa), Ci7 (126.15 MPa) and Wi5 (120.9 MPa), while the other groups showed less stress than CG. The association of large diameter reduced the stress values in the implants compared to smaller diameter. The opposite happened for the abutment, the $\sigma v_M$ stress was highest for Wi7 (199.99 MPa) followed by Wi9 (190.79 MPa), and lower values were found for Ci5 (65.83 MPa) and Ci7 (168.72 MPa). Smaller contact area bone-implant demanded more from the implants, increasing it stress values and reducing the stress on the abutment; while to groups with a higher contact area (Ci9, Wi9, Wi7), it demanded less of the implant and more of the abutment. This can be explained by the thickness of the implant wall. Wide implants has a thicker titanium wall (Figure 5) and this reinforces the implant structure. This dissipates less stress to the bone tissue. Meanwhile, the abutment has the exactly same shape and dimensions to regular or wide implants (Figure 6). So while the implants are reinforced, the abutments concentrated more stress.

The survival of short implants must be compared not with the success rates of long implants placed in native bone, but should be compared with the success rate of long implants associated with advanced surgical procedures, as emphasized by Annibali and colleagues. [19] When these options of treatment were compared the short implants were preferred. [5,9,14] The short implants have indisputable advantages in relation to processes graft, however, theses advantages could be irrelevant if short implants present more failures and low success rate. [11] Considering single and partial prosthesis, the fail rates of short implant is similar to long implants [9,14,15,17,24–26,48] and good survival rates are reported, [19,41,48,49] Despite a few sparse studies are reported for full arch rehabilitation with short implants, good results are found, [4,17,19,30] with survival rates of 98% to 456 implants supporting fixed and removable dentures. [19] High success rate (100% in 2 years) was observed in 20 cases of severely resorbed mandible from 56 short implants (8 mm). [5] Other study, with ten years of follow up, affirms that no clinical mobility, implant or abutment loosening could be documented in cases rehabilited with different implant lengths (8 or 9 mm) and diameter (3.5, 4.0 and 4.5). [17]

The success rate is influenced by the early failure, and the vast majority of the failure regarding short implants occurs before the loading application. [9,11,18,19,23] The early failure was also related in other studies. [11,18] This suggests that the main driver of failure is not the biomechanical behaviour,[11] as expected. Peri-implant also was related as a cause for early and late implant lost. [15,18] From 231 implants with 8mm, only 1.7% failed in 5 to 10 year of follow up, the peri-implantitis infection was appointed as a cause to lost implants in this period. [18] The same was reported in a retrospective study with 20 years of follow-up, where 108 short implants (8 mm) were placed but only four implants were lost due to severe peri-implantitis without early failures. [15]

The screw presented lower values of stress for the CG (74 MPa). Short implants, regardless of the length or diameter, resulted in increased stress in the screw that was the most significant, increasing up to twice from the CG. This can be due to the tiny and delicate structure of the screw. This study demonstrates that the fragility of the use of short implants lies in the retention screw. However, it can be considered as a favourable situation, since the screw can be easily replaced. Other mechanism that was not considered in this study is the fact that, in a real condition, no surface is completely smooth and bonded. The microroughness of the components can create in micro movements and when the screw interface is subjected to external loads, these micro movements may lead to in surface wear, decreasing the preload in the set of screw. [33] The fragility in the screw is a common problem. Clinical study, with 10 year of follow up, indicates that the screw loss is the more incident prosthetic complication[18] and is more relevant in single-tooth implant prosthesis. The use of short implants, regardless of the length or diameter, can possibly overload the screw, resulting in higher rates of screw loosening, which lead to a greater need of follow-up appointments. With short implants the increase in the implant diameter was not able to reduce the stress level in the screw, as demonstrated in previous study with long implant and different number of implants configuration (3 or 5 implants with 15 mm), where the large implant diameter reduced the stress values on the screw. [50] The groups with lower values after the CG were Ci5 and Wi5. This result is probably due to the most robust anatomy of the abutment present in this groups, and further dissipation of stress to the bone.

The factors that contribute to screw fracture listed in the literature include: applied force, the elastic modulus of the prosthesis and stiffness of the abutments. [33] There is no mention about the amount of contact area between bone-implant, and the length or diameter of the implants. However, it could observe that these factors changed significantly the values of maximum stress on the screw. Some FEA research analyses the set bone-implant isolated and there is no interest in the stress concentration on the prosthetic components. Thus, this result represents a partial results, which is impossible to know the what's happen with other components. [6,35] When a load was applied is dissipated and tends to remain in the body, which receives it. Statements that the stress reduced in the bone could not represent a better option of treatment since that not knows where the load is concentrated. Thus, is clear the need to analyse all the components involved in the rehabilitation.

Short implants was report as safe alternative to surgical procedures [9,11,16–22] and despite the main wariness with jaw fracture, less complication was reported to short implants than graft procedure, especially in severe resorbed cases. The patient could be treat in an outpatient clinic setting under local anaesthesia, with minor complications and morbility, which makes this modality more attractive to older population, [5] showing a better option than surgical procedures. Other relevant factor is the need for optimal blood circulation to supply the graft. The circulation in mandible extremely resorbed mandible, where there is hardly any cancellous bone in the interforaminal area, the blood supply is jeopardized, which can compromises successful integration of the graft. [5] Although the placement of four endosseous implants in the interforaminal area seems like a relatively simple surgical procedure, in an extremely resorbed mandible the use of sharp instruments and delicate surgical handling of the oral tissues are prerequisites for successful implant osseointegration. The preservation of basal bone can be a simple and good manoeuvre to maintenance the resistance of jaw. [1]

The 3-dimensional FEA was used in this study to illustrate possible differences between treatment options with short implants, allowing a better understanding of the biomechanical aspects, not to replicate exact in vivo stress condition. [35] This study appoints a trend of increase stress on cancellous bone and a weakness of the system to the screw when short implants are used to fixed prosthesis in an atrophic mandible. However, biological conditions are complex, and others factors, as the prosthesis-implant ratio or bone quality can be extreme relevant to biomechanical behaviour, so the exact extrapolation of this condition need carefully.

**Conclusion**

Short implants increase stress in the retention screw and cancellous bone. The Ci7, Ci5 and Wi5 result in more stress in implant and bone, with less stress in the abutment. Short-wide implants showed similar or better results than CG to bone and implants while increase stress concentration in abutment and retention screw.

**Acknowledgments**

The authors would like to thank the Neodent for the granting of the material. This study was supported by FAPESP with study scholarships awarded to the first named author #2011/21877-2.

**References**


1. Bianchi A, Sanfilippo F. Osteoporosis: the effect on mandibular bone resorption and therapeutic possibilities by means of implant prostheses. Int J Periodontics Restorative Dent. 2002;22(3):231–9.

2. Jahangiri L, Devlin H, Ting K, Nishimura I. Current perspectives in residual ridge remodeling and its clinical implications: a review. J Prosthet Dent. 1998;80(2):224–37.

3. Klemetti E. A review of residual ridge resorption and bone density. J Prosthet Dent. 1996;75(5):512–4.

4. Stellingsma C, Vissink a., Meijer HJ a., Kuiper C, Raghoebar GM. Implantology and the Severely Resorbed Edentulous Mandible. Crit Rev Oral Biol Med. 2004;15(4):240–8.

5. Stellingsma K, Raghoebar GM, Meijer HJ a, Stegenga B. The extremely resorbed mandible: a comparative prospective study of 2-year results with 3 treatment strategies. Int J Oral Maxillofac Implants. 2004;19(4):563–77.

6. Almeida EO, Rocha EP, Júnior ACF, Anchieta RB, Poveda R, Gupta N, et al. Tilted and Short Implants Supporting Fixed Prosthesis in an Atrophic Maxilla: A 3D-FEA Biomechanical Evaluation. Clin Implant Dent Relat Res. 2013 5;1–11.

7. McAllister BS, Haghighat K. Bone augmentation techniques. J Periodontol. 2007;78(3):377–96.

8. Kim J-W, Cho M-H, Kim S-J, Kim M-R. Alveolar distraction osteogenesis versus autogenous onlay bone graft for vertical augmentation of severely atrophied alveolar ridges after 12 years of long-term follow-up. Oral Surg Oral Med Oral Pathol Oral Radiol. 2013;116(5):540–9.

9. Felice P, Pistilli R, Piattelli M, Soardi E, Corvino V, Esposito M. Posterior atrophic jaws rehabilitated with prostheses supported by 5 x 5 mm implants with a novel nanostructured calcium-incorporated titanium surface or by longer implants in augmented bone. Preliminary results from a randomised controlled trial. Eur J Oral Implantol. 2012;5(2):149–61.

10. Peñarrocha-Diago M, Aloy-Prósper A, Peñarrocha-Oltra D, Guirado JLC, Peñarrocha-Diago M. Localized lateral alveolar ridge augmentation with block bone grafts: simultaneous versus delayed implant placement: a clinical and radiographic retrospective study. Int J Oral Maxillofac Implants. 2013;28(3):846–53.

11. Atieh M a, Zadeh H, Stanford CM, Cooper LF. Survival of short dental implants for treatment of posterior partial edentulism: a systematic review. Int J Oral Maxillofac Implants. 2012;27(6):1323–31.

12. Esposito M, Cannizarro G, Soardi E, Pellegrino G, Pistilli R, Felice P. A 3-year post-loading report of a randomised controlled trial on the rehabilitation of posterior atrophic mandibles: short implants or longer implants in vertically augmented bone? Eur J Oral Implantol. 2011;4(4):301–11.

13. Felice P, Checchi V, Pistilli R, Scarano A, Pellegrino G, Esposito M. Bone augmentation versus 5-mm dental implants in posterior atrophic jaws. Four-month post-loading results from a randomised controlled clinical trial. Eur J Oral Implantol. 2009;2(4):267–81.

14. Esposito M, Pellegrino G, Pistilli R, Felice P. Rehabilitation of postrior atrophic edentulous jaws: prostheses supported by 5 mm short implants or by longer implants in augmented bone? One-year results from a pilot randomised clinical trial. Eur J Oral Implantol. 2011;4(1):21–30.

15. Lops D, Bressan E, Pisoni G, Cea N, Corazza B, Romeo E. Short implants in partially edentuolous maxillae and mandibles: a 10 to 20 years retrospective evaluation. Int J Dent. 2012;2012:351793.

16. Karthikeyan I, Desai SR, Singh R. Short implants: A systematic review. J Indian Soc Periodontol. 2012;16(3):302–12.

17. Mertens C, Meyer-Bäumer A, Kappel H, Hoffmann J, Steveling HG. Use of 8-mm and 9-mm implants in atrophic alveolar ridges: 10-year results. Int J Oral Maxillofac Implants. 2012;27(6):1501–8.

18. Lai H, Si M, Zhuang L, Shen H, Liu Y, Wismeijer D. Long-term outcomes of short dental implants supporting single crowns in posterior region: a clinical retrospective study of 5-10 years. Clin Oral Implants Res. 2013;24(2):230–7.

19. Annibali S, Cristalli MP, Dell'Aquila D, Bignozzi I, La Monaca G, Pilloni a. Short dental implants: a systematic review. J Dent Res. 2012;91(1):25–32.

20. Bressan E, Sivolella S, Urrutia ZA, Salata LA, Lang NP, Botticelli D. Short implants (6 mm) installed immediately into extraction sockets: an experimental study in dogs. Clin Oral Implants Res. 2012;23(5):536–41.

21. Telleman G, Raghoebar GM, Vissink A, den Hartog L, Huddleston Slater JJR, Meijer HJ a. A systematic review of the prognosis of short (<10 mm) dental implants placed in the partially edentulous patient. J Clin Periodontol. 2011;38(7):667–76.

22. Maló P, Nobre M de, Lopes A. Short implants in posterior jaws. A prospective 1-year study. Eur J Oral Implantol. 2011;4(1):47–53.

23. Olate S, Lyrio MCN, de Moraes M, Mazzonetto R, Moreira RWF. Influence of diameter and length of implant on early dental implant failure. J Oral Maxillofac Surg. 2010;68(2):414–9.

24. Guljé F, Abrahamsson I, Chen S, Stanford C, Zadeh H, Palmer R. Implants of 6 mm vs. 11 mm lengths in the posterior maxilla and mandible: a 1-year multicenter randomized controlled trial. Clin Oral Implants Res. 2013;24(12):1325–31.

25. Monje A, Chan H-L, Fu J-H, Suarez F, Galindo-Moreno P, Wang H-L. Are short dental implants (<10 mm) effective? a meta-analysis on prospective clinical trials. J Periodontol. 2013;84(7):895–904.

26. Menchero-Cantalejo E, Barona-Dorado C, Cantero-Álvarez M, Fernández-Cáliz F, Martínez-González J-M. Meta-analysis on the survival of short implants. Med Oral Patol Oral Cir Bucal. 2011;16(4):e546–51.

27. Keller EE, Tolman DE. Mandibular ridge augmentation with simultaneous onlay iliac bone graft and endosseous implants: a preliminary report. Int J Oral Maxillofac Implants. 1992;7(2):176–84.

