



PRISCILLA CARDOSO LAZARI

**“INFLUENCE OF THE VENEER/FRAMEWORK INTERFACE ON
THE MECHANICAL BEHAVIOR OF CERAMIC VENEERS”**

**“INFLUÊNCIA DA UNIÃO ENTRE A CERÂMICA DE COBERTURA E
A INFRAESTRUTURA DE ZIRCÔNIA SOBRE O
COMPORTAMENTO MECÂNICO DA CERÂMICA DE
COBERTURA.”**

PIRACICABA

2013



UNIVERSIDADE ESTADUAL DE CAMPINAS
FACULDADE DE ODONTOLOGIA DE PIRACICABA

PRISCILLA CARDOSO LAZARI

**"INFLUENCE OF THE VENEER/FRAMEWORK INTERFACE ON
THE MECHANICAL BEHAVIOR OF CERAMIC VENEERS"**

Orientador: Prof. Dr. Eduardo Passos Rocha

Co-Orientadora: Prof.^a Dr.^a Altair Antoninha Del Bel Cury

**"INFLUÊNCIA DA UNIÃO ENTRE A CERÂMICA DE COBERTURA E A
INFRAESTRUTURA DE ZIRCÔNIA SOBRE O COMPORTAMENTO MECÂNICO
DA CERÂMICA DE COBERTURA"**

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Este exemplar corresponde à versão final da dissertação defendida pela aluna Priscilla Cardoso Lazari e orientada pelo Prof. Dr. Eduardo Passos Rocha.

Assinatura do Orientador

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Prof. Dr. EDUARDO PASSOS ROCHA

A handwritten signature in purple ink, appearing to read "Paulo Henrique dos Santos", written over a horizontal line.

Prof. Dr. PAULO HENRIQUE DOS SANTOS

A handwritten signature in purple ink, appearing to read "Bruno Salles Sotto Maior", written over a horizontal line.

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RESUMO

O uso do óxido de zircônia para a confecção de infraestruturas de coroas totais cerâmicas tem se expandido devido às suas excelentes propriedades mecânicas, entretanto estudos recentes demonstram a maior ocorrência de fraturas na cerâmica de cobertura de coroas totais com infraestrutura de zircônia quando comparados ao uso de infraestrutura metálica. Assim, o objetivo deste estudo foi avaliar o comportamento mecânico da cerâmica de cobertura sobre infraestrutura de zircônia ou metal, variando a união entre ambas, com o método dos elementos finitos tridimensional não linear. Os modelos geométricos de um incisivo central superior, portando uma coroa total com infraestrutura de zircônia ou prata/paládio e cerâmica de cobertura sobre retentores dente natural ou implante, foram confeccionados com os softwares SolidWorks Premium 2012 e Mimics. Os grupos em estudos foram: C – Coroa metalocerâmica com infraestrutura em prata/paládio cimentada sobre dente natural; Cz – Coroa cerâmica com infraestrutura em zircônia cimentada sobre dente natural; Ci - Coroa metalocerâmica com infraestrutura em prata/paládio, cimentada sobre implante cone morse; Czi – Coroa cerâmica com infraestrutura em zircônia, cimentada sobre implante cone morse. Os coeficientes de atrito entre a cerâmica de cobertura e a infraestrutura, e a interface de contato foram estabelecidos em 0,3 ou totalmente unidos, simulando desde uma união insatisfatória até uma união perfeita. Foram realizados dois carregamentos (C): C1- 49 N aplicados no terço incisal da superfície palatina com inclinação de 45° em relação ao longo eixo do dente, simulando contato em máxima intercuspidação habitual; C2- 25,5N aplicados perpendicularmente à borda incisal da coroa, simulando contato do tipo “topo a topo”. Os valores de tensão principal máxima (σ_{max}), tensão de cisalhamento (τ_{max}) e os deslocamentos (μ_{max}) foram obtidos para a cerâmica de cobertura, e tensão de von Mises (σ_vM) obtidos para as infraestruturas de zircônia ou prata/paládio. Os maiores valores de tensão foram observados para a cerâmica de cobertura com o coeficiente de fricção 0.3 independente do material utilizado como

infraestrutura. Entretanto, quando os modelos apresentavam-se com uma união perfeita entre as estruturas, as próteses metalocerâmicas apresentaram valores menores de tensão quando comparadas com a infraestrutura de zircônia. Os valores de tensão para os modelos sobre implante apresentaram valores de tensão inferiores aos observados nos modelos sobre dente, independente do material da infraestrutura. Dentro das limitações do estudo, podemos concluir que a união deficiente entre a cerâmica de cobertura e a infraestrutura da prótese afeta a resistência à fratura da cerâmica de cobertura, tornando-a susceptível à falhas independente do material da infraestrutura ou do suporte da coroa total.

Palavras-chave: zircônia, cerâmica de cobertura, método dos elementos finitos, coeficiente de fricção.

ABSTRACT

The excellent mechanical properties of zirconium YTZ-P make it a viable option for constructing the framework of metal-free crowns. However, recent studies indicate the occurrence of failures in ceramic veneer crowns with zirconia framework. The aim of this study was to use three-dimensional nonlinear finite element analysis to evaluate the mechanical behavior of ceramic veneers, partially debonded or bonded, over zirconia frameworks under two conditions of veneer/framework bond integrity and support by implant or natural tooth. Three-dimensional finite element analysis was used to compare the mechanical behavior of ceramic veneers on zirconia and metal frameworks under two conditions of bond integrity. The groups were created with the crowns partially bonded (0.3 frictional coefficient) or completely bonded): C - Crown with silver/palladium framework cemented onto natural tooth; Cz - Ceramic crown with zirconia framework cemented onto natural tooth; Ci - Crown with silver/palladium framework cemented on implant morse taper; CZI - Ceramic crown with zirconia framework cemented onto implant morse taper. The test loads consisted of 49 N applied to the palatal surface at 45° to the long axis of the crown and 25.5 N applied perpendicular to the incisal edge of the crown. The maximum principal stress (σ_{max}), shear stress (σ_{max}) and deformation (μ_{max}) were calculated for the ceramic veneer and the von Mises stress (σ_{vM}) was determined for the framework. Partially debonded of the veneer to the framework (friction coefficient 0.3) increased stress concentrations in all structures. The metal-ceramic crowns experienced lower stress values than all ceramic crowns in models simulating a perfect bond between the ceramic and framework. Frameworks cemented to tooth exhibited greater stress than frameworks cemented to implants regardless of the material used. The incomplete bonding between the ceramic veneer and the framework prosthesis affects the mechanical performance of the ceramic veneer, making it susceptible to failure independent of the material framework or full crown support.

Key words: zirconia, ceramic veneer, finite element analysis, frictional coefficient.

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INTRODUÇÃO

Impulsionada pela necessidade atual em utilizar restaurações livres de metal, a evolução dos sistemas cerâmicos para restaurações dentárias tem sido notável nas últimas três décadas. Os sistemas cerâmicos desenvolvidos ao longo dos últimos anos são particularmente adequados para imitar a translucidez dos dentes naturais e, por conseguinte, apresentam vantagens estéticas em relação às restaurações metalocerâmicas convencionais (Pelaez *et al.*, 2012), oferecendo cada vez maior desempenho do ponto de vista mecânico (Denry and Holloway, 2010).

A introdução de cerâmicas à base de zircônia como material dentário restaurador tem gerado considerável interesse na comunidade odontológica devido às suas excelentes propriedades mecânicas como os altos valores de tenacidade e resistência flexural (Kelly and Denry, 2008; Piconi and Maccauro, 1999; Abduo *et al.*, 2010), excelente estética, radiopacidade e biocompatibilidade (Vagkopoulou *et al.*, 2009) que permitem tanto a realização de próteses anteriores como posteriores, onde resistência e estética são fundamentais (Denry and Kelly, 2008). Devido à resistência à tração das coroas livres de metal variarem conforme as propriedades do material utilizado como infraestrutura (Guazzato *et al.*, 2004) a utilização da zircônia melhorou o desempenho dessas próteses quando comparadas aos outros tipos de cerâmica para infraestruturas (Vult von Steyern, 2005).

No entanto, falhas frequentes são encontradas na cerâmica de cobertura aplicada diretamente sobre uma infraestrutura de zircônia (Mainjot *et al.*, 2011; Bonfante *et al.*, 2010; Sailer *et al.*, 2007). Estas falhas são do tipo fratura ou lascamento e ocorrem de 25 a 50% das próteses com infraestrutura de zircônia (Sailer *et al.*, 2007; Tinschert *et al.*, 2008; Roediger *et al.*, n.d.; Raigrodski *et al.*, 2006). Estes números mostram-se elevados quando comparados as próteses metalocerâmicas, que apresentaram taxas 4% em um período de 10 anos de acompanhamento (Walton, 2003).

Alguns fatores podem ser atribuídos ao maior número dessas falhas serem encontrados nas próteses livres de metal, pois a interface de união entre a zircônia e a cerâmica de cobertura e as diferenças entre os coeficientes de expansão térmica dos dois materiais podem afetar o sucesso da restauração (al-Shehri *et al.*, 1996; Isgrò *et al.*, 2003; Kosmac *et al.*, 2000). A interface de união está intimamente relacionada com a Teoria de Adesão entre os dois materiais. Nas restaurações metalocerâmicas, a adesão entre os dois materiais pode ser dividida em três tipos: embricamento mecânico, adesão química e adesão física. A adesão química é considerada como fonte de união primária, e está relacionada com as ligações iônicas, covalentes e metálicas, que se estabelecem durante a queima da cerâmica, levando a uma sorção química pela difusão de óxidos das superfícies do metal. A adesão física, fonte de união secundária, é promovida pelas ligações de Van der Waals (forças de atração entre dois átomos). E por fim, o embricamento mecânico, que seria resultado das forças de compressão originadas pela diferença entre os coeficientes de expansão térmica da cerâmica e do metal (Anusavice, 2005). Não há relatos na literatura que evidenciem a união química primária entre a cerâmica feldspática e a zircônia. Sendo assim, a união entre os dois materiais pode estar intimamente ligada ao embricamento mecânico, que faz com que a interface de união entre a zircônia e a cerâmica de cobertura seja mais fraca que a interface cerâmica feldspática e metal em uma prótese metalocerâmica (Aboushelib *et al.*, 2007; Manicone *et al.*, 2007)

O fator que contribui para o potencial de falha na cerâmica de cobertura é a presença de tensão de tração residual como resultado da incompatibilidade dos coeficientes de expansão térmica (CET) entre a cerâmica de infraestrutura e cobertura (DeHoff *et al.*, 2008; Vagkopoulou *et al.*, 2009; Aboushelib *et al.*, 2006; Fischer *et al.*, 2009). Esta possível incompatibilidade térmica entre as cerâmicas, associada à queima indevida ou resfriamento rápido, podem causar tensões de tração na cerâmica de cobertura feldspática, devido à baixa condutividade térmica da zircônia. A dificuldade da zircônia em transferir calor durante o resfriamento pode gerar contrações precoces da cerâmica de cobertura ocasionando tensões

de compressão e de tração, estabelecendo assim pontos para propagação de falhas (Taskonak *et al.*, 2005; Swain, 2009), resultando em inadequada interação micromecânica entre a zircônia e a cerâmica de cobertura (Kim *et al.*, 2006; Rocha *et al.*, 2011). Portanto, as coroas totais com infraestrutura de zircônia demandam de atenção específica no tempo de resfriamento após a cocção da cerâmica de cobertura (Göstemeyer *et al.*, 2010), o que difere das coroas metalocerâmicas, pois o metal é um excelente condutor de calor (Piconi and Maccauro, 1999).

Falhas tanto na união quanto na cerâmica de cobertura permitem um micro descolamento tangencial entre os dois materiais, aumentando a concentração de tensões em comparação à situação de união perfeita (Rocha *et al.*, 2011). O comportamento mecânico desta união insatisfatória, quando submetida a esforços mastigatórios ainda é pouco pesquisado (Vagkopoulou *et al.*, 2009; De Jager *et al.*, 2006). Deve ser ressaltado que nos trabalhos disponíveis, esta condição de união tem sido considerada perfeita, o que nem sempre é verdadeiro (Göstemeyer *et al.*, 2010; Bonfante *et al.*, 2010).

Outro aspecto relevante quanto ao comportamento mecânico relacionado à união entre a infraestrutura e cerâmica de cobertura da coroa é quanto ao retentor da prótese, se dente natural ou implante osseointegrado. De acordo com o substrato utilizado as variações de união entre as duas cerâmicas podem assumir comportamentos mecânicos distintos. Essa diferença decorre, especialmente, do fato do conjunto implante/componente protético apresentar módulo de elasticidade muito maior em comparação ao dente natural (Burak Özcelik *et al.*, 2011). Com isso, pressupõe maior concentração de tensão e maior previsibilidade de falhas se houver deficiência de união entre os dois materiais. Há poucos trabalhos na literatura que avaliaram o comportamento mecânico da cerâmica de cobertura, especialmente com dentes naturais usados como retentores (Larsson and Vult von Steyern, 2010). Foram encontradas taxas de insucesso maiores para próteses metalocerâmicas quando estas se apresentavam sobre implantes osseointegrados quando comparados com os dentes naturais (Pjetursson *et al.*, 2007).

Assim, considerando a necessidade de mais trabalhos sobre a avaliação do comportamento mecânico da cerâmica de cobertura sobre infraestrutura de zircônia no que tange a união entre os dois materiais: infraestrutura e cerâmica de cobertura, o objetivo deste estudo foi avaliar, com o uso do método dos elementos finitos tridimensional não linear, o comportamento mecânico da cerâmica de cobertura sobre infraestrutura de zircônia variando a união entre ambos, desde uma união perfeita até união insatisfatória.

CAPÍTULO¹

Influence of the veneer/framework interface on the mechanical behavior of ceramic veneers: a nonlinear finite element analysis

Priscilla Cardoso Lazari DDS, MSc Student^a ; Bruno Salles Sotto-Maior DDS, MSc, PhD^b; Germana de Villa Camargos DDS, MSc, PhD Student^a; Eduardo Passos Rocha, DDS, MSc, PhD^c; Altair Antoninha Del Bel Cury, DDS, MSc, PhD.^d

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^a Graduate student, Department of Prosthodontics and Periodontology, Piracicaba Dental School, State University of Campinas, Piracicaba, São Paulo, Brazil

^b Professor, Department of Restorative Dentistry, Juiz de Fora Dental School, Federal University of Juiz de Fora, Minas Gerais, Brazil.

^c Professor, Department of Dental Materials and Prosthodontics, Araçatuba Dental School, São Paulo State University (UNESP), São Paulo, Brazil

^d Professor, Department of Prosthodontics and Periodontology, Piracicaba Dental School, State University of Campinas, Piracicaba, São Paulo, Brazil

* Corresponding author:

Altair Antoninha Del Bel Cury

Department of Prosthodontics and Periodontology; Piracicaba Dental School, University of Campinas. Avenida Limeira, 901. Zip Code: 13414-903. Piracicaba, São Paulo, Brazil.

Phone: +55 19 21065294; Fax +55 19 2106-5211;

E-mail: altcury@fop.unicamp.br

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ABSTRACT

The excellent mechanical properties of zirconium YTZ-P make it a viable option for constructing the framework of metal-free crowns. Three-dimensional finite element analysis was used to compare the mechanical behavior of ceramic veneers on zirconia and metal frameworks under two conditions of bond integrity (complete bond or partially debonded) cemented to teeth or implants. The framework material was zirconia or silver/palladium. Bond integrity was simulated by using framework/veneer friction coefficients of 0.3 or bonded. The test loads consisted of 49 N applied to the palatal surface at 45° to the long axis of the crown and 25.5 N applied perpendicular to the incisal edge of the crown. The maximum principal stress (σ_{max}), shear stress (σ_{max}) and deformation (μ_{max}) were calculated for the ceramic veneer and the von Mises stress (σ_{vM}) was determined for the framework. Partially debonded of the veneer to the framework (friction coefficient 0.3)

increased stress concentrations in all structures. The metal-ceramic crowns experienced lower stress values than all ceramic crowns in models simulating a perfect bond between the ceramic and framework. Frameworks cemented to tooth exhibited greater stress than frameworks cemented to implants regardless of the material used. The incomplete bonding between the ceramic veneer and the framework prosthesis affects the mechanical performance of the ceramic veneer, making it susceptible to failure independent of the material framework or full crown support.

CLINICAL IMPLICATIONS

Failures in the ceramic veneer/framework interface in zirconia crowns are common and can influence the biomechanical behavior of the ceramic veneer, increasing chipping or fracture rates in veneer.

INTRODUCTION

Due to its stiffness and flexural strength, zirconia (YTZ-P) has been used as a framework material in dental prostheses in an effort to improve the performance of metal-free crowns (Lawn *et al.*, 2001; Kelly and Denry, 2008; Piconi and Maccauro, 1999; Abduo *et al.*, 2010; Borba *et al.*, 2011). The material also possesses excellent properties in terms of aesthetics, radiopacity, and biocompatibility (Vagkopoulou *et al.*, 2009). Previous clinical trials have demonstrated the potential of zirconia to enhance the performance of prostheses (Vult von Steyern, 2005), since the tensile strength of metal-free crowns depends on the properties of the material used to construct the framework (Guazzato *et al.*, 2004).

However, metal-free prostheses have been associated with a high complication rate. Most of the reported failures are due to fracture, wear, or

chipping of the ceramic veneer (Vult von Steyern, 2005; Roediger *et al.*, n.d.; Denry and Kelly, 2008; Heintze *et al.*, 2008; Larsson *et al.*, 2006; Raigrodski *et al.*, 2006), with fractures occurring in 6-15% of restorations after 3-5 years (Sailer *et al.*, 2007; Sorrentino *et al.*, 2012). This failure rate is high compared to metal-ceramic prostheses, which have a 4% failure rate over 10 years. The greater number of failures in metal-free prostheses is due to the weaker interface between the zirconia structure and the ceramic veneer. The fragility of this interface is related to the difference in the thermal expansion coefficients (CTEs) of the ceramics (Vagkopoulou *et al.*, 2009; