UNIVERSIDADE ESTADUAL DE CAMPINAS

FACULDADE DE ODONTOLOGIA DE PIRACICABA

CELINA WANDERLEY DE ABREU

ANÁLISE EXTENSOMÉTRICA E DO DESAJUSTE MARGINAL DE INFRA-ESTRUTURAS IMPLANTO-RETIDAS NAS CONFIGURAÇÕES LINEAR E COMPENSADA COM DIFERENTES COIFAS SOB APLICAÇÃO DE CARGAS AXIAIS E NÃO AXIAIS

Tese apresentada à Faculdade de Odontologia de Piracicaba da UNICAMP para obtenção do Título de Doutor em Clínica Odontológica, na Área de Prótese Dental.

Orientador: Prof. Dr. Rafael L. Xediek Consani

Este exemplar corresponde à
versão final da Tese defendida
pelo aluno, e orientada pelo
Prof. Dr. Rafael L. Xediek Consani.

____

Assinatura do Orientador

PIRACICABA, 2011

FICHA CATALOGRÁFICA ELABORADA POR

GARDÊNIA BENOSSI – CRB8/8644 - BIBLIOTECA DA

FACULDADE DE ODONTOLOGIA DE PIRACICABA DA UNICAMP

Abreu, Celina Wanderley de, 1982-

Ab86a Análise extensométrica e do desajuste marginal de infra-estruturas implanto-retidas nas configurações linear e compensada com diferentes coifas sob aplicação de cargas axiais e não axiais / Celina Wanderley de Abreu. -- Piracicaba, SP : [s.n.], 2011.

Orientador: Rafael Leonardo Xediek Consani.

Tese (doutorado) - Universidade Estadual de Campinas, Faculdade de Odontologia de Piracicaba.

1. Implante dentário. 2. Tensão. 3. Prótese dentária. I. Consani, Rafael Leonardo Xediek. II. Universidade Estadual de Campinas. Faculdade de Odontologia de Piracicaba. III. Título.

Informações para a Biblioteca Digital

Título em Inglês: Analysis of marginal misfit and strain gauge in implant-supported frameworks using straight line and offset placement with different copings under axial and non-axial load

Palavras-chave em Inglês:

Dental implantation

Tension

Dental prosthesis

Área de concentração: Prótese Dental

Titulação: Doutor em Clínica Odontológica

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Data da defesa: 19-09-2011

Programa de Pós-Graduação: Clínica Odontológica

FOLHA DE APROVAÇÃO

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 19 de Setembro de 2011, considerou a candidata CELINA WANDERLEY DE ABREU aprovada.

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DEDICATÓRIA

*A **Deus** pelo dom da vida e por sempre me guiar para a concretização dos meus sonhos.*

*Aos meus pais, **Esdras Maia Nobre de Abreu** e **Glaura Falcão Wanderley de Abreu** pelo amor que sempre dedicaram a mim, exemplos de família e ensinamento dos verdadeiros valores da vida. Por todo apoio e sacrifício que realizaram sem medir esforços para viabilizar meus estudos. Minha eterna gratidão!*

AGRADECIMENTOS ESPECIAIS

Ao Prof. Dr. **Rafael Leonardo Xediek Consani**, docente da Área Prótese Total do Departamento de Prótese e Periodontia da Faculdade de Odontologia de Piracicaba - UNICAMP, pela tranquilidade e serenidade transmitidas ao longo do curso e pela orientação desta pesquisa. Meu eterno agradecimento pelo apoio nos momentos decisivos.

Ao Prof. Dr. **Renato Sussumu Nishioka,** docente da Área Prótese Fixa do Departamento de Materiais Odontológicos e Prótese da Faculdade de Odontologia de São José dos Campos – UNESP, pela atenção, disponibilidade e enorme colaboração na realização desta pesquisa.

Ao **Prof. Ivan Balducci,** docente de Bioestatística da Faculdade de Odontologia de São José dos Campos - UNESP e ao **amigo e Prof. Dr. Rodrigo Othávio,** docente de Prótese Fixa da Faculdade de Odontologia da Universidade Federal da Paraíba pela paciência e disponibilidade durante a realização da análise estatística deste trabalho.

AGRADECIMENTOS

À Universidade Estadual de Campinas, por meio de seu Reitor, Prof. Dr**. Fernando Ferreira Costa.**

À Faculdade de Odontologia de Piracicaba da Universidade Estadual de Campinas, por meio de seu Diretor, Prof. Dr. **Jacks Jorge Júnior** e Diretor Associado Prof Dr. **Alexandre Augusto Zaia.**

À **Profa. Dra. Renata Cunha Matheus Rodrigues Garcia** Coordenadora do Programa de Pós-graduação em Clínica Odontológica da Faculdade de Odontologia de Piracicaba - UNICAMP, pela seriedade na condução do Programa.

À **Fundação de Amparo à Pesquisa do Estado de Alagoas (FAPEAL)** pelo apoio financeiro concedido (Bolsa Processo n° 20081231913-8).

Aos professores da banca de qualificação **Mário Alexandre Coelho Sinhoreti, Américo Bortolazzo Correr e Wander José da Silva** pela colaboração e sugestões apresentadas para aprimorar esta tese.

Aos **Profºs Guilherme Elias Pessanha Henriques, Marcelo Ferraz Mesquita e Mauro Antônio de Arruda Nóbilo** pela amizade, conhecimentos transmitidos e contribuição prestada ao longo do curso.

Aos demais **Professores do Programa de Pós-Graduação em Clínica Odontológica: especialidade prótese dentária,** pelos ensinamentos transmitidos.

Às técnicas de laboratório **Ângela** e **Fátima** do laboratório de prótese dentária Trevisan, pela contribuição nas fases laboratoriais.

À secretária **Eliete Aparecida Ferreira Lima Marim e** à estagiária **Ketney Ferreira Lopes** do departamento de Prótese e Periodontia pela atenção dispensada e disponibilidade.

DEMAIS AGRADECIMENTOS

Aos meus avós maternos, **Pedro Rubens de Mendonça Wanderley** e **Marlena Falcão de Almeida Wanderley** pelas palavras e gestos de carinho, pela fonte de sabedoria e exemplos de vida que me inspiraram ao longo dessa caminhada.

À minha irmã **Lêda Wanderley de Abreu** *(Lêdinha)* por estar sempre ao meu lado.

Aos meus tios **Inês Almeida** e **Omar Almeida** por torcerem e comemorarem juntos comigo por cada etapa vencida, pela amizade e carinho.

Ao meu noivo **Fábio Módolo** pelo carinho, companheirismo e incentivo ao longo desta caminhada.

Às amigas-irmãs **Melissa Pontes, Viviana Pontes, Camila Neves e Vanessa Gonçalves** pela verdadeira amizade e por torcerem a cada vitória obtida por mim.

Às grandes amigas da pós-graduação **Luana Martins, Milene de Oliveira e Ana Paula Martins (Pola)** pela enorme companhia e por tornarem mais alegre os dias em Piracicaba.

Aos amigos de pós-graduação de São José dos Campos **Rodrigo Othávio, Helga Hadashi, Sheila Pestana e Diana Barca** pela amizade e momentos de alegria compartilhados.

Aos demais **colegas do programa de pós-graduação em Clínica Odontológica – especialidade Prótese Dentária da Faculdade de Odontologia de Piracicaba - UNICAMP** pelo convívio ao longo desta caminhada.

RESUMO

O objetivo neste estudo *in vitro,* foi analisar microscopicamente o desajuste vertical e passivo e quantificar a deformação usando análise de extensometria durante aplicação de carga axial e não-axial em prótese parcial fixa implanto-suportada de três elementos, variando a posição dos implantes, linear (L) ou compensada (C) e o tipo de coifa protética, plástica (P) ou colar metálico (M). Três implantes cone morse posicionados linear e três numa configuração compensada foram inseridos em dois blocos de poliuretano. Pilares *microunit* foram parafusados nos implantes aplicando torque de 20 Ncm. Coifas plásticas e com colar metálico foram parafusados nos pilares que receberam enceramentos padronizados. Os padrões de cera foram fundidos em liga Co-Cr (n=5) e separados em quatro grupos: G1- L/P; G2- L/M; G3- C/P e G4- C/M. Quatro *strain gauges* (SG) foram colados na superfície de cada bloco tangencialmente aos implantes. Os parafusos de retenção das supra-estruturas foram parafusados nos pilares com torque de 10 Ncm e, em seguida, foram aplicadas as cargas. A magnitude da microdeformação em cada *strain gauge* foi registrada em unidade de microdeformação (με). Os níveis de desajuste vertical foram mensurados com todos os parafusos apertados com torque de 10 Ncm e o desajuste passivo com apenas um parafuso apertado. A análise do desajuste foi feita utilizando microscópio óptico com precisão de 0,5 µm e 120x de aumento. Os dados foram analisados estatisticamente pela ANOVA e teste de Tukey ($p<0.05$). Não foi observada diferença estatisticamente significativa para desajuste passivo ($p>0.05$), porém houve diferença no desajuste vertical para o fator configuração ($p=0.0257$). Na quantidade de deformação por meio da extensometria foi encontrada diferença no fator configuração ($p=0.0005$). Após o teste Tukey foi observada uma diferença entre L/P (306.1±82.25) e C/P (146.6±93.64). Não houve diferença significante entre carga axial e não axial. Existiu evidência de que a posição offset é capaz de reduzir a deformação em torno do implante. Em adição, o tipo de carga, axial ou não-axial até 2mm não teve influência e o tipo de coifa usado também não interferiu.

Palavras-chave: implante dental, desajuste passivo, desajuste vertical, tensão.

ABSTRACT

The aim of this *in vitro* study was microscopically analyzing the vertical and passive misfit and quantify the strain development using strain gauge analysis during axial and non-axial loading in three-element implant-supported FPDs, varying the arrangement of the implants: straight line (L) and offset (O) and the type of prosthetic coping used: plastic (P) or metallic collar (M). Three Morse taper implants arranged in a straight line and three implants arranged in an offset manner were inserted into two polyurethane blocks. Microunit abutments were screwed onto the implants, using a torque of 20Ncm. Plastic and metallic collar copings were screwed onto the abutments, which received standard wax patterns. The wax patterns were cast in Co-Cr alloy (n=5), making a total of four groups: G1- L/P; G2- L/M; G3- O/P and G4- O/M. Four strain gauges (SG) were bonded on the surface of each block tangential to the implants. The superstructure's occlusal screws were tightened onto the microunit abutments using 10 Ncm torque with a manual torque driver and then an axial load was applied. The magnitude of microstrain on each strain gauge was recorded in units of microstrain (με). An optical microscope, with 0.5 µm of measurement accuracy and 120x magnification, was used to evaluate the vertical fit with all of the screws tightened to 10 Ncm torque and the passive fit with only one screw tightened to the appropriate torque. The data were analyzed statistically by ANOVA and Tukey's test ($p<0.05$). There was not statistically significant difference for passive misfit ($p>0.05$), but a significant difference existed in vertical misfit for the factor of configuration ($p=0.0257$). A significant difference was also observed for strain for the factor of configuration ($p=0.0005$). The Tukey's test revealed difference between L/P (306.1±82.25) and O/P (146.6±93.64). There was not statistically significant difference between axial and non-axial load. There was evidence that the offset placement is capable of reducing the strain around an implant. In addition, the type of loading, axial force or non-axial did until 2 mm not have an influence and the type of coping used did not interfere.

Key words: dental implant, passive misfit, vertical misfit, tension.

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1. INTRODUÇÃO

O uso de implantes para reabilitação protética atingiu índices de sucesso semelhante às próteses convencionais, porém apresentando diversas vantagens, como preservação da estrutura óssea, substituição de próteses parciais removíveis, dentre outras, tornando seu uso uma rotina clínica devido à possibilidade de substituição de estruturas dentárias perdidas nos pacientes total e parcialmente edêntulos, com melhora significativa na qualidade de vida dos indivíduos (Adell *et al.*, 1981).

Diversas modificações foram realizadas nos desenhos dos implantes visando à utilização em casos unitários ou parcialmente edêntulos (Binon, 1995), considerando que a técnica cirúrgica de instalação de implantes foi idealizada inicialmente para reabilitações totais (Adell *et al.*, 1981; Branemark *et al.*, 1995).

Inovações no desenho dos implantes têm sido realizadas na tentativa de melhorar a conexão pilar protético/ implante. O conceito do tipo cone morse foi desenvolvido por Franz Sutter (1974), inicialmente para a utilização em mandíbula edêntula, o qual requeria apenas um procedimento cirúrgico para inserção do implante, eliminando a necessidade de cirurgia de reabertura para a conexão do pilar protético (Scacchi, 2000; Sutter *et al.*, 1993). Até 1985, a porção endóssea do implante e o pilar protético não podiam ser separados. Porém, a partir de 1986, devido à utilização em regiões parcialmente edêntulas, o sistema foi modificado para o conceito de dois segmentos (Solnit; Schneider, 1998). Esses implantes de duas partes passaram a ser usados clinicamente por meio da técnica não submersa (Sutter *et al.*, 1988; Buser *et al.*, 1991; Andersson *et al.*, 1992). Esses implantes diferem dos submersos ou de dois estágios devido à eliminação da fenda no nível ósseo. A eliminação da fenda foi possível devido à presença de um “pescoço” transmucoso liso de 3 mm de altura, permitindo um perfil de emergência pré-fabricado formado pelo titânio liso com o pescoço (Sutter *et al.*, 1993).

O desenho do sistema cone morse caracteriza-se por apresentar paredes internas do implante e paredes externas do pilar protético fabricadas com um cone idêntico com 8 graus de conicidade. Durante o rosqueamento do pilar no corpo do implante, estabelece-se íntimo contato entre os dois componentes, criando travamento mecânico por fricção (Solnit; Schneider, 1998). O contato promove significante quantidade de retenção e resistência às forças laterais por adaptação friccional ao componente de ancoragem interna ou corpo do implante, mantendo a integridade por períodos longos de tempo em função quando submetidas às cargas mastigatórias (Sutter *et al*., 1988). Deste modo, a conexão tipo cone morse representa um sistema seguro do ponto de vista biomecânico (Glantz *et al*., 1993; Akça *et al*., 2003).

O estudo da biomecânica do implante é amplo, com numerosas variáveis, podendo ser influenciado pela magnitude, direção e localização de cargas oclusais, quantidade de tensão induzida na região peri-implantar do complexo prótese/osso/implante e consequente deformação óssea (Van Oosterwyck *et al*., 1998; Duyck *et al*., 2000 e 2001; Çehreli *et al*., 2004; Eskistacioglu *et al*., 2004; Hekimoglu *et al*., 2004; Khraisat *et al*., 2004; Karl *et al*., 2005; Nishioka *et al*, 2009; Abreu *et al*., 2010).

Além disso, existe a influência da quantidade de implantes envolvidos em cada elemento protético a ser substituído, observando que a falha na osseointegração de implantes e problemas mecânicos ocorre com maior frequência em próteses realizadas sobre dois implantes quando comparados com próteses confeccionadas sobre três (Heckmann *et al*., 2006). Duas fixações para uma resolução protética de três elementos resultam num comportamento biomecânico diferente da situação onde três fixações restabelecem três elementos protéticos. Assim sendo, próteses similares submetidas às cargas oclusais de mesma intensidade, porém, com grupo de três fixações instaladas sob diferentes configurações (linear ou compensada), podem mostrar diferentes resultantes das tensões a serem transmitidas para os implantes e para o osso de suporte (Heckmann *et al*., 2006).

A instalação de implante na posição compensada *(offset)* tem sido largamente reportada e aceita no caso de próteses suportadas por três implantes, avaliando de maneira favorável o efeito biomecânico e a influência do posicionamento *offset* na distribuição de tensão na estrutura óssea (Sato *et al*., 2000; Anitua; Orive, 2009).

A transferência de carga oclusal pode ser influenciada por fatores relacionados à precisão da interface pilar/prótese, sendo o *coping* um dos fatores responsáveis pela precisão, considerando que *copings* usinados apresentam maior precisão quando comparados aos *copings* plásticos (May *et al*., 1997; Heckmann *et al*., 2004). Esses autores relataram que a precisão dos *copings* está associada à distribuição de tensões, sinalizando a importância em comparar a precisão entre *copings* plásticos e com colar metálico.

O menor desajuste marginal, vertical ou horizontal, da estrutura metálica retida por implantes é a situação esperada para alcançar o sucesso da prótese em longo prazo (Carlson; Carlsson, 1994). A peça assentada passivamente promove mínimo desajuste das margens, proporcionando valores de até 150 µm e distribuição equilibrada das forças que incidem sobre a prótese (Sahin & Çehreli, 2001).

Dentre os fatores relacionados ao estudo da biomecânica a sobrecarga oclusal pode ocasionar a falha do implante, devido a maiores deformações (2000 a 3000 µε) que ocorrem no osso circundante (Stanford; Brand, 1999). Algumas falhas de implantes reportadas podem ser devidas às magnitudes de tensão desfavoráveis (Sahin & Çehreli, 2001).

Ao ocorrer sobrecarga patológica acima de 4000 µε (Wiskott; Belser, 1999), gradientes de tensão e deformação excedem a tolerância fisiológica do osso e causam microfraturas na interface osso-implante (Roberts, 1993; Ranger *et al*., 1997).

A extensometria é uma técnica de medição de deformações que encontra aplicação em pesquisas científicas e tecnológicas. Sensores denominados extensômetros lineares elétricos ou *strain gauges* são utilizados para o registro dessas deformações. De acordo com Spiekermann *et al.* (1995) e Clelland *et al*. (1993), esta técnica torna possível a obtenção de dados aproximados da realidade em relação às forças exercidas sobre os implantes e transferidas às estruturas de suporte, sendo uma interessante opção para avaliações experimentais que procuram delinear as características dos procedimentos clínicos e laboratoriais.

O desconhecimento dos conceitos biomecânicos pode ocasionar falha em reabilitações implantossuportadas (Akça; Iplikçioglu, 2001), tornando oportuno o estudo para avaliar a passividade de infra-estruturas implanto-retidas sob configurações linear ou compensada utilizando coifas plásticas e com colar metálico, por meio da análise do desajuste marginal e da extensometria, sob efeito de cargas axiais e não axiais.

O objetivo do presente estudo é fazer uma análise comparativa por meio da extensometria das deformações ao redor de três implantes com conexão protética cone morse, posicionados linearmente e *offset* sob aplicação de cargas axiais e não axiais, comparar também o tipo de coifa utilizada, plástica ou com colar metálico, com o nível de microdeformação produzida no momento da aplicação da carga, além de confrontar o desajuste marginal entre coifas plásticas e com colar metálico e nas diferentes configurações linear e *offset*.

2. CAPÍTULOS

Este trabalho foi apresentado no formato alternativo de tese de doutorado, de acordo com as normas estabelecidas pela deliberação 002/06 da Comissão Central de Pós-Graduação da Universidade Estadual de Campinas. Dois capítulos contendo artigos científicos compõem este estudo, conforme descrito abaixo:

Capítulo 1: *Analysis of marginal misfit and strain gauge in implant-supported frameworks using straight line and offset placement*

Artigo nas normas do Periódico Journal of Oral Implantology

Capítulo 2: *Straight and offset implant placement under axial and non-axial loads in three-element implant-supported prostheses: strain gauge analysis*

Artigo nas normas do Periódico Journal of Prosthodontics

CAPÍTULO 1

Analysis of marginal misfit and strain gauge in implant-supported frameworks using straight line and offset placement

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Artigo submetido para análise em 05 de Setembro de 2011.

Analysis of marginal misfit and strain gauge in implant-supported frameworks using straight line and offset placement

Abstract

Objective: The aim of this *in vitro* study was to quantify the strain development during axial loading using strain gauge analysis and to analyze microscopically the vertical and passive misfit. **Material and Method:** Six Morse taper implants were inserted into two polyurethane blocks, with three arranged in a straight line (L) and three in an offset configuration (O). Microunit abutments were screwed onto the implants with a torque of 20Ncm. Metallic collar (M) and plastic copings (P) were screwed onto the abutments, which received standard wax patterns that were cast in Co-Cr alloy (n=5). Four strain gauges (SG) were bonded on the surface of each block. The superstructure's occlusal screws were tightened onto the microunit abutments and then an axial load was applied. The magnitude of microstrain on each strain gauge was recorded in units of microstrain (με). An optical microscope, with 0.5 µm of measurement accuracy and 120x magnification, was used to evaluate the levels of vertical and passive fit. The data were analyzed statistically by two-way ANOVA and Tukey's test ($p<0.05$). **Results:** There was not statistically significant difference in passive fit for the factor coping and configuration, but a significant difference existed in vertical fit for the factor of configuration ($p=0.0257$). A significant difference was also observed for strain for the factor of configuration ($p=0.0005$). **Conclusion:** There was evidence of an advantage of offset implant placement in reducing the strain around the implant. The type of coping used did not interfere with the vertical and passive fit.

Key words: plastic coping, implant, marginal fit.

Introduction

The use of implants for oral prosthetic rehabilitation has become clinical routine. From a biomechanical point of view, the fixture-abutment joint should have junctions that reduce the peak bone interface stresses and strains. The design of an implant system, characterized by the fixture-abutment design, influences its biomechanical behavior[1].

The study of biomechanics is a wide field, with innumerable variables to be analyzed, and any modification in behavior may cause variations in the interpretation of responses. In other words, the result may be influenced by the magnitude, direction and location of occlusal loads and the amount of stress and strain forces exerted upon the prosthesis-implant-bone complex in the peri-implant region[2-8]. Because of these variations, the resulting tensions for implants and supporting bone can act differently in similar prostheses submitted to occlusal loads based on the configuration of the implants, either straight line and offset. The placement of implants in the offset configuration has been widely reported and accepted for prostheses supported with three implants [9-12]. However, little information exists regarding the effects and influence of the offset configuration of implants in the distribution of bone stresses[13].

The transference of occlusal loading can be still influenced by factors related to the precision of the abutment/prosthesis interface, with the coping being one of the factors responsible for the accuracy, with the observation that machined copings have higher precision when compared to plastic copings[14,15]. Moreover, these authors related that the precision of copings is associated to the distribution of stress, demonstrating the importance to comparing the precision between plastic and machined copings[14,15].

Prosthodontic studies investigate methods of achieving an accurate and passive fit of prosthetic components to implants[16]. This is because passive fit has been suggested as a prerequisite for successful long-term osseointegration[16-18].

Some studies have shown that implant components and bone appear to tolerate some lack of fit[17,18], but the lack of marginal fit that could be considered clinically acceptable must not exceed 150 µm and should provide an equal strength distribution on the prosthesis[19].

It is even more difficult to fabricate a passively fitting prosthesis on multiple implants[20]. Casting shrinkage can cause prosthetic misfits, especially for one-piece cast frameworks. Some advantages of one-piece castings include the possibility of an immediate evaluation of fit, maximum resistance of rigid connectors and time saving because of the elimination of welding procedures[21,22].

Therefore, the objective of the present study was to measure and compare the marginal fit and strain gauge analysis of one-piece castings of multiple-unit implant frameworks under straight line and offset configurations using plastic and metallic collar copings.

Material and method

Preparation of the test specimens

To simulate clinical conditions in a real-life arrangement, three straight line Morse taper implants (Conect AR; 3.75-mm diameter, 13-mm depth; Conexão Sistemas de Prótese, São Paulo, Brazil) and three offset Morse taper implants (Conect AR; 3.75-mm diameter, 13-mm depth; Conexão Sistemas de Prótese, São Paulo, Brazil) from mesial to distal: labeled 1, 2, and 3; were arranged in the middle of two 70 x 40 x 30 mm[17] rectangular polyurethane block (F16 Axson, Cercy – France).

A set of aluminum indices, consisting of three components, was used to standardize the straight line and offset placements of the implants in the polyurethane blocks and standardize the wax-up of the frameworks.

Component 3 (the upper one) was fixed onto the polyurethane blocks with screws to standardize the distance and locations for implant placement. Color-coded rings were screwed alternately into the three holes in component 3.

The rings had progressively larger internal diameters compatible with the standard twist drill used for implant placement (Conexão Sistemas de Prótese, São Paulo, SP, Brazil). The white ring was compatible with the 2 mm, the yellow ring with the 3 mm, and the blue ring with the 3.15 mm twist drills. A handpiece device with a reduction of 16:1 (Kavo Dental GmbH Biberach, Germany) was used to make the holes and insert the implants.

Three straight line Morse taper implants (L) and three offset Morse taper implants (figure 1) (O), measuring 3.75 mm in diameter and 13 mm in length (Conexão Sistemas de Prótese, São Paulo, SP, Brazil), were installed into the first and second polyurethane blocks, respectively. Microunit abutments (Conexão Sistemas de Prótese, São Paulo, SP, Brazil) were screwed onto the implants using 20 Ncm torque as measured with a manual torque driver (Conexão Sistemas de Prótese, São Paulo, SP, Brazil).

Fabrication of metallic frameworks

All wax-up procedures (Babinete, São Paulo, Brazil) were standardized using component 1 (base) and component 2, which resulted in a rectangular compartment that allowed for the systematic reproduction of the wax-up of all the test specimens, especially in terms of thickness.

Each specific polyurethane block also served as the base for the abutment and wax-up procedures. Both plastic copings and with metallic collars were initially positioned directly on the abutment and the wax-up was adapted under slight pressure.

Wax patterns, with dimensions of 35x16x2 mm[17], were sprued, invested and one-piece cast in an induction oven using cobalt-chromium alloy[23,24] (Wirobond SG–Bego Bremer Goldschalgerei). To avoid bias resulting from manufacturing conditions, random sets comprising superstructures of different types were put together and cast. After removal from the investment material, the sprues were eliminated with the aid of carbide discs at low speed. The castings were airborne particle abraded with 110 µm aluminium oxide (Korox, Bego Bremer Goldschalgerei), under 60 psi pressure. The castings were then ultrasonically cleaned in isopropyl alcohol (Vitasonic II, Vita, Bad Säckingen, Germany) for 10 min and dried at room temperature.

The metallic frameworks were fit individually to their respective abutments and polyurethane blocks: stability of the set was checked without torque tightening.

Each metallic structure was numbered and labeled according to its corresponding group. The whole sample consisted of 20 metallic structures (n=5) distributed to four groups: G1- L/P; G2- L/M; G3- O/P and G4- O/M.

Strain gauge analysis

For the exact determination of the sites for bonding the four strain gauges (KFG-02-120-c1-11N30C2 Kyowa Electronic Instruments Co., Ltd, Tokyo, Japan), a line was drawn with a ruler and a 0.7 mm lead pencil. The four strain gauges were centered along this line, tangential to the abutments. A thin film of methyl-2-cyanoacrylate resin (Vishay Measurements Group, Raleigh, NC) was used to fix each strain gauge, which was carefully positioned and held in place under slight pressure for three minutes. Each gauge was wired separately and the four strain gauges were connected to a multichannel bridge amplifier to form one leg of the bridge.

All SGs were set to zero and then the superstructure was placed on the abutments. The occlusal screws of the superstructure were tightened onto the microunit abutments using a hand-operated screwdriver, until the screws started to engage as indicated with tactile sensation and with a torque of 10 Ncm using the manufacture's manual torque-controlling device, which was previously calibrated. Each of the superstructures was screw tightened, according to the torque sequences with abutments: first screw: implant 2 (center), second: implant 1 and third screw: implant 3.

The experimental model was placed on the load application appliance with the framework in place, on which axial loads of 30 kgf [2,3] were applied for 10 seconds on the center of each implant, totaling three load application points. The points referred to were designated as: A (center of the retention screw of implant 1), B (center of the retention screw of implant 2) and C (center of the retention screw of implant 3). The microdeformations determined at the three points were recorded by four strain gauges for an the electrical signal conditioning appliance (Model 5100B Scanner – System 5000 – Raleigh, NC, USA) and the same procedure was performed for all of the frameworks, repeating three loadings per load application point. The final result was an average of these measurements for each framework.

The electrical variations were transformed arithmetically into microstrain units (με) by the data acquisition software (StrainSmart - Raleigh, NC, USA).

Marginal misfit analysis

The levels of vertical misfit were measured with all of the screws tightened and passive misfit was measured with only one screw tightened to a 10Ncm torque, according to the literature[16,25] and manufacturer's recommendations. The tightening sequence was standardized from the center to the edges of the piece, as proposed in other studies[26,27], was used to measure the vertical misfit and to measure the passive misfit when only the implant 3 was tightened. A misfit (lack of fit) was present when any of the matching surfaces of the frameworks and abutments were not in contact [25] (Figure 2).

All measurements were performed with an optical microscope at 120x magnification and 0.5 µm of measurement accuracy (Mikro Vision; Leika, Alemanha), which were connected with the Quadra Chek – 200 system.

Three measurements were performed in both the buccal and lingual aspects of each implant. The final result was an average of these six measurements with only one screw tightened (passive misfit), and with all screws tightened (vertical misfit).

Statistical analysis

The absolute values of strain were compared by two-way analysis of variance (ANOVA) followed by a *post hoc* Tukey's test at a 95 % confidence level (α= 0.05). The absolute values of the 4 strain gauges were compared for this current study and were only capable of detecting stresses in a limited segment around the implants and provide clear statements as to whether compressive or tensile forces were present in a polyurethane area of a given magnitude, although the values have been considered in module for the statistical analysis

Values of passive and vertical misfit for the different materials were also statistically analyzed using the two-way analysis of variance (ANOVA) followed by a *post hoc* Tukey's test at a 95 % confidence level (α= 0.05).

Results

The two-way ANOVA for passive misfit revealed that the coping factor (p=0.7510) and configuration factor (p=0.4477) were not significant and the interaction (p=0.8573) between the factors was not significant either. Mean values and standard deviation are presented for passive misfit (µm) in table 1.

Table 1. Mean and standard deviation for passive misfit (µm).

	Metallic collar	**Plastic**
Offset	$98.0 \pm 18.3^{A,a}$	$96.6 \pm 24.45^{A,a}$
Straight line	$92.05 \pm 29.45^{A,a}$	$87.0 \pm 13.99^{A,a}$

Means followed by same capital letters in column and small letter in line do not differ significantly.

The two-way ANOVA for vertical misfit revealed that the coping factor (p=0.0852) and the interaction between factors (p=0.1474) were not significant either, but the configuration factor showed a significant difference (p=0.0257) according table 2. The Tukey's test revealed that the difference was observed between straight line plastic (43.2±7.22) and offset metallic collar (32.2±5.93) (Table 3).

Table 2. Two-way ANOVA for vertical misfit (µm).

Source	**DF**	**SS**	**MS**	**F**	**P**
Configuration (C)	1	198.45	198.45	6.05	**0.0257***
Coping (Co)	1	110.450	110.450	3.37	0.0852
(C) x (Co)	1	76.050	76.050	2.32	0.1474
Error	16	524.800	32.800		
Total	19	909.750			

p<0,05

Table 3. Tukey HSD All-Pairwise Comparisons Test of vertical misfit for configuration x coping (µm).

Configura*coping	**Mean**	**Homogeneous group**
Straight plastic	43.2±7.22	A
Straight metallic	34.6±5.03	AB
Offset plastic	33.0±4.3	AB
Offset metallic	32.2±5.93	B

There are 2 groups (A and B) in which the means are not significantly different from one another.

The two-way ANOVA for strain gauge analysis revealed that the configuration factor was statistically significant (p=0.0005), whereas the coping factor (p=0.3730) and the interaction between factors (p=0.2821) was not significant (Table 4). The Tukey's test revealed a statistical difference between the plastic straight line (306.1 ± 82.25µε) and plastic offset (146.6 ± 49.43µε) configurations (Table 5).

Table 4. Two-way ANOVA for microstrain (µɛ).

Source	**DF**	**SS**	**MS**	**F**	**P**
Coping (Co)	1	2244.2	2244.2	0.84	0.3730
Configuration (Co)	1	50342.6	50342.6	18.84	**0.0005***
(Co) x (Co)	1	3310.2	3310.2	1.24	0.2821
Error	16	42743.6	2671.5		
Total	19	98640.6			

*p<0,05

Table 5. Tukey HSD All-Pairwise comparisons test of SG for Coping x Configuration (µɛ).

	Metallic collar	**Plastic**
Offset	219.7±118.1^{A,a}	146.6±93.64^{A,a}
Straight	264.5±23.18^{A,a}	306.1±82.25^{B,a}

Means followed by same capital letters in column and small letter in line do not differ significantly.

Discussion

Since the beginning of the study of osseointegration, dental implants have been widely used in the rehabilitation of partially or completely edentulous patients[28], indicating success of implant dentistry as a restorative prosthetic treatment[29]. Despite this, implant failures have been observed after delivery of an implant supported prosthesis, and reported to be mainly due to biomechanical complications[16]. The reason for studying strains around implants is as an attempt to define levels of safety, since there are studies reporting that an excessive load at the interface between the implant and the bone may be one of the causes of marginal bone loss[8]. The precise mechanism is not yet fully understood; undoubtedly, there is a remodeling response around the bone under a given stress, or even in situations with an absence of activity[30,31].

The present study used the strain gauge analysis to quantify the development of strain during the fixation of three-unit screw implant-supported FPDs, varying the type of prosthetic coping (plastic and metallic collar) in two different configurations (straight line and offset). Additionally, the relationship of the marginal misfit for these copings and configurations was analyzed. The mechanism is physiologically complex and any mechanical model can only be an approximation of the clinical situation.

The reason for the parameters of this current investigation, considering the type of coping and placement configurations, is based on the idea of choosing the best option when performing a treatment with a three-element fixed partial implant supported denture, to allow long term clinical success. According to the relevant literature, determining the best option continues to be a vital question for retrospective and prospective clinical studies supported by *in vivo*[5,6] and *in vitro*[9,23] biomechanical studies.

In the present study, the mean microstrain values (με) recorded for the straight line and offset configurations of implants were different (Table 4) when plastic copings were used (Table 5); however, the values measured between the copings for the same configuration were similar (Table 5). This independence in the use of copings is consistent with the results reported by Karl *et al.*[9], who performed a study using the same number of fixations, although their prosthesis was built with five elements. Abreu *et al.* [2] also found no difference between these two types of copings in three-element prostheses with Morse taper and Nishioka *et al*[3] found similar results when using external and internal hexagonal implants. This similarity of microstrain observed between plastic copings and plastic coping with metallic collar probably occurred due to necessity of the process of casting of both the copings, becoming the component related as similar structures.

Another issue of debate is implant placement. The current results demonstrated a statistically significant difference in the offset placement over the straight line placement, only when plastic copings were used. The results found with metallic collar copings demonstrated similar results for both the offset and straight line configurations. A hypothesis had suggested that an offset arrangement of three implants is preferred over straight line placement[32]. In another study,[3] the authors did not find statistically significant differences in implant placement, although had used external and internal hexagonal implants. It is unclear whether estabilishing tripod placement would counteract bending moments and is superior to two implants suporting a prosthesis or not[16].

However, one relevant concern would be the mismatch between the abutment and the prosthesis. The accuracy of metallic superstructures that adapt to abutments has received undue attention and a rather unmerited concern, probably due to the fact that the gold standard of the adaptation of conventional prostheses has been incorrectly applied to implant-supported prostheses.

There was no occurrence of passivity during the tightening of the frameworks in this current study, showing lack of vertical fit. These findings confirm the literature reports on the difficulty in obtaining one-piece cast frameworks with good marginal fit[2,22].

The values of vertical fit observed in this present study in Table 3 were considered biologically acceptable when compared with some scientific studies[17,33]. However, differences between plastic coping and plastic coping with metallic collar (metallic collar offset 32.2±5.93 µm versus plastic offset 33.0±4.3 µm and metallic collar straight 34.6±5.03 µm versus plastic straight 43.2±7.22 µm) were not observed, with the exception of the straight and offset configuration (metallic collar offset 32.2±5.93 µm versus metallic collar straight 34.6±5.03 µm and plastic offset 33.0±4.3 µm versus plastic straight 43.2±7.22 µm).

Similarly, the values of passive fit observed in the current study (Table 1) did not indicate differences between the plastic and metallic collar copings other than for the straight and offset configuration, varying the values of misfit between 87.0±13.99 µm and 98.0±18.3 µm. Previous studies considered that the acceptable limit for misfit was up to 150 µm[19,26,33].

The reason for the parameters of this current investigation, considering the type of coping and configuration, is based on the idea of choosing the best option when performing a treatment with a three-element fixed partial implant supported denture, to allow long term clinical success. According to the relevant literature[5,6,9], determining the best option continues to be a vital question for retrospective and prospective clinical studies supported by *in vivo* and *in vitro* biomechanical studies.

Conclusion

According to the current study, it was possible to conclude that:

1. The type of coping used, plastic or metallic collar did not interfere with the marginal misfit.
2. The implant placement configuration (straight and offset) did interfere with the level of microstrain at the time of load application, only when plastic copings were used.
3. The implant placement configuration (straight and offset) did not interfere with the marginal misfit.

Acknowledgements

The authors wish to thank FAPEAL (Alagoas State Research Foundation) for supporting this study.

References

1. Rieger MR, Fareed, K, Adams WK, Tanquist RA. Bone stress distribution for three endosseous implants. *Prosthet Dent* 1989; 61: 223-228.

2. Abreu CW, Vasconcellos LGO, Balducci I, Nishioka RS. A comparative study of microstrain around three-morse taper implants with machined and plastic copings under axial loading. *Braz J Oral Sci* 2010; 9(1):11-15.

3. Nishioka RS, Vasconcellos LGO, Nishioka LNBM. External hexagon and internal hexagon in straight and offset implant placement: strain gauge analysis. *Implant Dent.* 2009;18(6):512-520.

4. Çehreli MC, Duyck J, Cooman M, Puers R, Naert I. Implant design and interface force transfer. A photoelastic and strain-gauge analysis*. Clin Oral Impl Res* 2004; 15: 249-257.
5. Duyck J, VanOosterwyck H, Vander Sloten J, De Cooman M, Puers R, Naert I Magnitude and distribution of occlusal forces on oral implants supporting fixed prostheses: an *in vivo* study. *Clin Oral Implant Res* 2000; 11: 465-457.
6. Duyck J, Ronold H J, VanOosterwyck H , Naert I, Van Sloten J, Ellingsen J E. The influence of static and dynamic loading on marginal bone reactions around osseointegrated implants: an animal experimental study. *Clin Oral Impl Res* 2001; 12: 207-218.
7. Eskitascioglu G, Usumez A, Sevimay M, Soykan E, Unsal E. The influence of occlusal loading location on stresses transferred to implant-supported prostheses and supporting bone: a three-dimensional finite element study. *J Prosthet Dent* 2004; 91: 144-150.
8. Hekimoglu C, Anil N, Cehreli M. Analysis of strain around endosseous implants opposing natural teeth or implants. *J Prosthet Dent* 2004; 92:441-6.

9. Karl M, Rosch S, Graef F et al. Strain situation after fixation of three-unit ceramic veneered implant superstructures. *Implant Dent* 2005 Jun;14(2):157-65.

10. Khraisat A, Hashimoto A, Nomura S, Miyakawa O. Effect of lateral cyclic loading on abutment screw loosening of an external hexagon implant system. *J Prosthet Dent* 2004; 91:326-334.
11. Van Oosterwyck H, Duyck J, Vander Sloten J, Van der Perre G, De Cooman M, Lievens S, et al. The influence of bone mechanical properties and implant fixation upon bone loading around oral implants. *Clin Oral Implant Res*. 1998;9:407-18.

12. Sato Y, Shindoi N, Hosokawa R, Tsuga K, Akagawa Y. A biomechanical effect of wide implant placement and offset placement of three implants in the posterior partially edentulous region. *J Oral Rehabil* 2000;27(1):15-21.
13. Anitua E, Orive G. Finite element analysis of the influence of the offset placement of an implant-supported prosthesis on bone stress distribution. *J Biomed Mater Res Part B:Appl Biomater*. 2009: 275-281.
14. Heckmann SM, Karl M, Wichmann MG, Winter W, Graef F, Taylor TD. Cement fixation and screw retention: parameters of passive fit. An in vitro study of three-unit implant-supported fixed partial dentures. *Clin Oral Implant Res* 2004;15(4):466-73.
15. May KB, Edge MJ, Russell MM, Razzoog ME, Lang BR. The precision of fit at the implant prosthodontic interface. *J Prosthet Dent* 1997;77(5):497-502
16. Taylor TD, Agar JR, Vogiatzi T. Implant Prosthodontics: current perspective future directions. *Int J Oral Maxillofac Implants* 2000;15(1):66-75.
17. Carr AB. Effects of fabrication, finishing and polishing procedures on preload in protheses using conventional “gold” and plastic cylinders. *Int J Oral Maxillofac Implants*. 1996;1(5):589-98.

18. Kan JYK, Rungcharassaeng K, Bohsali K, Goodacre CJ, Lang BR. Clinical methods for evaluating implant framework fit. *J Prosthet Dent* 1999;**81**(1):7-13.

19. Sahin S, Çehreli MC. The significance of passive framework fit in implant prosthodontics: current status. *Implant Dent.* 2001; 10(2): 85-90.
20. Guichet DL, Yoshinobu D, Caputo AA. Effect of splinting and interproximal contact tightness on load transfer by implant restorations. *Journal of Prosthetic Dentistry* 2002;87:528–35.

21. Schiffleger BE, Ziebert GJ, Dhuru VB, Brantley WA, Sigaroudi K. Comparison of accuracy of multiunit one-piece castings. *Journal of Prosthetic Dentistry* 1985;54:770–6.
22. Torres EM, Rodrigues RCS, Mattos MGC, Ribeiro RF. The effect of commercially pure titanium and alternative dental alloys on the marginal fit of one-piece cast implants framework. *Journal of Dentistry* 2007;35:800-5.
23. Karl M, Rosch S, Graef F, Taylor, T, Hechmann S. Static implant loading caused by as-cast metal and ceramic-veneered superstructures. *J Prosthet Dent* 2005; 93: 324-30.
24. Karl M, Wichmann MG, Winter W, Graef F, Taylor T, Heckmann SM. Influence of fixation mode and superstructure span upon strain development of implant fixed partial dentures. *J Prosthodont*. 2008;17(1):3-8.
25. Cheshire PD, Hobkirk JA. An in vitro quantitative analysis of the fit of Nobel Biocare implant superstructures. *J Oral Rehabil* 1996;23:782-9.
26. Millington ND, Leung T. Inaccurate fit of implant superstructures. Part 1. Stresses generated on the superstructure relative to the size of fit discrepancy. *International Journal of Prosthodontics* 1995;8:511–6.
27. Uludamar A, Leung T. Inaccurate fit of implant superstructures. Part II. Efficacy of the Preci-disc system for the correction of errors. *International Journal of Prosthodontics*1996;9:16–20.

28. Branemark PI, Adell R, Breine U, Hansson BO, Lindstrom J, Olsson A. Intra-osseous anchorage of dental prostheses. I. Experimental studies. *Scand J Plast Reconstr Surg* 1969;3(2):81-100.
29. Smedberg JI, Nilner K, Rangert B, Svensson SA, Glantz SA. On the influence of superstructure connection on implant preload: a methodological and clinical study. *Clin Oral Implants Res* 1996; 7(1):55-63.
30. Frost H M. Wolff's law and bone's structural adaptations to mechanical usage: an overview for clinicians. *Angle Orthod*. 1994;64:175-88.
31. Wiskott H W, Belser U C. Lack of integration of smooth titanium surfaces: a working hypothesis based on strains generated in the surroundng bone. *Clin Oral Implants Res.* 1999;10:429-44.
32. Rangert B, Sullivan R, Jemt TM. Load factor control for implants in the posterior partially edentulous segment*. Int J Oral Maxillofac Implants* 1997; 12: 360-370.
33. Jemt T, Book K. Prothesis misfit and marginal bone loss in edentulous implant patients*. Int J Oral Maxillofac Implants*. 1996;11(5):620-5.

FIGURES

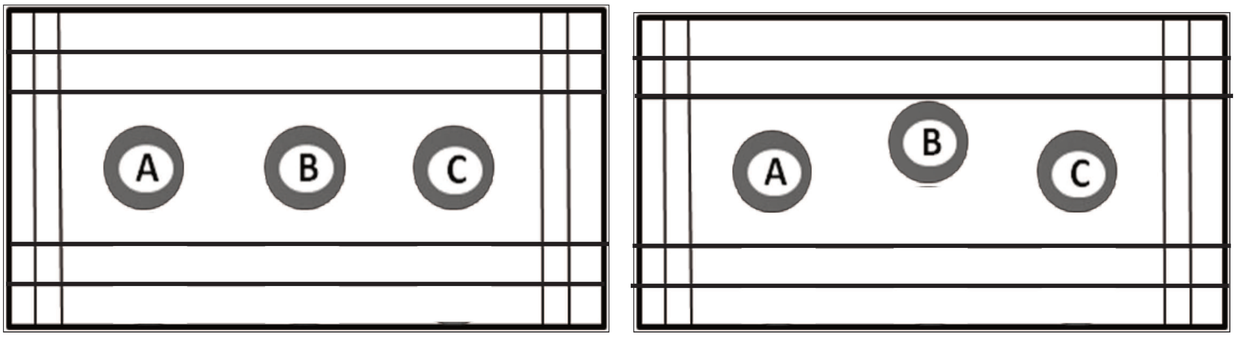

Figure 1 – Left figure: Straight line implants. Right figure:offset implants.

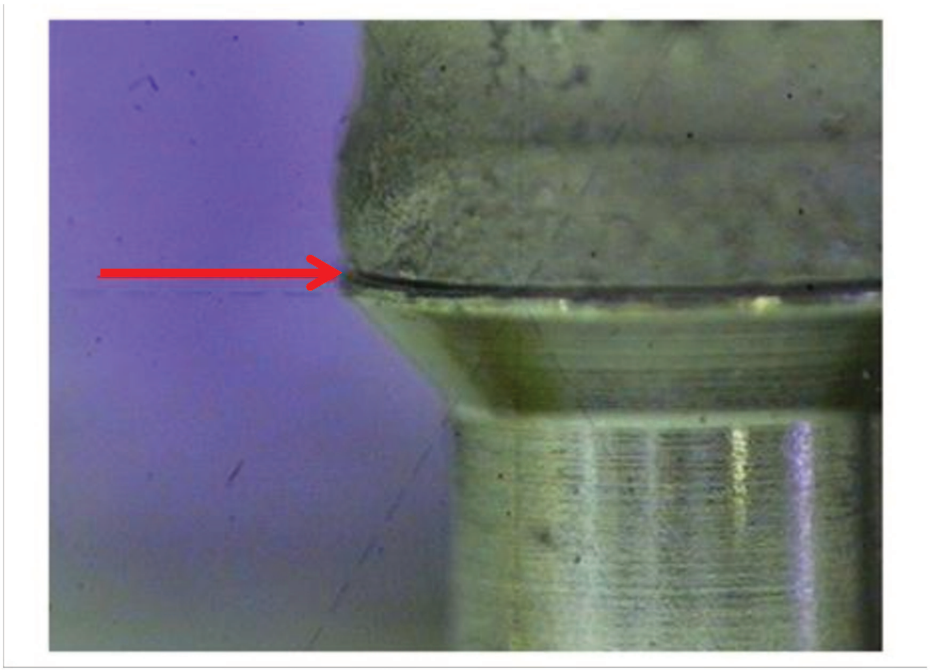

Figure 2 – Vertical misfit (arrow). 120x de aumento.

CAPÍTULO 2

Straight and offset implant placement under axial and non-axial loads in three-element implant-supported prostheses: strain gauge analysis

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Artigo submetido para análise em 01 de Setembro de 2011

Straight and offset implant placement under axial and non-axial loads in three-element implant-supported prostheses: strain gauge analysis

Abstract

Objective: The aim of this *in vitro* study was to quantify the strain development during axial and non-axial loading using strain gauge analysis for three-element implant-supported FPDs, varying the arrangement of implants, straight line (L) and offset (O). **Material and Method:** Three Morse taper implants, arranged in a straight line and three implants arranged in an offset configuration were inserted into two polyurethane blocks. Microunit abutments were screwed onto the implants, applying a torque of 20 Ncm. Plastic copings were screwed onto the abutments, which received standard wax patterns that were cast in Co-Cr alloy (n=10). Four strain gauges were bonded onto the surface of each block tangentially to the implants. The occlusal screws of the superstructure were tightened onto microunit abutments using 10 Ncm and then axial and non-axial loading of 30Kg was applied. The magnitude of microstrain on each strain gauge was recorded in units of microstrain (με). **Results:** The data were analyzed statistically by two-way ANOVA and Tukey's test ($p<0.05$). The configuration factor was statistically significant ($p=0.0004$), but the load factor ($p=0.2420$) and the interaction between the two factors was not significant ($p = 0.5494$). The Tukey's test revealed difference between axial offset (183.2±93.64) and axial straight line (285.3±61.04) and difference between non-axial 1mm offset (201.0±50.24) and non-axial 1mm straight line (315.8±59.28). **Conclusion:** There was evidence that the offset placement is capable of reducing the strain around an implant. In addition, the type of loading, axial force or non-axial did until 2 mm not have an influence.

Descriptors: strain gauge, Morse taper implant, axial load.

Introduction

Osseointegrated dental implants have been a well-accepted and predictable treatment modality for the rehabilitation of partially and completely edentulous patients. An implant-supported prosthesis may be under the influence of external (functional or parafunctional) and/or internal (preload) forces. The magnitude of these forces affects the amount of induced strains and stresses in all components of the bone-implant-prosthesis complex[1-7].

Strain is defined as the ratio between the length of an object under stress and its original dimension; it is a dimensionless entity. A strain gauge is considered an indirect measurement that analyzes a physical effect, mechanical deformation, based on electrical measurements taken with a device which is called a “transducer”. In short, it can be stated that deformations are normally imperceptible to the naked eye, so a strain gauge is necessary to measure them. The strain gauge is an electric sensor that quantifies a superficial deformation; its working principle is based on the variation of the electrical resistance transformed into deformation levels[8].

Mechanical stress can have both positive and negative consequences for bone tissue and, thereby, also for maintaining osseointegration of an implant. It is important to design an abutment connection that distributes functional forces at a desirable level of bone strain. The bone carrying mechanical loads adapts its strength to the applied load, and this continuous remodeling maintains the mechanical competence of the bone[6,9].

The application of a functional load induces stress and strain on the bone/implant complex and affects the peri-implant bone remodeling[10,11]. A fraction of this occlusal load is transmitted to the implants, with the induced stress dependent upon where the load is applied to the prosthesis[12]. Excessive loading on the bone/implant interface is one of the main factors accounting for marginal loss bone, motivating this current strain study[5].

Rangert *et al.*[13] indicated that the bending moment for all implants would be diminished if the implants were placed with an *offset* placement. However, some studies have apparent disagreements on the effect of this *offset* placement. These studies found that the *offset* placement of implants did not always decrease the load in all implants[14,15].

Mastication mainly induces vertical forces on the dentition. However, transverse forces are also created and transferred through the prosthesis into the fixture, and eventually into bone. Two main types of loading of the anchorage unit should be considered: axial load and non-axial load. The axial force is more favorable, as it distributes stress more evenly throughout the implant, while the non-axial load exerts stress gradients on the implant as well as in the bone[13].

The aim of this current study was to compare the influence of axial and non-axial on simulated bone tissue surrounding implants, analyzed using a strain gauge. The hypothesis is that the offset implants promote decrease levels of strain than straight line and axial load promotes less strain than non-axial load.

Material and method

Preparation of the test specimens

To simulate clinical conditions in a real-life arrangement, three straight line Morse taper implants (Conect AR; 3.75-mm diameter, 13-mm depth; Connection Prosthesis Systems, Sao Paulo, SP, Brazil) and three offset Morse taper implants (Conect AR; 3.75-mm diameter, 13-mm depth; Connection Prosthesis Systems) from mesial to distal: labeled 1, 2, and 3 were arranged in the middle of two models rectangular polyurethane block[16] (F16 Axson, Cercy – France) with known mechanical properties (Young's modulus of 3.6 GPa).

A set of aluminium indices, consisting of three components, was used to standardize both the straight line and offset implant placement into the polyurethane blocks and standardize the wax-up of superstructures.

Component 3 (the upper one), which standardized the distance and locations for implant placement, was fixed onto the polyurethane blocks using horizontal screws. Color-coded rings were screwed alternately into the three holes in component 3. The rings had progressively larger internal diameters which were compatible with the standard twist drill used for implant placement (Connection Prosthesis Systems). The white ring was compatible with the 2mm, the yellow one with the 3mm, and the blue one with the 3.15mm twist drills. A handpiece (contra-angle) with a reduction of 16:1 (KavoDental GmbH Biberach, Germany) was used to make the holes and insert the implants .

Three straight line Morse taper implants (L) and three offset Morse taper implants (O), measuring 3.75mm in diameter and 13 mm in length (Connection Prosthesis Systems, São Paulo, Brazil), were installed into the first and second polyurethane blocks, respectively. Microunit abutments (Connection Prosthesis Systems, São Paulo, Brazil) were screwed into the implants with 20 Ncm torque using a manual torque driver (Connection Prosthesis Systems, São Paulo, Brazil).

Fabrication of metallic frameworks

The patterns were fabricated using a wax (Babinete, São Paulo, Brazil) and each specific polyurethane block served as the base for the abutment and wax-up procedures. Plastic copings were initially positioned directly on the abutment and the wax-up was adapted under slight pressure.

The wax patterns were sprued, invested and one-piece cast in an induction oven[17,18] using cobalt-chromium alloy (Wirobond SG – Bego Bremer). To avoid bias resulting from manufacturing conditions, random sets comprising superstructures of different types were put together and cast. After removal from the investment material, the sprues were eliminated using carbide discs at low speed. The castings were airborne particle abraded with 110 μm aluminium oxide (Korox, Bego Bremer Goldschalgerei, Bremen, Germany), under 60 psi pressure. The castings were then ultrasonically cleaned in isopropyl alcohol (Vitasonic II, Vita, Bad Säckingen, Germany) for 10 min and dried at room temperature.

The frameworks were fit individually to their respective abutments and polyurethane blocks: stability of the set was checked without torque tightening.

Each metallic structure was numbered and labeled according to its corresponding group. The whole sample was composed of 20 frameworks distributed randomly and equally between two groups (n=10): G1- L and G2- O.

Strain gauge analysis

Four strain gauges (KFG-02-120-c1-11N30C2 Kyowa Electronic Instruments Co., Ltd – Tokyo, Japan) were bonded on the surface of each polyurethane block with a thin film of methyl-2-cyanocrylate resin (Vishay Measurements Group, Raleigh, NC) which was carefully positioned and held in place under slight manual pressure for three minutes. Each gauge was wired separately and the four strain gauges were connected to a multichannel bridge amplifier to form one leg of the bridge.

All SGs were set to zero and then the superstructure was placed on the abutments. The screws of the occlusal frameworks were tightened in the microunit abutments using a hand-operated screwdriver, until the screws started to engage as indicated by tactile sensation and then applying a torque of 10 Ncm using the manufacture's manual torque-controlling device. Each of the superstructures was screw tightened according the torque sequences for abutments: first screw: implant 2 (center), second: implant 1 and third screw: implant 3.

An idealized load application device was connected to the electrical signal conditioning appliance (Model 5100B Scanner – System 5000 – Raleigh, NC, USA) in order to apply the load. The experimental model was placed on the load application appliance (Figure 1) with the framework submitted to an axial load of 30 kgf[19] applied for 10 seconds on the center of each implant and at 1 mm and 2 mm from the implants, totaling nine load application points (Figure 2). The referred points were designated as: A (axial point, center of the retention screw of implant 1), A1 (non-axial point, 1mm from point A), A2 (non-axial point, 2mm from point A), B (axial point, center of the retention screw of implant 2), B1 (non-axial point, 1mm from point B), B2 (non-axial point, 2mm from point B), C (axial point, center of the retention screw of implant 3), C1 (non-axial point, 1mm from point C), C2 (non-axial point, 2mm from point C). The microstrains determined at the nine points were recorded by four strain gauges and the same procedure was performed for all of the frameworks. Three loadings were made per load application point.

The final result was an average of measurements for axial load (A, B, C), an average for non-axial load 1mm (A1, B1, C1) and an average for non-axial load 2mm (A2, B2, C2) for each framework.

The electrical variations were transformed arithmetically into microstrain units (με) by the data acquisition software (StrainSmart - Raleigh, NC, USA).

Statistical analysis

The absolute values of strains were compared by two-way analysis of variance (ANOVA) followed by a *post hoc* Tukey's test at a 95 % confidence level ($\alpha = 0.05$). The absolute values of the 4 SGs were compared, as the strain gauges were only capable of detecting stresses in a limited segment around the implants and did not provide clear statements as to whether compressive or tensile forces were present in a polyurethane area of a given magnitude.

Results

The two-way ANOVA revealed that the configuration factor was statistically significant ($p=0.0004$), whereas the load factor ($p=0.2420$) and the interaction between the two factors was not significant ($p = 0.5494$) (Table 1). The Tukey's test revealed that was difference between straight line axial load (285.32± 61.04) and offset axial load (183.19±93.64), offset non-axial 1mm (200.96±50.24) and straight line non-axial 1mm (315.77±59.28) (Table 2).

Table 1. Two-way ANOVA for conditional experiments (μƐ).

Source	DF	SS	MS	F	P
Configuration	1	145952	145952	18.8	**0.0004***
Error configuration	18	139712	7762		
Load	2	8008	4004	1.48	0.2420
Configuration*Load	2	3304	1652	0.61	0.5494
Error configra*Load	36	97659	2713		
Total	59	394635			

*p<0,05

Table 2. Tukey HSD All-Pairwise comparisons test of SG for Configuration x point (μƐ).

	Offset	Straight line
Axial	183.2±93.64[A,a]	285.3±61.04[A,b]
Non-axial 1mm	201.0±50.24[A,a]	315.8±59.28[A,b]
Non-axial 2mm	219.7±66.69[A,a]	298.6±58.27[A,a]

Means followed by same capital letters in column and small letter in line do not differ significantly by Tukey's test (5%).

Discussion

To ensure the success of a surgical intervention for prosthodontics, a factor that must be taken into account is the transfer of stresses and strains that occurs around bone[2-4,13,20-22].

The mechanism is complex physiologically and any mechanical model can only be an approximation of the clinical situation. This current study used the strain gauge analysis to compare the strain distribution during two types of load: axial and non-axial load in three-element prostheses, varying the implant configurations (straight line and offset).

The bone quality is one of the factors that influence treatment with implants. The bone surrounding implants does not constitute a homogeneous substratum and its physical properties vary with the age, functional state and systemic factors of the patient[23]. Additionally, *in vitro* studies have used homogeneous and isotropic materials[1,24].

Associated to these factors, a homogeneous model with uniform elastic properties was used in this present study to simulate the human bone[25].

According to Wiskott; Belser[25], the polyurethane block used in the current study possess a similar modulus of elasticity to the human medullary bone (Polyurethane: 3.6GPa, according to the manufacturer/medullary bone: 4.0 4.5Gpa).

Some strain gauge studies used special devices for the application of loading on implants[7,12], but others used universal testing machines[24] to apply the load. The quantity of load used in this present work was based on the study developed by Merick-Stern *et al.*[19], investigating the occlusal force in patients with fixed partial implant supported dentures. Those authors claimed that 30.6 kgf (300 N) was the mean value for the maximum force verified in the region of the second molars[19], justifying this same amount of load used in the present study.

The biomechanical behavior of each component of the bone-implant-superstructure assembly is different. Functional loads applied on an implant may introduce complex deformation patterns in the prosthesis, the implant and the surrounding cortical bone which may affect the maintenance of the bone-implant interface[13].

The current results demonstrated that the mean microdeformation with reference to configuration factor (Table 1) had significant difference (p=0.0004). This difference showed lower values for offset configurating comparing straight line (axial offset (183.2±93.64) and axial straight line (285.3±61.04); non-axial 1mm offset (201.0±50.24) and non-axial 1mm straight line (315.8±59.28)). These results are in disagreement with previous studies, that the offset placement of implants did not always decrease the load in implants [8,14,15]. However, the current study agreed with the results of Rangert *et al.*[13] and Daellenbach *et al.* [27] which indicated that the bending moment would be diminished if the implants were placed in an offset placement. A hypothesis suggested by Rangert *et al.*[13] is that the offset arrangement of three implants would be preferred over the straight line placement. Another particular point of concern that may have affected the type of strains is the morse taper design of the implant used in this study. This feature is based on the incorporating of an abutment into the implant and different data may be recorded with the utilization of external and internal hexagon designs.

Offset placement of implants in the posterior region of the mouth requires sufficient width of the residual ridge which is not available in many clinical situations[1]. Yet, it is unclear whether establishing tripoded placement would counteract bending moments and is superior to two implants supporting a prosthesis or not[28].

Based on the physiological balance, clinical and laboratory studies indicate that permanent mechanical stimulation is needed[29]. Deformation intensities above 100 με are necessary to prevent bone resorption. However, the stimulation values must not exceed the physiological limit of 4000 με[25,30].

The data presented in Table 2 indicates that the values of microstrain are between 183.2με and 315.8με, considered within the physiologic bone tolerance limit. Additionally, no differences were observed between values of microstrain when points of axial load (A, B and C), points of non-axial load 1mm (A1, B1and C1) and points of non-axial load 2mm (A2, B2 and C2) were compared. This present result disagrees with a previous study[13], which found that non-axial load cause higher microstrain than axial loads. The proximity of the implants and the short distance of the non-axial from the axial load are probably the factors responsible for the different results found in the present study.

The question arises whether the difference in axial versus non-axial loading has a clinical significance that indicates mandatory safety measures to be followed during treatment planning or not. It may be stated that sufficient control of offset loading of implants should be provided, when possible. As the occlusal contact points screw retained fixed prosthesis are estabilished around the screws, offset loading of implants is inevitable.

Conclusion

According to the limitations of this study, there was evidence that the offset placement was capable of reducing the strain around an implant.

Additionally, the type of loading, axial load, non-axial load 1mm or non-axial load 2mm, did not have an influence until the non-axial loading was located 2 mm from the axial load.

Acknowledgements

The authors wish to thank FAPEAL (Alagoas State Research Foundation) for supporting this study and express their gratitude to Rodrigo Othávio for the statistical analysis of this study.

References

1. Çehreli MC, Duyck J, Cooman M, Puers R, Naert I. Implant design and interface force transfer. A photoelastic and strain-gauge analysis. Clin Oral Impl Res 2004; 15: 249-257.
2. Duyck J, Ronold H J, VanOosterwyck H , Naert I, Van Sloten J, Ellingsen J E. The influence of static and dynamic loading on marginal bone reactions around osseointegrated implants: an animal experimental study. Clin Oral Impl Res 2001; 12: 207-218.
3. Duyck J, VanOosterwyck H, Vander Sloten J, De Cooman M, Puers R, Naert I Magnitude and distribution of occlusal forces on oral implants supporting fixed prostheses: an *in vivo* study. Clin Oral Implant Res 2000; 11: 465-457.
4. Eskitascioglu G, Usumez A, Sevimay M, Soykan E, Unsal E. The influence of occlusal loading location on stresses transferred to implant-supported prostheses and supporting bone: a three-dimensional finite element study. J Prosthet Dent 2004; 91: 144-150.
5. Hekimoglu C, Anil N, Cehreli M. Analysis of strain around endosseous implants opposing natural teeth or implants. J Prosthet Dent 2004; 92:441-6.
6. Nishioka RS, Vasconcellos LGO, Nishioka LNBM. External hexagon and internal hexagon in straight and offset implant placement: strain gauge analysis. Implant Dent. 2009;18(6):512-520.

7. Abreu CW, Vasconcellos LGO, Balducci I, Nishioka RS. A comparative study of microstrain around three-morse taper implants with machined and plastic copings under axial loading. Braz J Oral Sci. 2010: 9(1):11-15.
8. Nishioka RS, Nishioka LNB, Abreu CW, Vasconcellos LGO, Balducci I. Machined and plastic copings in three-element prostheses with different types of implant abutment joints: a strain-gauge comparative analysis. J Appl Oral Sci 2010;18(3)225-230.
9. Frost HM. A 2003 update of bone physiology and Wolff's law for clinicians. Angle Orthod. 2004;74:3-15.
10. Bidez MW, Misch CE. Force transfer in implant dentistry: basic concepts and principals. J Oral Implantol. 1992; 23: 264-74.
11. Branemark PI, Zarb GA, Albrektsson T. Tissue-integrated prosthesis. Osseointegration in clinical dentistry. Chicago: Quintessence; 1987. 129p.
12. Assif D, Marshak B, Horowitz A. Analysis of load transfer and stress distribution by an implant-supported fixed partial denture. J Prosthet Dent. 1996; 75: 285-91.
13. 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.
14. Sato Y, Shindoi N, Hosokawa R, Tsuga K, Akagawa Y. A biomechanical effect of wide implant placement and offset placement of three implants in the posterior partially edentulous region. J Oral Rehabil. 2000;27(1)15-21.
15. Huang HL, Lin CL, Ko CC, Chang CH, Hsu JT, Huang JS. Stress analysis of implant-supported partial prostheses in anisotropic mandibular bone: in-line versus offset placements of implants. J Oral Rehabil. 2006 Jul;33(7):501-8.
16. Carr AB. Effects of fabrication, finishing and polishing procedures on preload in prostheses using conventional "gold" and plastic cylinders. Int J Oral Maxillofac Implants. 1996;11:589-98.

17. Castilio D, Pedreira APRV, Rossetti PHO, Rossetti LMN, Bonachela WC. The influence of screw type, alloy and cylinder position on the marginal fit of implant frameworks before and after laser welding. J Appl Oral Sci. 2006;14:77-81.

18. Chao Y, Zarb GA, Judes H. A study into the use of chromium-cobalt alloy for constructing the framework for osseointegrated. Clin Mater. 1988;3:309-15.

19. Mericske-Stern R, Assal P, Merickse E, Ing WB. Oclussal force and oral tactile sensibility measured in partially edentulous patients with ITI implants. Int J Oral Maxillofac Implants. 1995; 10: 345-54.

20. Quirynen M, Naert I, van Steenberghe D. Fixture design and overload influence marginal bone loss and fixture success of the Branemark system. Clin Oral Implants Res. 1992;3:104-11.

21. Skalak R Biomechanical considerations in osseointegrated prostheses. J Prosthet Dent. 1983;49:843-8.

22. Van Oosterwyck H, Duyck J, Vander Sloten J, Van der Perre G, De Cooman M, Lievens S, et al. The influence of bone mechanical properties and implant fixation upon bone loading around oral implants. Clin Oral Implant Res 1998; 9: 407-418.

23. Sahin S, Çehreli MC, Yalçin E. The influence of functional forces on the biomechanics of implant-supported prostheses – a review. J Dent 2002,30:271-82.

24. Akça K, Cehreli MC, Iplikçioglu H. A comparison of three-dimensional finite element stress analysis with in vitro strain gauge measurements. Int J Prosthodont. 2002; 15: 115-21.

25. Wiskott H W, Belser U C. Lack of integration of smooth titanium surfaces: a working hypothesis based on strains generated in the surrounding bone. Clin Oral Implants Res. 1999;10:429-44.

26. Heckmann SM, Karl M, Wichmann MG, Winter W, Graef F, Taylor TD. Cement fixation and screw retention: parameters of passive fit. An in vitro

study of three-unit implant-supported fixed partial dentures. Clin Oral Implants Res 2004 Aug;15(4):466-73.

27. Daellenbach K, Hurley E, Brunski JB. Biomechanics of in-line vs. offset implants supporting a partial prosthesis. *Journal of Dental Research* 1996;75:183.

28. Taylor TD, Agar JR, Vogiatzi. Implant prosthodontics: current perspective and future directions. Int J Oral and Maxillofac Imp.2000;15:66-75.

29. Smedberg JI, Nilner K, Rangert B, Svensson SA, Glantz SA. On the influence of superstructure connection on implant preload: a methodological and clinical study. Clin Oral Implants Res. 1996; 7: 55-63.

30. Frost H M. Wolff's law and bone's structural adaptations to mechanical usage: an overview for clinicians. Angle Orthod. 1994;64:175-88.

FIGURES

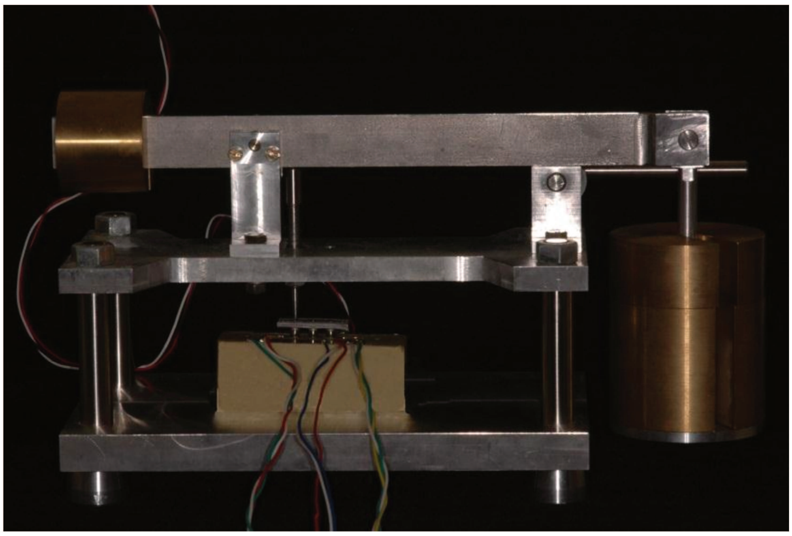

Figure 1 - Experimental model in the loading apparatus with load applied at point A.

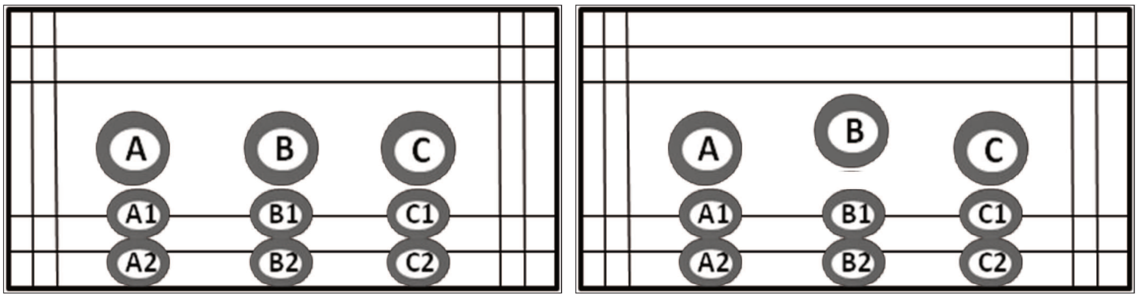

Figure 2 – Left figure: straight line implants. Right figure: offset implants.

3. CONSIDERAÇÕES GERAIS

A possibilidade de substituir estruturas dentais ausentes nos pacientes total e parcialmente edêntulos representa melhora significativa na qualidade de vida, tornando o uso dos implantes para reabilitação protética uma rotina clínica com elevados índices de sucesso.

Diversos fatores podem interferir no comportamento dos implantes e da prótese, como a quantidade de tensão e deformação gerada no complexo prótese/osso/implante, localização da carga oclusal, tipo de *coping* utilizado, além da adaptação da estrutura protética, comprometendo o resultado clínico final.

A popularização do uso de *copings* plásticos e com colar metálico é diretamente atribuído à redução de custos (Abreu *et al*., 2010). No presente estudo, as médias de microdeformação (με) registrada para as configurações linear e offset dos implantes foram diferentes quando *copings* plásticos foram usados. Contudo, os valores mensurados entre *copings* para a mesma configuração foram similares. Essa similaridade de microdeformação observada entre *copings* plásticos e com colar metálico provavelmente ocorreu devido à necessidade do processo de fundição de ambos os componentes, tornando-os como estruturas semelhantes.

O presente estudo utilizou uma metodologia baseada num modelo homogêneo com propriedades elásticas uniformes, simulando o osso humano (Wiskott; Belser, 1999). Além disso, a metodologia usada buscou eliminar etapas que promoveriam alterações dimensionais, como aquelas resultando da moldagem de transferência e obtenção do modelo. Este método foi embasado no estudo de Heckman *et al.* (2004) os quais concluíram que estruturas de metal fabricadas em modelos produziram maiores deformações quando comparadas com aquelas feitas sem o procedimento de moldagem.

Alguns estudos de extensometria utilizaram dispositivos especiais para aplicação de carga nos implantes (Abreu *et al.*, 2010; Nishioka *et al.*, 2010), assim como apresentado na corrente pesquisa. A quantidade de carga usada foi baseada em Merick-Stern *et al.* (1995) os quais determinaram um valor médio de 300 N para a máxima força verificada na região de segundos molares.

Tensões mecânicas podem ter consequências positiva ou negativa para o tecido ósseo e também para a manutenção da osseointegração do implante. O osso recebendo carga mecânica precisa se adaptar à força da carga aplicada para manter o processo de remodelação contínua ao redor do implante. Estudos clínicos e laboratoriais indicam que estimulação mecânica permanente com intensidade acima de 100 με é necessária para prevenir reabsorção óssea. Contudo, os valores de estimulação não devem exceder o limite fisiológico de 4000 με (Frost, 1994; Wiskot; Belser, 1999). Os resultados de microdeformação obtidos no presente estudo encontram-se dentro do limite de tolerância fisiológica do osso.

A passividade da estrutura metálica causada por uma adaptação com menor desajuste marginal é a situação desejada por gerar menor tensão à estrutura óssea levando ao sucesso da prótese em longo prazo. Porém, no presente estudo não ocorreu passividade durante o aperto das estruturas, mostrando ausência de adaptação vertical. Esses achados confirmam o reportado na literatura no que diz respeito à dificuldade para obtenção de estruturas em monobloco com boa adaptação marginal (Torres *et al.*, 2007). Apesar disso, os valores encontrados no corrente estudo podem ser considerados biologicamente aceitáveis quando comparados com alguns estudos anteriores (Carr, 1996; Jemt; Book, 1996).

Os valores e adaptação passiva observados no presente estudo não indicaram diferenças entre *copings* plásticos e com colar metálico como também entre configuração linear e offset, variando os valores de desajuste entre 87.0±13.99 µm e 98.0±18.3 µm. Um estudo prévio considerou um limite aceitável para desajuste até 150 µm (Sahin *et al.*, 2002).

O posicionamento de implantes de maneira compensada *(offset)* tem sido largamente reportado e aceito no caso de próteses suportadas por três implantes (Sato et al., 2000). Contudo, esta informação ainda é muito discutida na literatura e poucos dados existem a respeito do efeito biomecânico desta posição offset na distribuição de tensão na estrutura óssea (Anitua;Orive, 2009). A instalação offset de implantes na região posterior da boca requer suficiente largura de osso residual, fato este nem sempre disponível em muitas situações clínicas (Çehereli et al., 2002).

Os resultados do presente estudo observaram valores de menor microdeformação encontrados para os implantes offset comparados com os implantes na posição linear. Contudo, é obscuro estabelecer uma relação de que o efeito do tripoidismo neutralizaria momentos de flexão, pois existem vários fatores que podem também interferir neste processo, inclusive o tipo de implante. No atual estudo, o implante utilizado foi do tipo cone morse, enquanto que, utilizando metodologia semelhante, porém com implantes do tipo hexágono externo e interno, Nishioka et al. em 2009, observaram valores similares para ambas as configurações.

A razão dos parâmetros desta investigação é baseada na escolha da melhor opção de tratamento com uma prótese parcial fixa sobre implante de três elementos para permitir o sucesso clínico em longo prazo. A determinação da melhor opção continua ser uma questão vital para estudos biomecânicos clínicos prospectivos e retrospectivos.

Diante disso, o presente estudo teve como objetivo pesquisar os componentes que atuam no comportamento mecânico de próteses implanto-suportadas para preservar a manutenção do complexo prótese/osso/implante permitindo o sucesso da reabilitação protética.

4. CONCLUSÃO

De acordo com os resultados analisados e discutidos foi possível concluir que:

1. A configuração dos implantes de maneira linear ou compensada interferiu no grau de microdeformação óssea.

2. O tipo de *coping* plástico ou com colar metálico não promoveu diferença na quantidade de microdeformação óssea envolvida.

3. As cargas oclusal axial e não-axial não promoveram diferença na deformação óssea para o deslocamento de 1 a 2 mm.

4. As adaptações marginal e vertical não foram influenciadas pelos *copings* plásticos ou com colar metálico, mas houve diferença nas configurações linear ou compensada.

Abreu CW, Vasconcellos LGO, Balducci I, Nishioka RS. A comparative study of microstrain around three-morse taper implants with machined and plastic copings under axial loading. Braz J Oral Sci 2010; 9(1):11-15.

Adell R, Lekholm U, Rockler B, Branemark PI. A 15-year study of osseointegrated implants in the treatment of the edentulous jaw. Int J Oral Surg1981; 10:387-416.

Akça K, Cehreli MC, Iplikçioglu H. Evaluation of the mechanical characteristics of the implant-abutment with a reduced-diameter Morse-taper implant. A nonlinear finite element stress analysis. Clin Oral Impl Res. 2003;14(4): 444-54.

Akça K, Iplikcioglu H. Finite element stress analysis of the influence of staggered versus straight placement of dental implants. Int J Oral Maxillofac Implants 2001 Sep-Oct; 16(5):722-30.

Alkan I, Sertgöz A, Bülent E. Influence of occlusal forces on stress distribution in preloaded dental implant screws. J Prosthet Dent. 2004; 91:319-25.

Andersson B, Odman P, Carlsson L, Branemark PI. A new Branemark single tooth abutment: handling and early clinical results. Int J Oral Maxillofac Implants. 1992;7:105-11.

Anitua E, Orive G. Finite element analysis of the influence of the offset placement of an implant-supported prosthesis on bone stress distribution. J Biomed Mater Res Part B:Appl Biomater 89B. 2009: 275-

*De acordo com a norma da FOP/UNICAMP, baseada na norma do International Committee of Medical Journal Editors – Grupo de Vancouver. Abreviatura dos periódicos em conformidade com Medline.

Binon P. Evaluation of machining accuracy and consistency of select implants, standard abutments, and laboratory analogs. Int J Prosthodont 1995;8(2):162-78.

Branemark PI, Svensson B, Van SteenbergheD. Ten-year survival rates of fixed prostheses on four or six implants ad modum Branemark in full edentulism. Clin Oral Implants Res 1995; 6: 227-31.

Buser D, Weber HP, Bragger U, Balsiger C. Tissue integration of one-stage ITI Implants: 3-year results of a longitudinal study with hollow-cylinder and hollow-screw implants. Int J Oral Maxillofac Implants. 1991;6(4):405-12.

Carlson B, Carlsson GE. Prosthodontic complications in osseointegrated dental implant treatment. Int J Oral Maxillofac Implants 1994; 9(1):90-4.

Çehreli M, Duyck J, De Cooman M, Puers R, Naert I. Implant design and interface force transfer: a photoelastic and strain-gauge analysis. Clin Oral Implants Res 2004 Apr;15(2):249-57.

Çehreli MC, Iplikcioglu H. In vitro strain gauge analysis of axial and off-axial loading on implant supported fixed partial dentures. Implant Dent 2002;11(3):286-92.

Clelland NL, Gilat A, McGlumphy EA, Brantley WA. A photoelastic and strain gauge analysis of angled abutments for an implant system. Int J Oral Maxillofac Implants. 1993;8(5):541-8.

Duyck J, Van Oosterwyck H, Vander Stolen J, De Cooman M, Puers R, Naert I. Pre-load on oral implants after screw tightening fixed full prostheses: an in vivo study. J Oral Rehabil. 2001(3);28:226-33.

Duyck J, Van Oosterwyck H, Vander Sloten J, De Cooman M, Puers R, Naert I. Mangnitude and distribuition of occlusal forces on oral implants supporting fixed prostheses: an in vivo study. Clin Oral Implants Res 2000;11(5):465-75.

Eskitascioglu G, Usumez A, Sevimay M, Soykan E, Unsal E. The influence of occlusal loading location on stresses transferred to implant-supported prostheses and supporting bone: a three-dimensional finite element study. J Prosthet Dent. 2004;91(2):144-50.

Glantz PO, Rangert B, Svensson A, Stanfford GD, Arnvidarson B, Randow K. et al. On clinical loading of osseointegrated implants. A methodological and clinical study. Clin Oral Implants Res. 1993 4(2):99-105.

Heckmann SM, Karl M, Wichmann MG, Winter W, Graef F, Taylor TD. Cement fixation and screw retention: parameters of passive fit. An in vitro study of three-unit implant-supported fixed partial dentures. Clin Oral Implants Res 2004 Aug;15(4):466-73.

Heckmann SM, Karl M, Winter W, Grael F, Taylor TD. Loading of bone surrounding implants through three-unit fixed partial denture fixation: a finite –elements analysis based on *in vitro* and *in vivo* strain measurements. Clin Oral Implants Res 2006 Jun;17(3):345-50.

Hekimoglu C, Anil N, Çehreli MC. Analysis of strain endosseous dental implants opposing natural teeth or implants. J Prosthet Dent 2004;92(5):441-6.

Karl M, Rosch S, Graef F, Taylor TD, Heckmann SM. Strain situation after fixation of three-unit ceramic veneered implantsuperstructures. Implant Dent 2005 Jun;14(2):157-65.

Khraisat A, Hashimoto A, Nomura S, Miyakawa O. Effect of lateral cyclic loading on abutment screw loosening of an external hexagon implant system. J Prosthet Dent 2004; 91:326-334.

May KB, Edge MJ, Russell MM, Razzoog ME, Lang BR. The precision of fit at the implant prosthodontic interface. J Prosthet Dent 1997. 77(5):497-502.

Nishioka RS, Vaconcellos LGO, Nishioka LNBM. External hexagon and internal hexagon in straight and offset implant placement: strain gauge analysis. Implant Dent 2009; 18:512-520.

Patterson E A, Burguete RL, Thoi MH, Jonhs R B. Distribution of load in an oral prosthesis system: an in vitro study. Int J Oral Maxillofac Implants. 1995;10(5):552-60.

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.

Roberts WE. Fundamental principles of bone physiology, metabolism and loading. In: Naert I, van Steenberghe D, Worthington P, editors. Osseointegration in oral rehabilitation. An introductory textbook. London: Quintessence; 1993. p.163-4.

Sahin S, Çehreli MC. The significance of passive framework fit in implant prosthodontics: current status. Implant Dent. 2001; 10(2): 85-90.

Sato Y, Shindoi N, Hosokawa R, Tsuga K, Akagawa Y. A biomechanical effect of wide implant placement and offset placement of three implants in the posterior partially edentulous region. J Oral Rehabil. 2000;27(1)15-21.

Scacchi M. The development of the ITI Dental implant system. Part 1: a review of the literature. Clin Oral Impl Res. 2000: 11 Suppl: 8-21.

Solnit GS, Schneider RL. An alternative to splinting multiple implants: use of the ITI system. Journal of Prosthodontics 1998; 7 (2): 114-119.

Spiekermann H, Jansen VK, Ritcher EJ. A 10-year follow-up study of IMZ and TPS implants in the edentulous mandible using bar-retained overdentures. Int J Oral Maxillofac Implants. 1995 Mar-Apr;10(2):231-43.

Stanford CM, Brand RA. Toward an understanding of implant occlusion and strain adaptive bone modelling and remodeling. J Prosthet Dent. 1999;81(5):553-61.

Sutter F, Weber H P, Sorensen J, Belser U. The new restorative concept of the ITI dental implant system: design and engineering. Int J Period and Rest Dent. 1993;13: 409-31.

Sutter F, Schroeder A, Buser D. The new concept of ITI hollow-cylinder and hollow-screw implants: Part 1. Engineering and design. Int J Oral Maxillofac Implants. 1988;3(3):161-72.

Van Oosterwyck H, Duyck J, Vander Sloten J, et al. The influence of bone mechanical properties and implant fixation upon bone loading around oral implants. Clinical Oral Implants Research. 1998; 9: 407–418.

Wiskott HWA, Belser UC. Lack of integration of smooth titanium surfaces: a working hypothesis based on strains generated in the surrounding bone. Clin Oral Implants Res 1999;10:429-44