28. Ten Bruggenkate CM, Asikainen P, Foitzik C, Krekeler G, Sutter F. Short (6-mm) nonsubmerged dental implants: results of a Multicenter clinical trial of 1 to 7 years. Int J Oral Maxillofac Implants. 1998;13(6):791–8.

29. Stellingsma C, Meijer HJ, Raghoebar GM. Use of short endosseous implants and an overdenture in the extremely resorbed mandible: a five-year retrospective study. J Oral Maxillofac Surg. 2000;58(4):382–7.

30. Friberg B, Gröndahl K, Lekholm U, Brånemark PI. Long-term follow-up of severely atrophic edentulous mandibles reconstructed with short Brånemark implants. Clin Implant Dent Relat Res. 2000;2(4):184–9.

31. Müller F, Hernandez M, Grütter L, Aracil-Kessler L, Weingart D, Schimmel M. Masseter muscle thickness, chewing efficiency and bite force in edentulous patients with fixed and removable implant-supported prostheses: a cross-sectional multicenter study. Clin Oral Implants Res. 2012;23(2):144–50.

32. Cruz M, Wassall T, Toledo EM, da Silva Barra LP, Cruz S. Finite element stress analysis of dental prostheses supported by straight and angled implants. The Int J Oral & Maxillofac Impl. 2009;24(3):391–403.

33. Geng JP, Tan KB, Liu GR. Application of finite element analysis in implant dentistry: a review of the literature. J Prosthet Dent. 2001;85(6):585–98.

34. Reilly DT, Burstein a H. The elastic and ultimate properties of compact bone tissue. J biomech. 1975;8(6):393–405.

35. Toniollo MB, Macedo AP, Rodrigues RCS, Ribeiro RF, de Mattos M da GC. Three-dimensional finite element analysis of stress distribution on different bony ridges with different lengths of morse taper implants and prosthesis dimensions. J Craniofac Surg. 2012;23(6):1888–92.

36. Feldman S, Boitel N, Weng D, Kohles SS, Stach RM. Five-year survival distributions of short-length (10 mm or less) machined-surfaced and Osseotite implants. Clin Implant Dent Relat Res. 2004;6(1):16–23.

37. Gentile MA, Chuang S-K, Dodson TB. Survival estimates and risk factors for failure with 6 x 5.7-mm implants. Int J Oral Maxillofac Implants. 2005;20(6):930–7.

38. Rokni S, Todescan R, Watson P, Pharoah M, Adegbembo AO, Deporter D. An assessment of crown-to-root ratios with short sintered porous-surfaced implants supporting prostheses in partially edentulous patients. Int J Oral Maxillofac Implants. 2005;20(1):69–76.

39. Renouard F, Nisand D. Short implants in the severely resorbed maxilla: a 2-year retrospective clinical study. Clin Implant Dent Relat Res. 2005;7 Suppl 1:S104–10.

40. Tawil G, Od D, Younan R. Clinical Evaluation of Short , Machined-Surface Implants Followed for 12 to 92 Months. Int J Oral Maxilofac Implants 2003;18(6).

41. Anitua E, Orive G, Aguirre JJ, Andía I. Five-year clinical evaluation of short dental implants placed in posterior areas: a retrospective study. J Periodontol. 2008;79(1):42–8.

42. Anitua E, Tapia R, Luzuriaga F, Orive G. Influence of implant length, diameter, and geometry on stress distribution: a finite element analysis. Int J Periodontics Restorative Dent. 2010;30(1):89–95.

43. Hasan I, Heinemann F, Aitlahrach M, Bourauel C. Biomechanical finite element analysis of small diameter and short dental implant. Biomed Tech. 2010;55(6):341–50.

44. De Carvalho NA, de Almeida EO, Rocha EP, Freitas AC, Anchieta RB, Kina S. Short implant to support maxillary restorations: bone stress analysis using regular and switching platform. J Craniofac Surg. 2012;23(3):678–81.

45. Das Neves FD, Fones D, Bernardes SR, do Prado CJ, Neto AJF. Short implants--an analysis of longitudinal studies. Int J Oral Maxillofac Implants. 2006;21(1):86–93.

46. Soehardi A, Meijer GJ, Manders R, Stoelnga PJW. An inventory of mandibular fractures associated with implants in atrophic edentulous mandibles: a survey of Dutch oral and maxillofacial surgeons. Int J Oral Maxillofac Implants. 2011;26(5):1087–93.

47. Oh W, Roumanas ED, Beumer J. Mandibular fracture in conjunction with bicortical penetration, using wide-diameter endosseous dental implants. J Prosthodont. 2010;19(8):625–9.

48. Arlin ML. Short dental implants as a treatment option: results from an observational study in a single private practice. Int J Oral Maxillofac Implants. 2006;21(5):769–76.

49. Griffin TJ, Cheung WS. The use of short, wide implants in posterior areas with reduced bone height: a retrospective investigation. J Prosthet Dent. 2004;92(2):139–44.

50. Silva-Neto JP, Pimentel MJ, Das Neves FD, Consani RLX, Santos MBF Dos. Stress analysis of different configurations of 3 implants to support a fixed prosthesis in an edentulous jaw. Braz Oral Res. 2013 25;28(1):67–73.

CAPÍTULO 3

***Influence of prosthesis-implant ratio to fixed prosthesis in atrophic mandibular***

Marcele Jardim PIMENTEL; Altair Antoninha DEL BEL CURY

## Abstract

**Objective**: The aim of this study was to evaluate the influence of prosthesis-implant (P:I) ratio when short implants are used to support complete denture in atrophic mandible. **Method**: Seven virtual models were created using the *SolidWorks*®. Each model consists of the anterior section of mandible, four implants and respective abutments connected by a rigid bar (15mm of cantilever) and resin denture retained by screws. The control group (P:I ratio = 1.2:1 / 14mm of prosthesis height (P), 11mm implant length (I)) was compared to P:I of 1.7:1 (P-16mm and I-9.0mm), P:I of 2.5:1 (P-18mm and I-7.0mm) and P:I 4.0:1 (P-20mm and I-5.0mm). The short implants were tested with two diameters (4.0 and 5.0mm). Axial load (100N) was applied in the last molar using the *Ansys Workbench* 14.0. The values of von Mises stress ($\sigma_{vM}$) were computed for implants and prosthetic components, and maximum principal stress ($\sigma_{max}$) for bone tissue. **Result**: The P:I of 1.7 increased $\sigma_{vM}$ on the screw (72.86% to 97.82%). The P:I of 2.5 increased the stress values for the cancellous bone (1.34% to 36.3%) and screw (> 70%). The P:I of 4.0 resulted the highest stress values for cortical bone (25.79% to 57.26%), cancellous bone (3.16%) and implants (10.48% to 91.75%). Compared to smallest diameter, wide implants reduce the stress to bone and implants, but increased the stress concentration in the abutments and screws. **Conclusion**: Implants with 5mm of length associated with higher prosthesis-implant ratio proved to be the most unfavorable condition with overloading the bone and implants.

**Key Words:** Prosthesis-implant ratio; Biomechanical; Short Implants

**Descriptors:** Denture, Complete; Prosthesis and Implants

## Introduction

The crown-implant ratio is defined as the "physical relationship between the portion of the implant-supported restoration within alveolar bone compared with the portion not within the alveolar bone". [1] The choice of the best treatment with dental implants sometimes is based on empiricism, mathematical models or extrapolations of the principles from conventional prosthesis applied to natural teeth. [2] Often certain guidelines applied to natural teeth are used in rehabilitation with implants [3] and the crown-root ratio initially was one of them. However the implants proved to be slightly different, and seem to resist a proportion considered unfavorable for natural teeth. [2,3] Nevertheless, the crown-implant ratio guidelines have not been established yet. [3]

Short implant has been proposed to replace graft procedures. Generally are indicated when remaining bone is restricted and necessarily implies that the prosthesis height will present greater dimensions to replace the bone loss and achieve the occlusal plane. This result in an unfavourable crown-implant ratio, which could increase the failure rate of short implants, since that the biomechanical factors can be harmful for any implant length. [4,5] It is reasonable to assume that a long crown supported by short fixture creates an unfavourable scenario, while the inverse represents a desirable situation.[2] This also occurs in cases of severe ridge atrophy, where the ratio between implants length and the distance to restore the vertical dimension of the patient results in unfavourable biomechanics due P:I ratio. [6] Misch and colleagues [7] brought together 15 studies between 1995 and 2005 relative to implant length affirming that the majority of failures are related to the implant size and biomechanical factors.

On the other hand, clinical studies showed favourable results regarding the crown-implants analysis. In a recent retrospective clinical trial conduced with 309 single-tooth implants the mean of prosthesis-implant ration ranged from 0.9 to 3.2. The follow up (mean of 20.9 months) showed that this ratio had no effect on the success of short implants. [3] Another study reported no fail in 52 implants (8 and 9 mm) after 10 years of follow up, and the authors concluded that the crown-implant ratio did not seem to have any negative influence on short implants success. [8] The authors also appointed that the crown-implant ratio or length of the implants seem not influence the survival rates.

However, another factors as surface topography, implant surface treatment or surgical protocols shows seen to more relevant. [4,9]

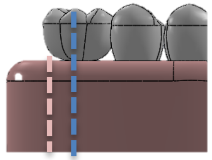
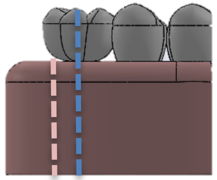
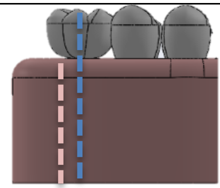
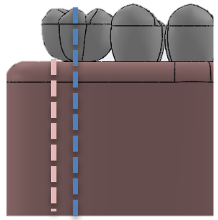
Thus, the issues about the biomechanical behaviour of short implants are controversial, revealing the necessity of more research in order to increase the knowledge, enhance predictability of this treatment option. The knowledge of the biological limits is important especially in cases of severely resorbed bone, when more caution is required. There is no broad discussion in the literature about the prosthesis-implant ratio for fixed prostheses in complete edentulous jaw. Therefore, the aim of this study was to evaluate the impact of the different prosthesis-implant ratio when short implants are used to support fixed complete prosthesis in atrophic mandible, using a tridimensional finite element analysis method.

**Methodology**

*Groups*

An experimental "*in silico*" study was performed and seven groups composed the study. The experimental groups were tested with two diameters (4.0 mm - conventional/Ci and 5.0 mm - wide/Wi) and three different implant length (5.0 mm, 7.0 mm, 9.0 mm), associated with different prosthesis height (20 mm, 18 mm and 16 mm). All of them were compared to a control group of conventional implants (11.0 x 4.0 mm and 14 mm of prosthesis height). The prosthesis-implants ratio was calculated dividing the length of the prosthesis by the length of the implant. [2,3] The groups are described at Table 1 and Figure 1.

**Table 1:** Groups distribution and variation of prosthesis height depending on the length of the implant.

| Groups | Implant Diameter | Length Implant | Base Height | Prosthesis Height | P:I Ratio | * |
|---|---|---|---|---|---|---|
| CG | 4.0 mm | 11.0 mm | 9.0 mm | 14 mm | 1.2:1 |  |
| Ci9 | 4.0 mm | 9.0 mm | 11.0 mm | 16 mm | 1.7:1 |  |
| Wi9 | 5.0 mm | | | | | |
| Ci7 | 4.0 mm | 7.0 mm | 13.0 mm | 18 mm | 2.5:1 |  |
| Wi7 | 5.0 mm | | | | | |
| Ci5 | 4.0 mm | 5.0 mm | 15.0 mm | 20 mm | 4.0:1 |  |
| Wi5 | 5.0 mm | | | | | |

Ci – Conventional Implant (4.0 mm of diameter); Wi – Wide Implant (5.0 mm of diameter)
P:I Ratio = prosthesis-implant ratio.
* The illustrations correspond to the distal portion of the prosthesis, location of load application. Base height (pink line), Prosthesis height (blue line).

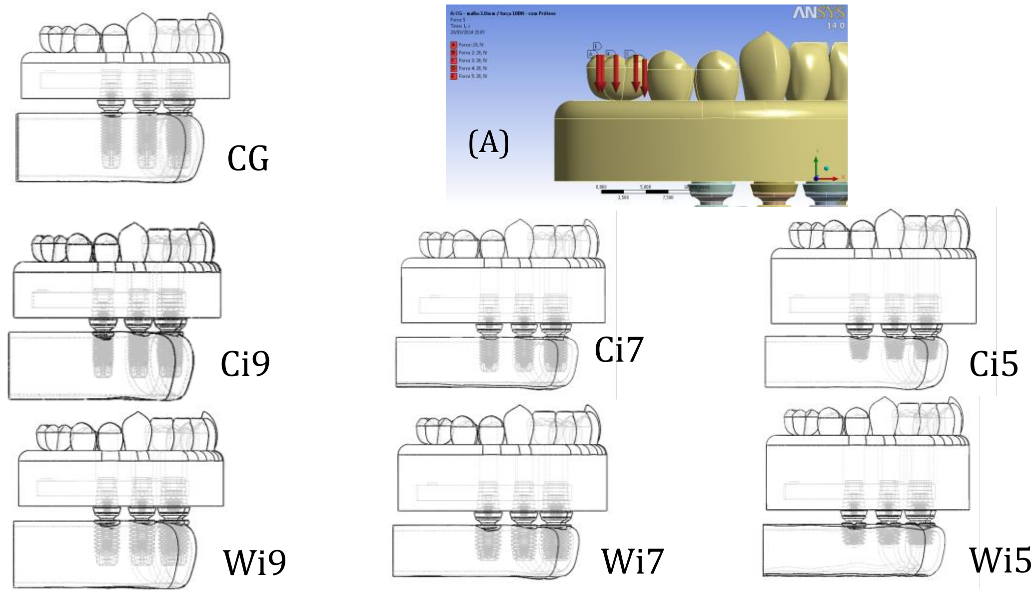



Figure 1: Lateral right view of the models for all groups. Observe the prosthesis-implant ratio. The load model was at last molar in Ansys Software (A). Boundary condition includes fixed support bilaterally at the distal faces and the inferior border of the mandible.

*Model Construction*

This method was replicated from a previous study in order to provide comparisons between the results (Pimentel and Cury – Chapper 2). The models were constructed with Solid Works software 2013® (Dassault Systèmes SolidWorks Corp, Concord, MA, EUA). All groups were constructed with the aim to mimics a bone fragment of the anterior region of the mandible. The distributions of implants follow the previous study arrangement (Pimentel and Del Bel Cury, 2014 – Chapper 1). The height of the mandible changed between the groups to represent atrophic bone (13 and 10mm) and approaching of the clinical indication of short implants. The cortical portion has 1mm of thickness for all groups. The different implants of each group were positioned and subtracted from mandibular model by boolean operations

Four Morse taper implants and respective abutments (1.5mm of length) were chosen for all groups. The implants and prosthetic components CAD were obtained from the manufacturer (Neodent System® Curitiba, PR, Brazil), respecting the exactly implants and components design. The files were exported to SolidWorks for geometry simplification and design refinement. Boolean operations were required to ensure a perfect fit between pieces during assembly of the groups. The implants were insert vertically with the same depth, at bone level, and were distributed equidistantly between the foramen distances (40 mm), equal for all groups.

The implants were splinted with a chromo-cobalt bar that was constructed following the arch shape and connected to the cylinders by boolean operation in SolidWorks. The bar was the same to all groups with 3mm of height, 5mm of thickness and 15mm of cantilever. The retention screws were the same to all groups. The abutments have the same tridimensional shape to (Ci11, Ci9, Ci7, Wi9 and Wi7). The Ci5 and Wi5 differed from them due the anatomic internal cone of implant with 5.0 mm of height. The distance from the bone level to the bar was constant for all groups (5.0 mm). The CG has 14mm of prosthesis height (P). While the implant length decreases 2 mm between the groups, 2 mm were adding to the denture base, increasing the P:I ratio (Table 1).

*Finite Element Analysis*

All groups were assembled at Solid Work and the CAD models were exported to the Ansys Workbench 14.0 FEA software (Swanson Analysis Inc, Houston, PA, USA). The mechanical properties such as elastic modulus and Poisson's ratio were obtained from the literature (Table 2). The mesh was constructed through convergence of analysis. Different element size were tested until does not alter more than 5% to the maximum stress values to all components (elements sizes tested: 1.8; 1.6; 1.4; 1.2; 1.0; 0.8; 0.6; 0.4 mm). At the end was determined a tetrahedral element with 1mm of size, used in all models. The number of elements and nodes in each group was: 172,975 and 298,761 (Ci5); 227,686 and 378,933 (Wi5); 214,050 and 359,659 (Ci7); 227,918 and 387,382 (Wi7); 217,956 and 369966 (Ci9); 295,248 and 484,479 (Wi9); 298,612 and 488,917 (CG).

Concern the interface conditions all structures were considered isotropic, homogeneous and linear elastic. [10] The boundary conditions were defined by fixing the distal surfaces bilaterally of the bone segment, and the inferior border, limiting body movement in all directions. The models were loaded in the cantilever extension (last molar) with axial loading of 100 N (Figure 1 A) divided in 5 points (20 N each) based on the average bite force considering conventional denture as opposed to overdentures (mean 88.1 ± 61.20 N).[11] The maximum principal stress ($\sigma_{max}$) for the bone segment and the von Mises stress ($\sigma_{vM}$) for the prosthetic components and implants were obtained.

Table 2: Mechanical properties.

| Material | Elastic Modulus ($E$) GPa | Poisson Ration ($v$) | References |
|---|---|---|---|
| Cortical Bone | 13.7 | 0.30 | Cruz et al., 2009[12] |
| Cancellous Bone | 1.37 | 0.30 | Cruz et al., 2009[12] |
| Titanium | 110.0 | 0.33 | Cruz et al., 2009[12] |
| Chromo-Cobalt | 218 | 0.33 | Geng et al., 2001[13] |
| Resin | 2.0 | 0.30 | Darbar et al., 1995[14] |

**Results**

Comparing the different prosthesis-implant ratio for the atrophic mandible it was observed that the increment of this relation could reflect in changes of the biomechanical behavior (Table 3). The groups Ci9 and Wi9 have prosthesis-implant ratio (P:I) of 1.7, and this ratio was 1.4 times bigger than the CG. Comparing Ci9 to CG, it was observed an increase of maximum principal stress ($\sigma_{max}$) on the bone (cancellous 0.33%) and the von Mises Stress ($\sigma_{vM}$) on the screw (72.86%). The increasing of the implant diameter (Wi9) reduces the stress on the bone, but increased the stress concentration in the screw.

The models Ci7 and Wi7 presented the P:I ratio (2.5) two times bigger than CG. Comparing to the CG, it was observed an increased stress for the cancellous bone (36.3% Ci7, and 1.34% Wi) and screw (more than 70%). Comparing Ci7 and Wi7, the wide implants reduced the stress levels in bone tissue and increase, in 4%, the stress in the screw. To Ci5 and Wi5 the P:I ratio (4.0) was 3.3 times bigger than CG. Comparing to the CG, it was observed an increase of the stress values of the $\sigma_{max}$ to the cortical bone (57.26% Ci5, and 25.79% Wi5), cancellous bone (3.16% Ci5), and implants (91.75% Ci5 and 10.48% Wi5). The Ci5 group proved to be the most unfavourable condition showing the worsen stress values to bone and implants. However, compared to the other experimental groups, implants with 5 mm of length presented the smaller values of stress in the screw.

Analyzing the bone behavior, the cortical bone showed the highest values of stress to Ci5 (34.63MPa) and Wi5 (27.70MPa) (Figure 2). For the cancelous bone, the highest values were observed to Ci7 (8.13 MPa) and Ci5 (6.14 MPa) (Figure 3). The increase of implant diameter reduced the $\sigma_{max}$ between the experimental groups. The

$\sigma_{vM}$ in the implants was highest to Ci5 (187.44 MPa) and Wi5 (108 MPa) (Figure 4). The abutment and the bar presented a reduction in stress values to all groups, while the stress in the retention screw increased, with similar behavior between Ci9 Ci7 Wi9 and Wi7 (Figure 5). The lowest stress values at the cortical bone (18.60 MPa), cancellous bone (4,79 MPa) and implant (68.03 MPa) were observed to Wi9, while the Ci5 showed the lowest values for abutment (63.13 MPa), bar (44,36 MPa) and screw (19,07 MPa).

**Table 3:** Stress Values (MPa) in bone, implants and prosthetic components after loading on prosthesis. The percentage values represent the difference between the experimental groups (Ci9, Ci7, Ci5, Wi9, Wi7, Wi5) and the control group (CG).

| P-I Ratio | | Cortical Bone | | Cancelous Bone | | Implants | | Abutment | | Bar | | Screw | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | **MPa** | **%** | **MPa** | **%** | **MPa** | **%** | **MPa** | **%** | **MPa** | **%** | **MPa** | **%** |
| 1.2 | CG | 22.02 | | 5.95 | | 97.75 | | 151.06 | | 295.48 | | 48.75 | |
| 1.7 | Ci9 | 23.40 | + 6.38% | 5.97 | + 0.33% | 81.30 | -16.82% | 145.87 | - 3.43% | 197.82 | -33.05% | 84.27 | +72.86% |
| | Wi9 | 18.60 | - 15.53% | 4.79 | -19.49 % | 68.03 | - 30.40% | 150.26 | - 0.52% | 231.62 | -21.61% | 96.44 | +97.82% |
| 2.5 | Ci7 | 18.27 | - 17.02% | 8.13 | + 36.63% | 96.40 | - 1.38% | 121.94 | - 19.27% | 196.04 | - 33.65% | 83.12 | + 70.50% |
| | Wi7 | 17.09 | - 22.38% | 6.03 | + 1.34% | 60.42 | - 38.18% | 149.31 | - 1.15% | 198.64 | - 32.77% | 84.95 | + 74.25% |
| | Ci5 | 34.63 | +57.26% | 6.14 | +3.19% | 187.44 | + 91.75% | 63.13 | -58.20% | 44.36 | -84.98% | 19.07 | - 60.88% |
| 4.0 | Wi5 | 27.70 | + 25.79% | 5.01 | - 15.79% | 108.0 | +10.48% | 84.17 | - 44.28% | 192.82 | - 34.74% | 54.34 | +11.46% |

Ci – Conventional Implant (4 mm of diameter); Wi – Wide Implant (5 mm of diameter). The Maximum Principal Stress ($\sigma_{max}$) was adopted for bone and von Mises Stress ($\sigma_{vM}$) was adopted for implant and prosthetic components.

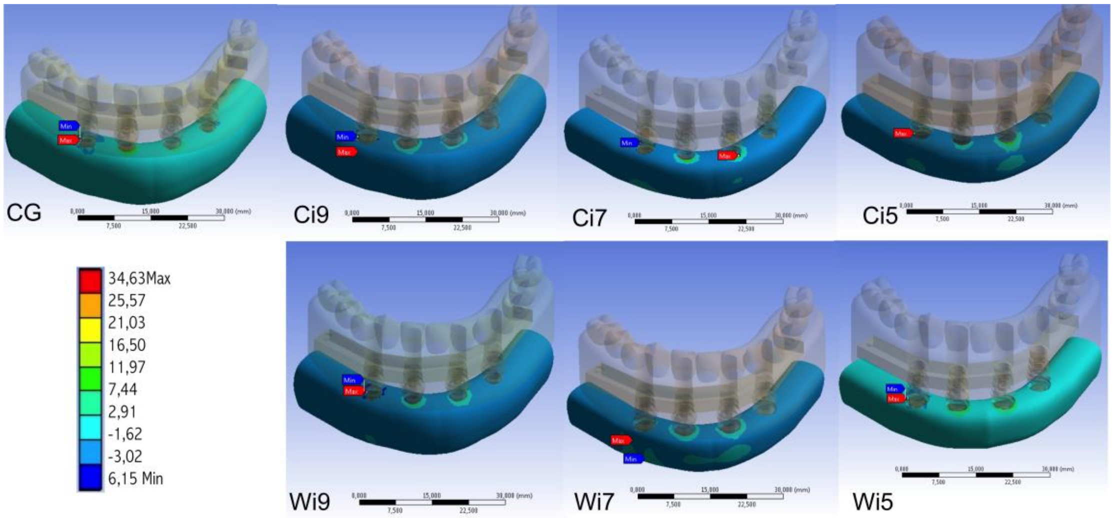



Figure 2: Isometric view of the cortical bone. The red point identifies the peak stress to the Maximum Principal Stress ($\sigma_{max}$) criteria. The scale was standardized to the maximum value (Ci5 - 34.63 MPa) for comparison of stress distribution between the groups.

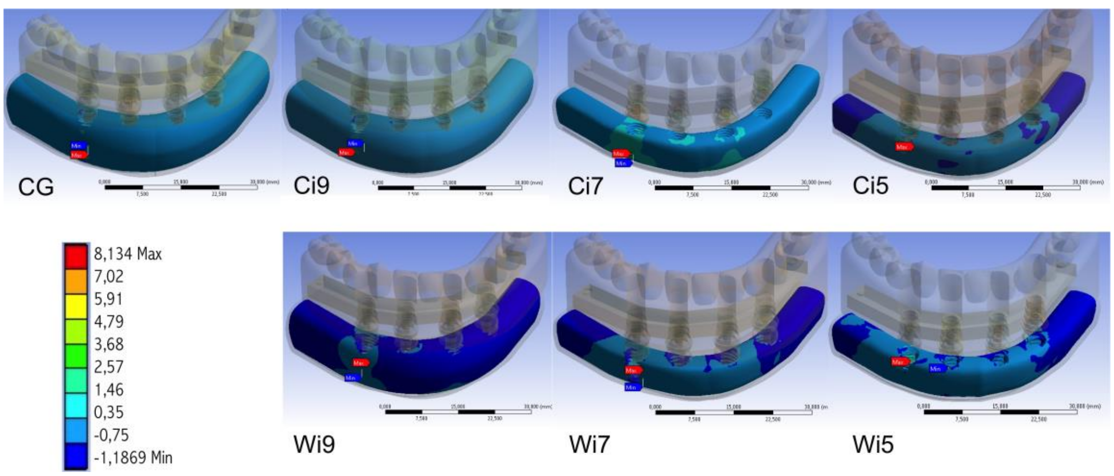



Figure 3: Isometric view of the cancelous bone. The red point identifies the peak stress to the Maximum Principal Stress ($\sigma_{max}$) criteria. The scale was standardized to the maximum principal stress value (Ci7 -8.81 MPa) for comparison of stress distribution between groups

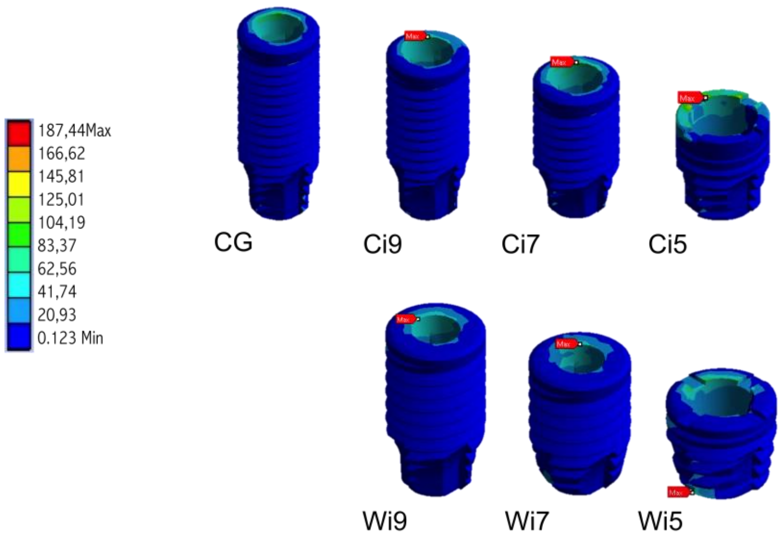



Figure 4: Isometric views of the implants. The red point identifies the peak stress to von Mises Stress ($\sigma_{vM}$) criteria. The scale was standardized to the maximum stress value (Ci5 – 187.44 MPa) for comparison of stress distribution between groups.

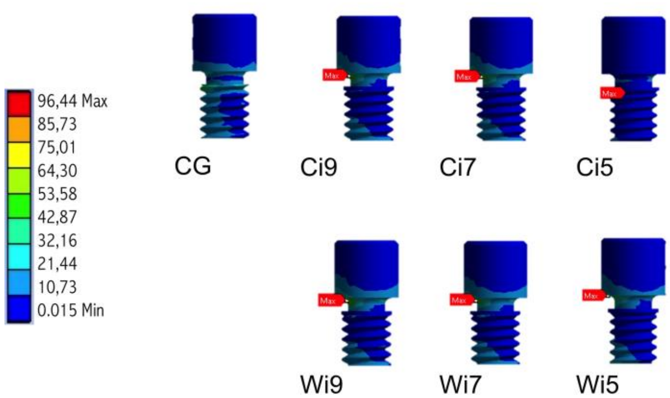



Figure 5: Front views of the screw. The red point identifies the peak stress to von Mises Stress ($\sigma_{vM}$) criteria. The scale was standardized to the maximum stress value (Wi9 – 96.44.0 MPa) for comparison of stress distribution between groups.

**Discussion**

This study evaluated the influence of prosthesis-implant (P:I) ratio when short implants are used to support fixed prosthesis in atrophic mandible. Three prosthesis-implant ratios (1.7:1; 2.5:1; 4.0:1) associated with two implants diameters (4.0 and 5.0 mm) were compared to CG (1.2:1 with 4.0 mm of implant diameter). The prosthesis height ranged from 14 to 20 mm between the groups. Previous study determined that the mean measure of crown length to restore short implants was 13.3mm, ranging from 6.2 to 21.7mm from a total of 309 single-tooth implants analysed. More than 93% had a crown-implant ratio equal or greater than 1.5, and more than 45% present P:I ratio equal or greater than 2.0. The results from analyses of crown-implant ratio suggested that 2.0:1 ratio or even great could produce a stable favourable outcome. [3] A longitudinal study evaluated the crown-implant ratio for partial edentulous and found that 26% (51 implants) presented P:I ratio ≥ 2 mm (mean of prosthesis and implant length are 13.57 and 8.01 mm, respectively). After 10 years only 3 implants failed giving a cumulative survival rate of 94.1%.[2] According to our results, the more unfavorable P:I (4:1) showed important increase of stress values for bone and implants, especially when associated with smallest implants diameter (Ci5). Despite the differences between the groups no one achieve the physiologic bone limits. [15]

The present results appoint that the bigger P:I ratio increased the stress values in the cortical bone, suggesting that the Ci5 group (P:I 4.0:1, and smallest implant diameter) represent an extreme condition for bone behaviour. A photoelasticity study analysing short implant showed no statistical difference between implants with 11, 9 and 7 mm of length, to stress concentration around the implants. However, implants with 5 mm represent an extreme and different condition (Pimentel and Del Bel Cury – Chapter 1). If compared to previous study without P:I influences, (Pimentel and Del Bel Cury - Chaper 2) analysing the percentage difference between experimental groups and CG in each study, we can observe that the values of $\sigma_{max}$ to cortical bone trend to increase with the prosthesis influence, for all groups. Analysing the cancellous bone the $\sigma_{max}$ increased compared to the CG however, the increase of stress concentration on cancellous bone was more related to the length of the implants than of P:I ratio ( Pimentel and Del Bel Cury - Chapter 2).

The increase of the stress in cortical bone due to an unfavorable P:I ratio, not necessarily results in marginal bone loss. Previous study analysing the annual bone loss in different crown-implant ratios[2] found a unexpected result where implants restoration with high P:I ratio showed significant less marginal bone loss than implants restored with low P:I ratio. However the author don't specifies the largest P:I ratio tested, it was only described that 26% of implant has P:I ratio ≥ 2:1, with no more details or extreme biomechanically unfavourable situation. In addition, another follow up of short implants reported that P:I ratio between 1:1 and 3:1 did not affect the crest bone levels. [16] This extrapolation must to be careful since that there no details regarding the P:I influence in clinical studies with short implants in complete dentures. [5,17,18] The lowest stress values at the cortical bone (18.60MPa), cancellous bone (4,79MPa) and implant (68.03MPa) were observed to Wi9 even with bigger P:I ratio than CG. This corroborate with previous biomechanical study that suggested that wide and relatively long implant is the best choice to minimizes the stress in the crestal alveolar bone [26] and proves that the increase in implant diameter can render the performance of short implants better than long implants with smaller diameter. [8]

Considering implants behaviour, the ratio 4.0:1 was the only one that demanded more from the implants (91,75% Ci5 and 10.48% Wi5 compared with CG). The others ratio reduced the stress percentage difference from the CG, compared to previous study (Pimentel and Del Bel Cury – Chaper 2). This means that the P:I ratio reflects more strongly on the bone tissue than the implants length, suggesting a possible exemption of guilt to the short implants in the cortical stress increase, in the simulated condition. The association with short and wide implants reduced stress levels to tissue bone and implants. This confirms that the magnitude of the stress on the bone decreased by increasing the diameter of implant.[19] The benefits of a large diameter implants were also describe previously. [20–23] Regardless of the implant length or the prosthesis-implant ratio, the increment on the implant diameter was sufficient to reduce the stress on the bone and implant, but increased the level of stress on prosthetic components, compared to implant with a smallest diameter. This behaviour is independent of the P:I ratio, since that previous study, without prosthesis height interferes, showed similar behaviour for wide implants (Pimentel e Del Bel Cury – Chaper 1 and 2).

The concepts that an unfavourable prosthesis-implant ratio could increase the failure rate of short implants must be discussed. The present study appoints that not every short implant compromises the stress levels. Although reported [7] that the failures of the short implants occurs primarily after prosthetic loading (reinforcing the biomechanical influence), a recent clinical trial comparing short (5.0 x 5.0 mm) vs longer implants (5.0 x 10.0 mm) associated with bone graft, showed that all complications occurred before loading.[24] In addition, a recent systematic review affirms that 70% of the short implant failures occurs before the loading, [4,25] due different reasons. This suggests that the main driver of failure is not the biomechanical behaviour fact as the crow-implant ratio.[25]

The Ci5 showed lowest values for abutment (63.13 MPa), bar (44,36 MPa) and screw (19,07 MPa). This group represents the more unfavorable P:I ratio (4:1) and the smallest contact area between implant/bone. The smaller P:I ratio associated with bigger bone/implant contact area reduces the stress concentration on the set bone/implant and an increase in the prosthetic components. On the other hand, a biggest P:I ratio associated with the smaller bone/implant contact area increasing the stress concentration in the set bone/implant, reducing the concentration in prosthetic components. The Ci5 proved to be the most unfavourable condition with worsen stress values to bone, and implants. Compared to the other experimental groups, implants with 5.0mm of length presented the smaller values of stress in the screw, and greater requirements in the bone. This result may raise the risk of bone fractures, in a bone already very reabsorbed. A clinical retrospective study appointed that atrophic mandibles are more susceptible to fractures, especially when associated with implants with 5.0 mm of length, [27] which could be explained by this increased stress concentration on bone. Bone quality is also related to the implant rates fail and mandible fracture indices. In cases of serious atrophy, the mandibular undergo changes in shape and density. [28] However, this factor was not adopted in this study, representing a limitation. The insertion of this variable could hide the influence of each factor analyzed.

The abutment and the bar presented a decrease in stress values to all groups, while the stress values in the screw trend to increase. The percentages values changed more to retention screw, comparing to the CG, however, it does not seem to be related to P:I ratio, but with the implant length (Pimentel and Del Bel Cury - Chaper 2). The loss of screw is cited as a complication for short implants in 10 years of follow up study. [29] Although observed an increase of the stress in the screw, in a previous study with 14 years of follow-up, only 2 abutment-framework screws were lost from 265 implants (8 and 10 mm) for single, partial or total edentulous patient. The authors reported the use of 8 mm implants for complete edentulous, however, was not describe in detail the number of complete dentures installed, number of implants or other relevant data for analysis. [5]

Analysing the influence of prosthetic parameters on the survival and complications rates of short implants, a previous study observed that the more prevalent complication was the screw loosing (7.8%). However the authors did not correlated this with P:I ratio.[30] This is in accordance with our results, since that the increase stress in the screw is associated with implant length, regardless the P:I ratio. A systemic review did not found technical complications related to implant components and suprastructure according to different C/I ratio, when short implant are used. [2] However, this review contains only two studies, due to the scarce studies aiming to analyze these factors, especially in complete edentulism. In the present study, the influence of P:I on the screw was clear only when the less favourable P:I ratio (4:1) was evaluated, where the opposite behaviour occurred, with reduction in the amount of stress on the screw. This may be explained for the greater leverage generated, and the trend of prosthesis rotation, that concentrates higher levels of stress on the bone, which becomes the most fragile component at the time of failure, which is not desirable.

Although differences in stress distribution between long and short implants to support a fixed denture demonstrated in this study, these results do not invalidate the short implants treatment option. Is important remember that short implants are an alternative to advanced surgical techniques.[4] Thereby, short implants must be preferable to large bone reconstruction procedures, since that reduces the time of treatment, cost, risk of infections and morbidity. [24,25,31,32]

One important finding of this study was a trend of weakness to the bone and implant when extra-short implants (5.0 mm) are used with a big P:I ratio, and the improvement of the results when short/wide implants are used. The 3-dimensional FEA method was used here to illustrate a possible differences between treatment options with short implants supported fixed complete prosthesis with different ratio, to allowing a better understand of the biomechanical aspects, and not to replicate exactly the in vivo stress condition. [33] All models were considered isotropic, homogeneous and linear elasticity, since that the simplifications were applied to all models these assumptions did not affect the final comparison between the groups. [21] Beside this, there are few reports to test this application, and the clinical found are sovereign on the mathematical models. It is interesting to highlight that in vitro experimental results cannot be extrapolated literally to clinical scenario. [2]

**Conclusion**

The 4:1 P-I ratio (CI5 and Wi5) was the worst, increasing levels in cortical and implants. The best results were found for short implants associated with a wide diameter (Wi9 and Wi7), regardless the P:I ratio.

**Acknowledgments**

The authors would like to thank the Neodent for the granting of the material. This study was supported by FAPESP with study scholarships awarded to the first named author #2011/21877-2.

**References**

1. The glossary of prosthodontic terms. J Prosthet Dent. 2005 Jul;94(1):10–92.

2. Blanes RJ, Bernard JP, Blanes ZM, Belser UC. A 10-year prospective study of ITI dental implants placed in the posterior region. II: Influence of the crown-to-implant ratio and different prosthetic treatment modalities on crestal bone loss. Clin Oral Implants Res. 2007;18(6):707–14.

3. Birdi H, Schulte J, Kovacs A, Weed M, Chuang S-K. Crown-to-implant ratios of short-length implants. J Oral Implantol. 2010;36(6):425–33.

4. Menchero-Cantalejo E, Barona-Dorado C, Cantero-Álvarez M, Fernández-Cáliz F, Martínez-González J-M. Meta-analysis on the survival of short implants. Med Oral Patol Oral Cir Bucal. 2011;16(4):e546–51.

5. Romeo E, Ghisolfi M, Rozza R, Chiapasco M, Lops D. Short (8-mm) dental implants in the rehabilitation of partial and complete edentulism: a 3- to 14-year longitudinal study. Int J Prosthodont. 2006;19(6):586–92.

6. Stellingsma C, Vissink a., Meijer HJ a., Kuiper C, Raghoebar GM. Implantology and the Severely Resorbed Edentulous Mandible. Crit Rev Oral Biol Med. 2004 Jul 1;15(4):240–8.

7. Misch CE, Steignga J, Barboza E, Misch-Dietsh F, Cianciola LJ, Kazor C. Short dental implants in posterior partial edentulism: a multicenter retrospective 6-year case series study. J Periodontol. 2006;77(8):1340–7.

8. Mertens C, Meyer-Bäumer A, Kappel H, Hoffmann J, Steveling HG. Use of 8-mm and 9-mm implants in atrophic alveolar ridges: 10-year results. Int J Oral Maxillofac Implants. 2012;27(6):1501–8.

9. Renouard F, Nisand D. Short implants in the severely resorbed maxilla: a 2-year retrospective clinical study. Clin Implant Dent Relat Res. 2005;7 Suppl 1:S104–10.

10. Almeida EO, Rocha EP, Júnior ACF, Anchieta RB, Poveda R, Gupta N, et al. Tilted and Short Implants Supporting Fixed Prosthesis in an Atrophic Maxilla: A 3D-FEA Biomechanical Evaluation. Clinical implant dentistry and related research. 2013; 5:1–11.

11. Müller F, Hernandez M, Grütter L, Aracil-Kessler L, Weingart D, Schimmel M. Masseter muscle thickness, chewing efficiency and bite force in edentulous patients with fixed and removable implant-supported prostheses: a cross-sectional multicenter study. Clin Oral Implants Res. 2012;23(2):144–50.

12. Cruz M, Wassall T, Toledo EM, da Silva Barra LP, Cruz S. Finite element stress analysis of dental prostheses supported by straight and angled implants. Int J Oral Maxillofac Implants. 2009;24(3):391–403.

13. Geng JP, Tan KB, Liu GR. Application of finite element analysis in implant dentistry: a review of the literature. J Prosthet Dent. 2001;85(6):585–98.

14. Darbar UR, Huggett R, Harrison a, Williams K. Finite element analysis of stress distribution at the tooth-denture base interface of acrylic resin teeth debonding from the denture base. J Prosthet Dent. 1995;74(6):591–4.

15. Reilly DT, Burstein a H. The elastic and ultimate properties of compact bone tissue. Journal of biomechanics. 1975;8(6):393–405.

16. Rokni S, Todescan R, Watson P, Pharoah M, Adegbembo AO, Deporter D. An assessment of crown-to-root ratios with short sintered porous-surfaced implants supporting prostheses in partially edentulous patients. Int J Oral Maxillofac Implants. 2005;20(1):69–76.

17. Lops D, Bressan E, Pisoni G, Cea N, Corazza B, Romeo E. Short implants in partially edentuolous maxillae and mandibles: a 10 to 20 years retrospective evaluation. Int J Dent. 2012;2012:351793.

18. Blanes RJ. To what extent does the crown-implant ratio affect the survival and complications of implant-supported reconstructions? A systematic review. Clin Oral Implants Res. 2009;20 Suppl 4:67–72.

19. Hasan I, Heinemann F, Aitlahrach M, Bourauel C. Biomechanical finite element analysis of small diameter and short dental implant. Biomed Tech. 2010;55(6):341–50.

20. De Paula GA, da Mota AS, Moreira AN, de Magahlães CS, Cornacchia TPM, Cimini CA. The effect of prosthesis length and implant diameter on the stress distribution in tooth-implant-supported prostheses: a finite element analysis. Int J Oral Maxillofac Implants. 2012;27(3):19–28.

21. Anitua E, Tapia R, Luzuriaga F, Orive G. Influence of implant length, diameter, and geometry on stress distribution: a finite element analysis. Int J Periodontics Restorative Dent. 2010;30(1):89–95.

22. Das Neves FD, Fones D, Bernardes SR, do Prado CJ, Neto AJF. Short implants--an analysis of longitudinal studies. Int J Oral Maxillofac Implants. 2006;21(1):86–93.

23. Renouard F, Nisand D. Impact of implant length and diameter on survival rates. Clin Oral Implants Res. 2006;17 Suppl 2:35–51.

24. Felice P, Pistilli R, Piattelli M, Soardi E, Corvino V, Esposito M. Posterior atrophic jaws rehabilitated with prostheses supported by 5 x 5 mm implants with a novel nanostructured calcium-incorporated titanium surface or by longer implants in augmented bone. Preliminary results from a randomised controlled trial. Eur J Oral Implantol. 2012;5(2):149–61.

25. Atieh M a, Zadeh H, Stanford CM, Cooper LF. Survival of short dental implants for treatment of posterior partial edentulism: a systematic review. Int J Oral Maxillofac Implants. 2012;27(6):1323–31.

26. Petrie CS, Williams JL. Comparative evaluation of implant designs: influence of diameter, length, and taper on strains in the alveolar crest. A three-dimensional finite-element analysis. Clin Oral Implants Res. 2005;16(4):486–94.

27. Soehardi A, Meijer GJ, Manders R, Stoelnga PJW. An inventory of mandibular fractures associated with implants in atrophic edentulous mandibles: a survey of Dutch oral and maxillofacial surgeons. Int J Oral Maxillofac Implants. 2011;26(5):1087–93.

28. Bianchi A, Sanfilippo F. Osteoporosis: the effect on mandibular bone resorption and therapeutic possibilities by means of implant prostheses. Int J Periodontics Restorative Dent. 2002;22(3):231–9.

29. Lai H, Si M, Zhuang L, Shen H, Liu Y, Wismeijer D. Long-term outcomes of short dental implants supporting single crowns in posterior region: a clinical retrospective study of 5-10 years. Clin Oral Implants Res. 2013;24(2):230–7.

30. Tawil G, Younan R. Clinical evaluation of short, machined-surface implants followed for 12 to 92 months. Int J Oral Maxillofac Implants. 2003;18(6):894–901.

31. Esposito M, Cannizarro G, Soardi E, Pellegrino G, Pistilli R, Felice P. A 3-year post-loading report of a randomised controlled trial on the rehabilitation of posterior atrophic mandibles: short implants or longer implants in vertically augmented bone? Eur J Oral Implantol. 2011;4(4):301–11.

32. Stellingsma K, Raghoebar GM, Meijer HJ a, Stegenga B. The extremely resorbed mandible: a comparative prospective study of 2-year results with 3 treatment strategies. Int J Oral Maxillofac Implants. 2004;19(4):563–77.

33. Toniollo MB, Macedo AP, Rodrigues RCS, Ribeiro RF, de Mattos M da GC. Three-dimensional finite element analysis of stress distribution on different bony ridges with different lengths of morse taper implants and prosthesis dimensions. J Craniofac Surg. 2012;23(6):1888–92.

34. Sotto-Maior BS, Senna PM, da Silva WJ, Rocha EP, Del Bel Cury A. Influence of Crown-to-Implant Ratio, Retention System, Restorative Material, and Occlusal Loading on Stress Concentrations in Single Short Implant. Int J Oral Maxillofac Implants 2012;27:13–e18.

## CONSIDERAÇÕES FINAIS

A representação extremamente precisa de um sistema biológico complexo e influenciável por fatores diversos como fixação flutuante e muscular da mandíbula e carregamento oclusal variável entre indivíduos é de difícil reprodutibilidade. A busca por simulações próximas da realidade em pesquisas biológicas é o ponto desejável para qualquer metodologia em ciência. Para análise de tensão o mesmo acontece, entretanto métodos como os aplicados neste trabalho apresentam limitações inerentes a técnica, que limitam essa aproximação.

Mesmo para FEA é prevista a simplificação do modelo, decorrente da dificuldade em se representar minuciosamente toda a complexidade de características biomecânicas do corpo humano (Geng *et al.,* 2001). Neste estudo, a aplicação dos diferentes métodos tinha a finalidade de ilustrar uma possível diferença entre opções de tratamento com implantes curtos, permitindo uma melhor compreensão dos aspectos biomecânicos, e não replicar exatamente uma condição biológicas extremante complexas como acontecem *in vivo* (Toniollo *et al.,* 2012).

Muitos fatores podem influenciar significativamente a acurácia dos resultados obtidos por FEA (Geng *et al.,* 2001):

(1) a detalhada geometria

(2) a propriedade inserida a cada material

(3) as condições de contorno

(4) a interface entre osso e implante

A geometria detalhada foi alcançada pela precisão exata do conjunto implante e componentes protéticos, que apresentam a configuração e forma exata do fabricante. Quanto à geometria e às propriedades do osso há uma capacidade limitada de se determinar o padrão trabecular, ou aferir diferentes características ósseas dentre uma infinidade de indivíduos, e que, mesmo considerando apenas um indivíduo, encontra-se em mudanças constantes pelo processo de remodelação óssea crônica (Bianchi e Sanfilippo, 2002). Assim, pela simplificação assume-se que o osso trabecular tem um padrão sólido dentro da casca interna do osso cortical. Ambos os tipos de osso foram modelados de forma simplificada como materiais lineares, homogêneos e isotrópicos. Essa condição é encontrada na maioria dos trabalhos por FEA (Geng *et al.,* 2001). A interface osso-implante foi assumida como perfeita, com estado ótimo de osseointegração, tratando-se de uma análise linear. Quanto às propriedades inseridas a cada material, uma gama de parâmetros de materiais diferentes tem sido recomendada para o uso em estudos anteriores (Geng *et al.,* 2001), o que dificulta a padronização e comparação numérica exata de diversos achados na literatura. Assim, os valores obtidos não representam diretamente os valores numéricos absolutos do que acontece no conjunto biológico, mas sim, encontrar uma tendência de comportamento para diferentes condições de tratamento, reagindo ao mesmo estímulo.

As condições de contorno determinaram a fixação do corpo eliminando seus movimentos, situação essa simulada largamente pela maioria dos estudos (Geng *et al.,* 2001), e mais próxima da simulação realizada em laboratório pelo método fotoelástico. Essa simulação das condições teve a finalidade de aproximar a realidade das duas condições, na tentativa de viabilizar uma comparação de resultados, sem comprometer a tendência de comportamentos, quando comparados a testes pilotos com diferentes modelos de fixação. Apesar de não apresentarem uma condição exatamente coincidente, os dois experimentos apresentam tendências de comportamento similares.

Na análise fotoelástica, abordada no capítulo 1, foi observado que implantes curtos demandam maior área do osso para distribuição da força aplicada. A redução do comprimento aumentou os níveis de tensão em volta do implante, mas sem diferença estatística entre implantes de 11, 9 e 7 mm. Já os implantes de 5 mm apresentaram níveis de tensão significativamente maiores em torno dos implantes. Para o estudo pelo método de elementos finitos, foi feita uma análise com base nos valores de tensão máxima obtidos, havendo maior concentração de tensão na região cervical, representada pelo osso cortical. Entretanto, os valores máximos de tensão não se apresentaram maiores em relação aos dos implantes longos, exceto para implantes de 5 mm. Essas tendência mostra também que implantes de 5 mm são destoantes e aumentam o risco biológico. A redução do comprimento exige mais do osso, entretanto pode ser uma opção de tratamento a ser considerada, já que pode, não apresentar níveis tão discrepantes dos alcançados com implante longos, como para implantes de 9 e 7 mm, e ainda encontram-se dentro dos limites biológicos do osso humano (Reilly e Burstein, 1975).

A associação destes experimentos é interessante a partir do momento que podemos observar o que acontece com os implantes e componentes protéticos. Assim, podemos formular a conclusões mais interessantes, onde a opção por implantes curtos segue a tendência de sobrecarregar o parafuso protético em níveis altos, enquanto implantes extra curtos tendem a aliviar a tensão sobre os componentes protéticos e passam a sobrecarregar implante e osso.

O aumento do diâmetro foi claramente determinante para a redução da concentração de tensão em torno do implante. Como revelado no capítulo 1 uma menor quantidade da força aplicada na barra foi transmitida para resina, quando implantes largos são utilizados. O mesmo comportamento foi observado quando se avalia o tecido ósseo para os demais ensaios, abordados nos capítulos 2 e 3, o aumento do diâmetro reduz a exigência sobre o osso. Em contra partida, há maior exigência dos componentes protéticos. O contrário acontece para implantes curtos de menor diâmetro.

Os valores de carga aplicados em ambos os experimentos foram idealizados dentro de cada metodologia, não sendo possível uma padronização. O carregamento aplicado no método fotoelástico é determinado para permitir uma análise quantitativa do comportamento, podendo assim, ser sugerida diferença estatística entre os grupos. Já o carregamento aplicado no método de elementos finitos foi baseado em estudo que determina a força de mordida alcançada em diferentes tratamentos protéticos (Müller *et al.,* 2012). Assim, os valores obtidos de tensão, entre os experimentos não podem ser confrontados diretamente, mas podem sim direcionar uma linha de pensamento. Outra razão para isto é o material no qual o implante é inserido. As propriedades da resina fotoelástica diferem das propriedades ósseas consideradas no programa de análise por elementos finitos, assim o comportamento do conjunto também é diferente. O que procuramos encontrar com este trabalho foram tendências de comportamentos, e comportamentos destoantes, a fim de sugerir possibilidades de tratamento que diminuam o risco biológico.

De uma maneira geral, implantes que proporcionam menor suporte, com reduzida área de contato osso/implante, tendem a aumentar os níveis de tensão no implante e consequentemente no osso, em especial o implante extra curto (5 mm). Enquanto, implantes com maior área de contato osso/implante tendem a diminuir o risco biológico, porém sobrecarregam os componentes protéticos.

Essa tendência é seguida na análise da proporção prótese-implante com influência dos níveis de tensão na cortical. A opção de maior risco foi apresentada por implantes extra-curtos com proporção 4.0:1, aumentando os níveis de tensão sobre o implante e o osso cortical. A proporção de 2.5 com implantes de menor diâmetro também se aproximaram mais desse comportamento.

## CONCLUSÃO

- Implantes curtos aumentam os níveis de tensão ao torno do implante e no parafuso protético.

- O comportamento biomecânico dos implantes extra curtos (5 mm) foram considerados diferentes dos implantes longos e passíveis de aumentar o risco de falha.

- O aumento do diâmetro é efetivo para redução da tensão sobre implantes e osso, aumentando a exigência sobre os componentes protéticos.

- Proporção P:I extrema, representada pela proporção 4:1, resultou em aumento significativo dos valores de tensão no osso e implantes.

## REFERÊNCIAS


Atieh M a, Zadeh H, Stanford CM, Cooper LF. Survival of short dental implants for treatment of posterior partial edentulism: a systematic review. Int J Oral Maxillofac Implants. 2012; 27(6): 1323–31.

Bianchi A, Sanfilippo F. Osteoporosis: the effect on mandibular bone resorption and therapeutic possibilities by means of implant prostheses. Int J Periodontics Restorative Dent. 2002; 22(3): 231–9.

Birdi H, Schulte J, Kovacs A, Weed M, Chuang S-K. Crown-to-implant ratios of short-length implants. J Oral Implantol. 2010; 36(6): 425–33.

Blanes RJ, Bernard JP, Blanes ZM, Belser UC. A 10-year prospective study of ITI dental implants placed in the posterior region. II: Influence of the crown-to-implant ratio and different prosthetic treatment modalities on crestal bone loss. Clin Oral Implants Res. 2007; 18(6): 707–14.

Chiapasco M, Casentini P, Zaniboni M. Bone augmentation procedures in implant dentistry. Int J Oral Maxillofac Implants. 2009; 24 Suppl(1): 237–59.

Chiapasco M, Zaniboni M, Boisco M. Augmentation procedures for the rehabilitation of deficient edentulous ridges with oral implants. Clin Oral Implants Res. 2006; 17 Suppl 2(c): 136–59.

Das Neves FD, Fones D, Bernardes SR, do Prado CJ, Neto AJF. Short implants--an analysis of longitudinal studies. Int J Oral Maxillofac Implants. 2006; 21(1): 86–93.

De Santis D, Cucchi A, Longhi C, Vincenzo B. Short threaded implants with an oxidized surface to restore posterior teeth: 1- to 3-year results of a prospective study. Int J Oral Maxillofac Implants. 2011; 26(2): 393–403.

Elangovan S, Mawardi HH, Karimbux NY. Quality assessment of systematic reviews on short dental implants. J Periodontol. 2013; 84(6): 758–67.

Esposito M, Cannizarro G, Soardi E, Pellegrino G, Pistilli R, Felice P. A 3-year post-loading report of a randomised controlled trial on the rehabilitation of posterior atrophic mandibles: short implants or longer implants in vertically augmented bone? Eur J Oral Implantol. 2011; 4(4): 301–11. (a)

Esposito M, Grusovin MG, Coulthard P, Worthington H V. The efficacy of various bone augmentation procedures for dental implants: a Cochrane systematic review of randomized controlled clinical trials. Int J Oral Maxillofac Implants. 2006; 21(5): 696–710.

Esposito M, Pellegrino G, Pistilli R, Felice P. Rehabilitation of posterior atrophic edentulous jaws : prostheses supported by 5 mm short implants or by longer implants in augmented bone ? One-year results from a pilot randomised clinical trial. 2011; 4(1): 21–30. (b)

Felice P, Checchi V, Pistilli R, Scarano A, Pellegrino G, Esposito M. Bone augmentation versus 5-mm dental implants in posterior atrophic jaws. Four-month post-loading results from a randomised controlled clinical trial. Eur J Oral Implantol. 2009; 2(4): 267–81.

Felice P, Pellegrino G, Checchi L, Pistilli R, Esposito M. Vertical augmentation with interpositional blocks of anorganic bovine bone vs. 7-mm-long implants in posterior mandibles: 1-year results of a randomized clinical trial. Clin Oral Implants Res. 2010; 21(12): 1394–403.

Felice P, Pistilli R, Piattelli M, Soardi E, Corvino V, Esposito M. Posterior atrophic jaws rehabilitated with prostheses supported by 5 × 5 mm implants with a novel nanostructured calcium-incorporated titanium surface or by longer implants in augmented bone . Preliminary results from a randomised controlled trial. 2012; 5(2): 149–61.

Geng JP, Tan KB, Liu GR. Application of finite element analysis in implant dentistry: a review of the literature. J Prosthet Dent. 2001; 85(6): 585–98.

Glantz PO, Nilner K. Biomechanical aspects of prosthetic implant-borne reconstructions. Periodontol 2000. 1998; 17(12): 119–24.

Grant B-TN, Pancko FX, Kraut R a. Outcomes of placing short dental implants in the posterior mandible: a retrospective study of 124 cases. J Oral Maxillofac Surg. American Association of Oral and Maxillofacial Surgeons; 2009; 67(4): 713–7.

Griffin TJ, Cheung WS. The use of short, wide implants in posterior areas with reduced bone height: a retrospective investigation. J Prosthet Dent. 2004; 92(2): 139–44.

Gulje F. Implants of 6 mm vs. 11 mm lengths in the posterior maxilla and mandible : a 1-year multicenter randomized controlled trial. Clin Oral Implants Res. 2013; 24(12): 1325-31.

Jemt T. Failures and complications in 391 consecutively inserted fixed prostheses supported by Brånemark implants in edentulous jaws: a study of treatment from the time of prosthesis placement to the first annual checkup. Int J Oral Maxillofac Implants. 1991; 6(3): 270–6.

Jiansheng H, Dongying X, Xianfeng W, Baoyi X, Qiong L, Jincai Z. Clinical evaluation of short and wide-diameter implants immediately placed into extraction sockets of posterior areas: a 2-year retrospective study. J Oral Implantol. 2012; 38(6): 729–37.

Karthikeyan I, Desai SR, Singh R. Short implants : A systematic review. J Indian Soc Periodontol. 2012; 16(3): 302–312.

Keller EE, Tolman DE. Mandibular ridge augmentation with simultaneous onlay iliac bone graft and endosseous implants: a preliminary report. Int J Oral Maxillofac Implants. 1992; 7(2): 176–84.

Lai H, Si M, Zhuang L, Liu Y. Long-term outcomes of short dental implants supporting single crowns in posterior region : a clinical retrospective study of 5 – 10 years. Clin Oral Implants Res. 2013; 24(2): 230-7.

Lekholm U, Gunne J, Henry P, Higuchi K, Lindén U, Bergström C, et al. Survival of the Brånemark implant in partially edentulous jaws: a 10-year prospective multicenter study. Int J Oral Maxillofac Implants. 1999; 14(5): 639–45.

Lops D, Bressan E, Pisoni G, Corazza B, Romeo E. Short Implants in Partially Edentulous Maxillae and Mandibles : A 10 to 20 Years Retrospective Evaluation. Int J Dent. 2012; 2012: 351793.

Maestre-Ferrín L, Boronat-López A, Peñarrocha-Diago M, Peñarrocha-Diago M. Augmentation procedures for deficient edentulous ridges, using onlay autologous grafts: an update. Med Oral Patol Oral Cir Bucal. 2009; 14(8): e402–7.

Maló P, Nobre M, Lopes A. Short implants in posterior jaws . A prospective 1-year study. Eur J Oral Implantol. 2011; 4(1): 47-53.

Maló P, de Araújo Nobre M, Rangert B. Short implants placed one-stage in maxillae and mandibles: a retrospective clinical study with 1 to 9 years of follow-up. Clin Implant Dent Relat Res. 2007; 9(1): 15–21.

Menchero-cantalejo E, Barona-dorado C, Cantero-álvarez M, Fernández-cáliz F. Meta-analysis on the survival of short implants. Med Oral Patol Oral Cir Bucal. 2011; 16(4): 546-51.

Mertens C, Meyer-Bäumer A, Kappel H, Hoffmann J, Steveling HG. Use of 8-mm and 9-mm implants in atrophic alveolar ridges: 10-year results. Int J Oral Maxillofac Implants. 2012; 27(6): 1501–8.

Misch CE, Steignga J, Barboza E, Misch-Dietsh F, Cianciola LJ, Kazor C. Short dental implants in posterior partial edentulism: a multicenter retrospective 6-year case series study. J Periodontol. 2006;77(8): 1340–7.

Monje A, Chan H-L, Fu J-H, Suarez F, Galindo-Moreno P, Wang H-L. Are short dental implants (<10 mm) effective? a meta-analysis on prospective clinical trials. J Periodontol. 2013; 84(7): 895–904.

Müller F, Hernandez M, Grütter L, Aracil-Kessler L, Weingart D, Schimmel M. Masseter muscle thickness, chewing efficiency and bite force in edentulous patients with fixed and removable implant-supported prostheses: a cross-sectional multicenter study. Clin Oral Implants Res. 2012; 23(2): 144–50.

Nedir R, Bischof M, Briaux J-M, Beyer S, Szmukler-Moncler S, Bernard J-P. A 7-year life table analysis from a prospective study on ITI implants with special emphasis on the use of short implants. Clin Oral Implants Res. 2004; 15(2): 150–7.

Pommer B, Frantal S, Willer J, Posch M, Watzek G, Impact TG. Impact of dental implant length on early failure rates : a meta- analysis of observational studies. J Clin Periodontol. 2011; 38(9): 856-63.

Rangert BR, Sullivan RM, Jemt TM. Load factor control for implants in the posterior partially edentulous segment. Int J Oral Maxillofac Implants. 1997; 12(3): 360–70.

Reilly DT, Burstein a H. The elastic and ultimate properties of compact bone tissue. J Biomech. 1975; 8(6): 393–405.

Renouard F, Nisand D. Impact of implant length and diameter on survival rates. Clin Oral Implants Res. 2006; 17 (Suppl 2): 35–51.

Romeo E, Ghisolfi M, Rozza R, Chiapasco M, Lops D. Short (8-mm) dental implants in the rehabilitation of partial and complete edentulism: a 3- to 14-year longitudinal study. Int J Prosthodont. 2006; 19(6): 586–92.

Stellingsma K, Raghoebar GM, Meijer HJ a, Stegenga B. The extremely resorbed mandible: a comparative prospective study of 2-year results with 3 treatment strategies. Int J Oral Maxillofac Implants. 2004; 19(4): 563–77.

Soehardi A, Meijer GJ, Manders R, Stoelnga PJW. An inventory of mandibular fractures associated with implants in atrophic edentulous mandibles: a survey of Dutch oral and maxillofacial surgeons. Int J Oral Maxillofac Implants. 2011; 26(5): 1087–93.

Telleman G, Raghoebar GM, Vissink A, den Hartog L, Huddleston Slater JJR, Meijer HJ a. A systematic review of the prognosis of short (<10 mm) dental implants placed in the partially edentulous patient. J Clin Periodontol. 2011; 38(7): 667–76.

Toniollo MB, Macedo AP, Cristina R, Rodrigues S, Ribeiro RF, Chiarello G. Three-Dimensional Finite Element Analysis of Stress Distribution on Different Bony Ridges With Different Lengths of Morse Taper Implants and Prosthesis Dimensions. 2012;23(6):1888–92.

**Apêndice 1**

*Obtenção dos modelos fotoelásticos*

Para obtenção do modelo fotoelástico foi confeccionada uma matriz de vidro em dimensões estabelecidas a partir da análise métrica de peças dissecadas para distribuição tridimensional dos implantes (Figura 1). Resultando num modelo plano de dois braços de 50mm de extensão, com aproximadamente 130° entre eles, altura de 20mm e espessura de 10mm.

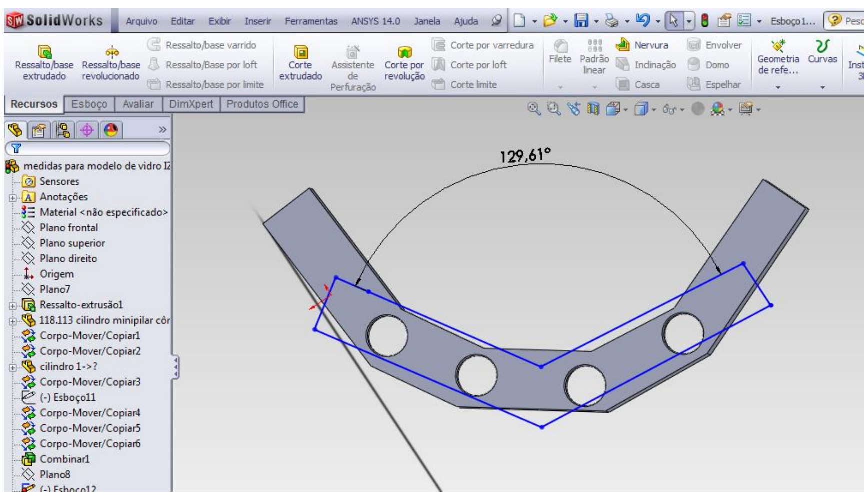



**Figura 1:** Angulação conferida a matriz de vidro para obtenção de moldes de silicone

Foram confeccionadas quatro infraestruturas em cromo-cobalto, a partir de uma matriz em gesso com quatro análogos de minipilar posicionados de acordo com a distribuição espacial dos implantes, estabelecida no teste 3D. Essa posição foi fixada com resina acrílica autopolimerizável e o conjunto foi imerso em molde de silicone obtido por moldagem de arco desdentado, para que a barra respeitasse a curvatura mandibular (Figura 2).

**Figura 2:** Sequência para obtenção da matriz de gesso para confecção das infraestruturas metálicas.

Os implantes foram posicionados na barra, garantindo passividade máxima ao sistema. As barras foram fixadas com auxílio de uma lâmina de resina acrílica em um dispositivo composto por uma haste vertical fixa, duas hastes móveis (uma vertical e outra horizontal), fabricado especificamente para este fim (Apêndice 2). O conjunto foi posicionado no molde onde a resina fotoelástica (GIV, Polipox) foi vertida (Figuras 3 e 4).

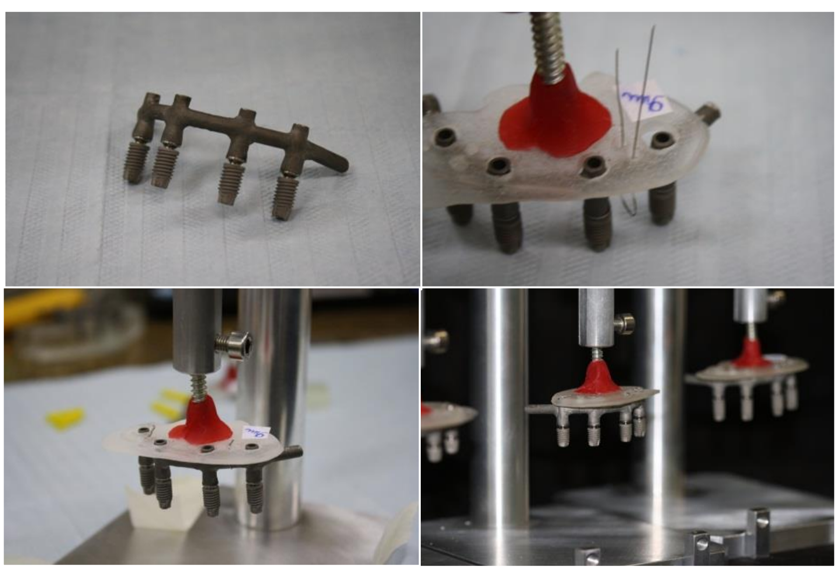


**Figura 3:** Sequência de posicionamento dos implantes e fixação da barra.

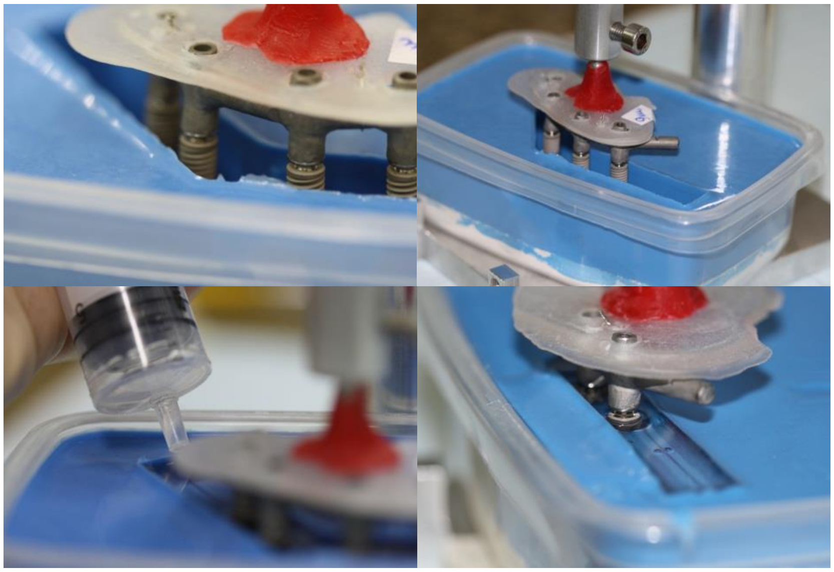


**Figura 4:** Sequência de posicionamento do conjunto e a resina sendo vertida no molde.

O conjunto foi levado à panela de pressão (60 psi/ 10min) para eliminação de bolhas de ar que tenham sido aprisionadas durante o preenchimento do molde. Foi então esperado o tempo de presa e cura do material (48h). O modelo final foi visualmente avaliado quanto à lisura e transparência obtidas para posterior análise, apresentando o aspecto final como na demonstrado na Figura 5A. Para garantir que a carga exercida nas infraestruturas fosse realizada sempre na mesma posição, foram confeccionadas canaletas em todas as infraestruturas (Figura 5B).

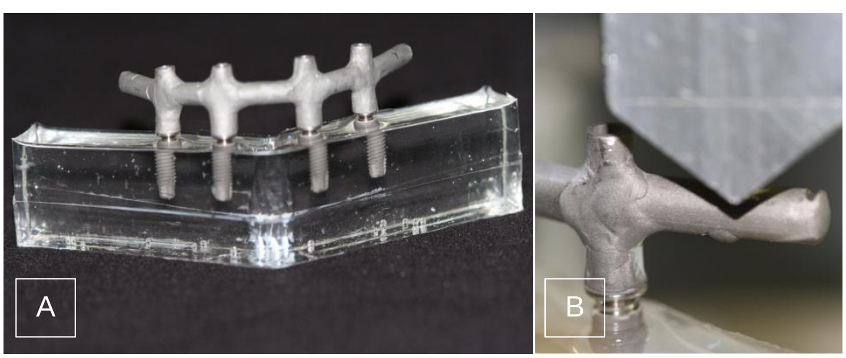



**Figura 5:** A) Aspecto final do modelo. B) Fenda para posicionamento da célula de carga.

O carregamento foi realizado com auxílio de uma ponteira metálica conectada à célula de carga do polariscópio. Para viabilizar a análise quantitativa a carga exercida deve se limitar a formação de franjas até a ordem 4. A sobrecarga resulta em maior número de franjas impossibilitando o reconhecimento, pelo software, da diferença de comportamento entre os grupos. Assim, foi realizado um pré-teste para determinação do valor da carga. A carga inicialmente aplicada foi de 0,5 kgf. A carga foi reduzida gradativamente até que fosse atingido a ordem de franja 4 para o grupo com maior concentração de tensão. A carga final determinada no teste piloto foi de 0,15 kgf, aplicada a 15 mm do implante distal (final do *cantilever*).

## Apêndice 2

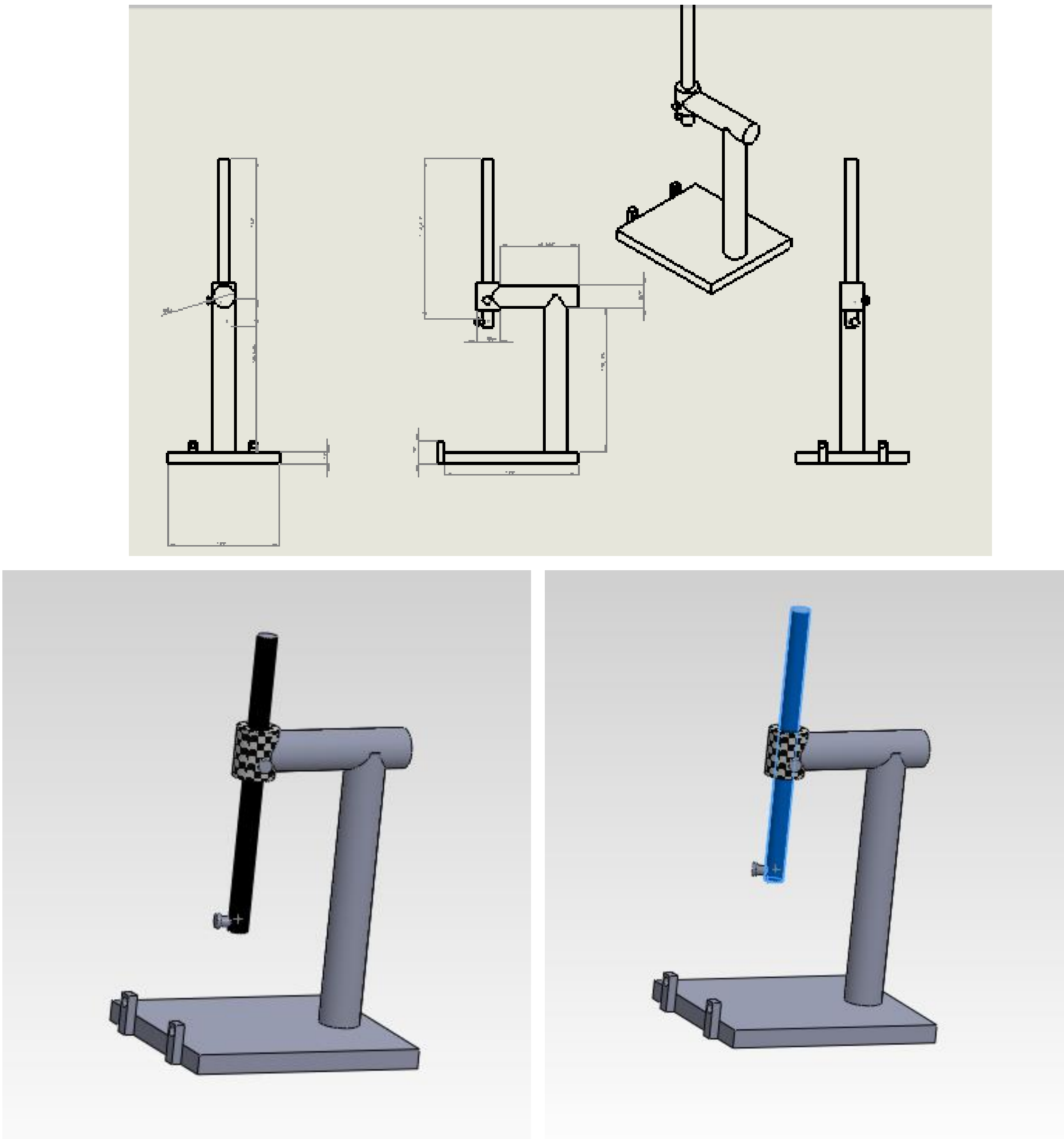


**Figura 6:** Dispositivo auxiliar para confecção do modelo fotoelástico.

## Apêndice 3

### *Obtenção dos modelos virtuais*

#### *Modelagem*

Os modelos 3D dos implantes dentais e de seus respectivos componentes protéticos foram fornecidos pelo fabricante (Neodent, Curitiba, Brazil) no formato *igs*. Esses modelos foram posteriormente importados no software SolidWorks® para que fossem corrigidos os erros inerentes ao processo de importação. Em adição, foram realizadas alterações nas roscas internas dos implantes por meio das operações booleanas (combinação, adição ou subtração) para obter a perfeita adaptação entre as roscas dos parafusos protéticos com as roscas internas dos implantes, permitindo exato contato entre ambos. Os modelos foram desenvolvidos no programa SolidWorks 2013®, sendo modeladas as peças: implantes, minipilares, barra e parafusos de retenção (Figuras 7 a 10).

A mandíbula foi modelada com base em medidas métricas encontradas em ossos dissecados calculando a distância interforame, onde os quatro implantes seriam inseridos. Como o objetivo do estudo é avaliar o comportamento biomecânico do osso ao redor dos implantes, no corpo dos implantes e componentes protéticos, apenas o segmento de interesse da mandíbula foi reconstruído.

Para isto foi iniciado um esboço do contorno em secção transversal da região anterior da mandíbula no software SolidWorks. Planos subsequentes foram criados conferindo geometria do arco (Figura 11). O recurso loft foi utilizado para dar forma sólida à peça (Figura 12) e foi feito o espelhamento do conjunto (Figura 13).

Foram modelados dois modelos com alturas distintas compatíveis com a indicação para os diferentes comprimentos dos implantes curtos e os modelos finais apresentaram alturas de 13 (para os grupos GC e IC9) e 10 (para os grupos IC5 e IC7). A cortical para ambos apresentou 1 mm de espessura. Os implantes foram distribuidos equidistante respeitando a distância média entre forames de peças dissecadas (aproximadamente 40mm).

**Figura 7:** Implantes Cone-Morse diâmetro de 4mm e comprimentos 5, 7, 9 e 11mm.

**Figura 8:** Implantes Cone-Morse diâmetro de 5mm e comprimentos 5, 7, e 9mm.

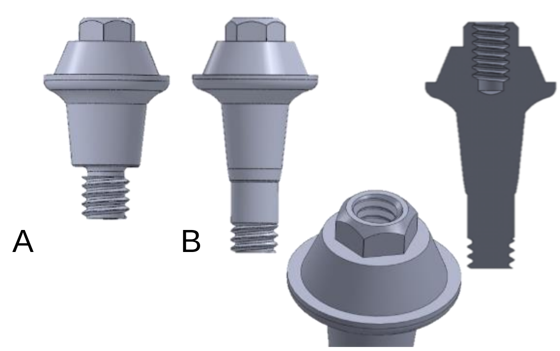



**Figura 9**: Modelos de minipilares para implantes cone-morse de 5mm (A) e  11, 9 e 7mm (B).

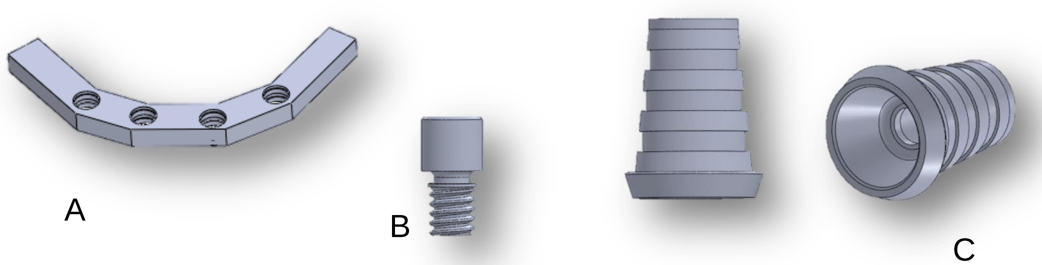



**Figura 10**: Componentes protéticos: barra (A); parafusos de retenção (B) e cilindros (C).

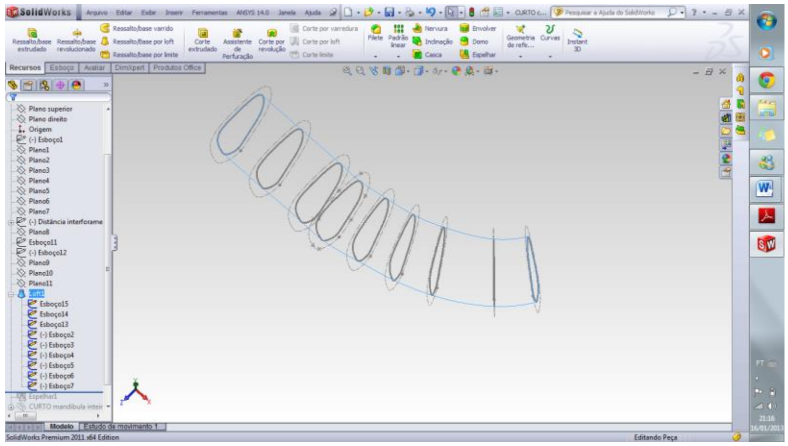


**Figura 11:** Planos em arco com esboços

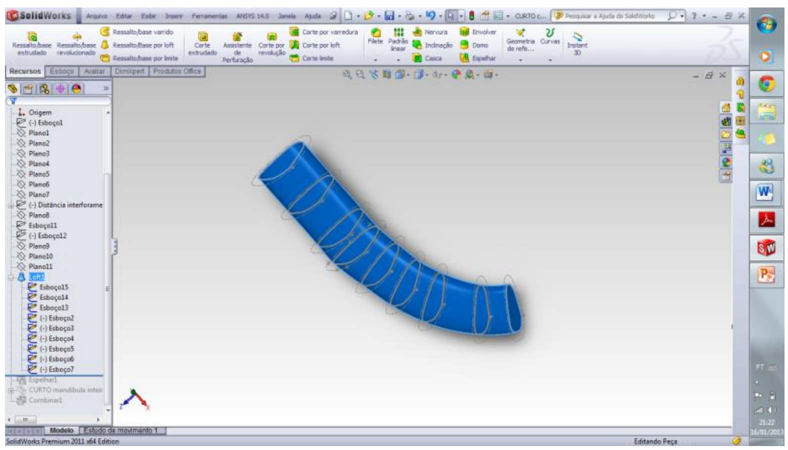


**Figura 12:** Recurso “loft” para união dos planos formando o segmento de hemi-arco.

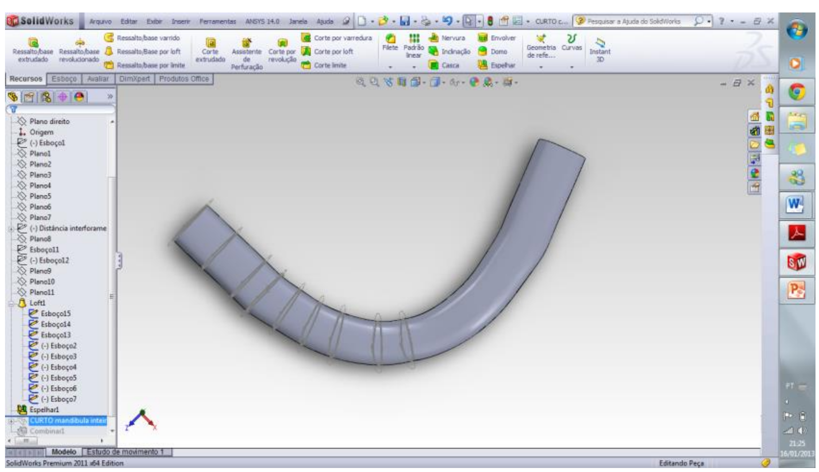


**Figura 13:** Segmento de hemi-arco espelhado, completando o arco.

## Apêndice 4

### *Análise de Convergência*

***Determinação do tamanho da malha - Análise de Convergência***

Os números de elementos presentes na malha determina a qualidade dos resultados obtidos, a análise de convergência tem o objetivo de verificar qual o tamanho do elemento suficiente para garantir a veracidade dos resultados sem que sejam necessários elementos muito pequenos, o que sobrecarrega o tempo de análise e o custo computacional.

Para isso, foi realizada uma análise de convergência em um dos modelos obtidos, onde foram testados seis tamanhos diferentes de elementos, variando 0,2 mm entre eles: malha default; 1,8; 1,6; 1,4; 1,2; 1,0; 0,8; 0,6; 0,4 mm (figura 14). Foram obtidos resultados de tensão no osso cortical, osso medular, nos implantes e componentes protéticos. Os valores correspondem aos picos de Tensão Máxima Principal para o osso e von Misses para os implantes e componentes, obtidos sob carregamento (100N).

Os resultados alcançados para os diferentes tamanhos das malhas foram comparados entre si utilizando critério de convergência menor que 5% no pico entre os valores gerados da tensão buscando um tamanho de malha eficaz para todos os componentes avaliados (Gráfico 1).

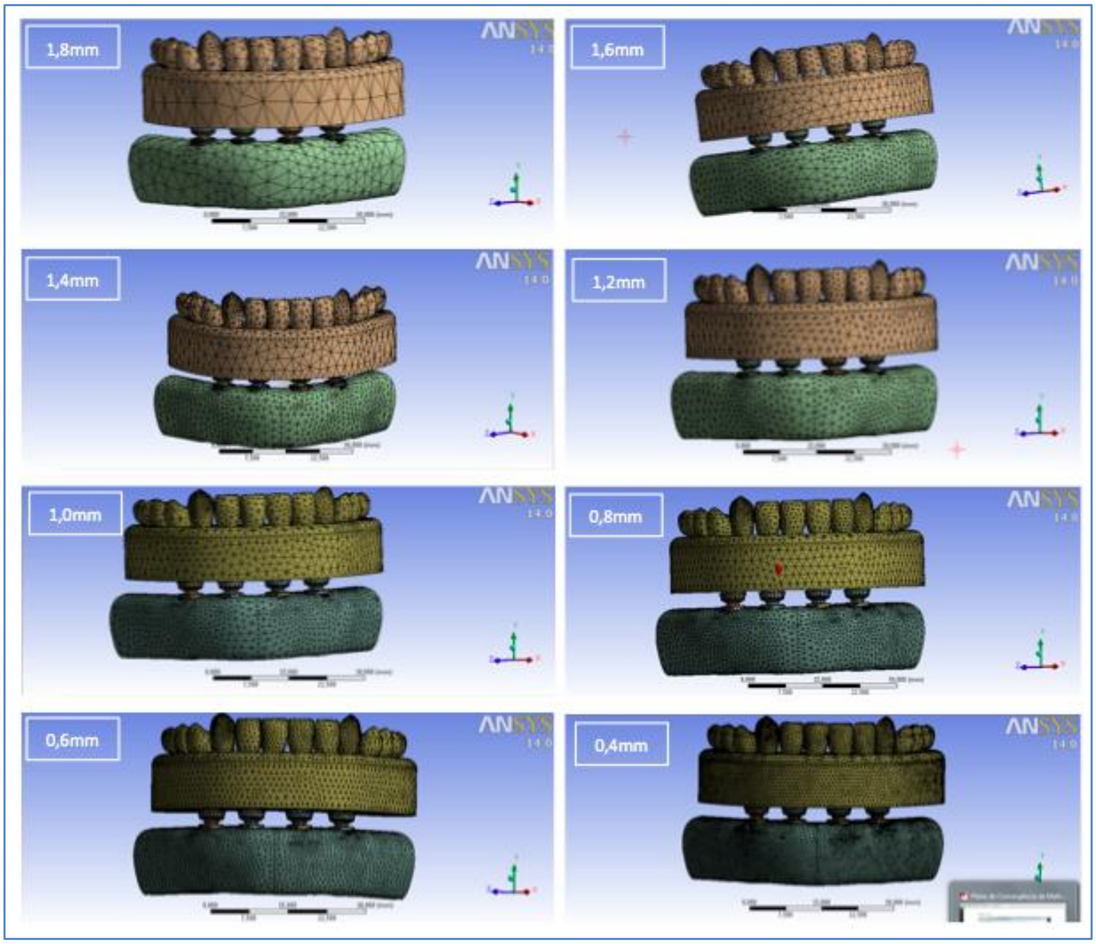



**Figura 14** – Diferentes tamanhos de elementos de malha dos modelos de elementos finitos

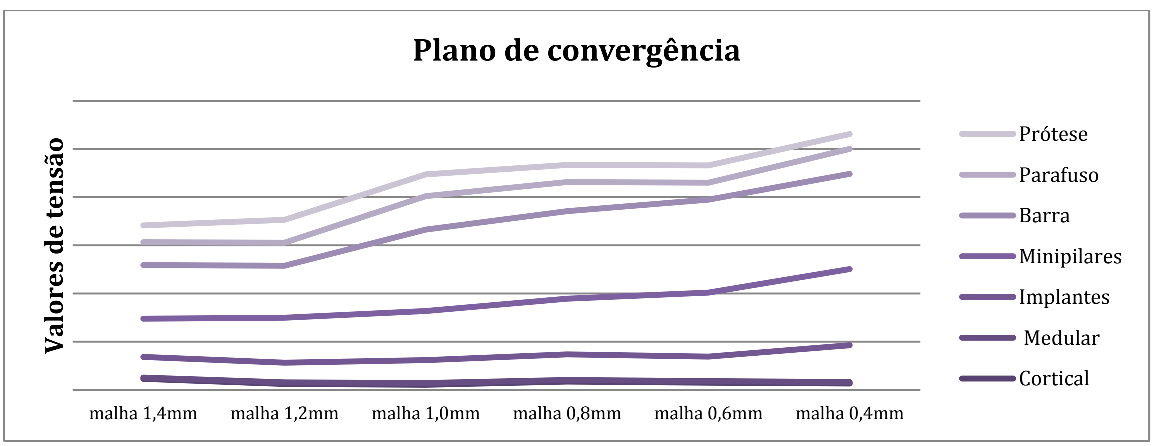



**Gráfico 1:** Picos de tensão obtidos após carregamento para cada peça com diferentes tamanhos de malha

**Anexo 1**

ScholarOne Manuscripts 14/05/14 23:01

Edit Account | Instructions & Forms | Log Out | Get Help Now

**CLINICAL IMPLANT DENTISTRY**
**and Related Research**

SCHOLARONE™ Manuscripts

Main Menu → Author Dashboard → Submission Confirmation

You are logged in as Marcele Pimentel

## Submission Confirmation

Thank you for submitting your manuscript to *Clinical Implant Dentistry and Related Research.*

| | |
|---|---|
| Manuscript ID: | CID-14-209 |
| Title: | Short implants to support fixed prosthesis in atrophic mandible – Photoelastic Testing |
| Authors: | Pimentel, Marcele<br>da Silva, Wander<br>Del Bel Cury, Altair |
| Date Submitted: | 14-May-2014 |

Print Return to Dashboard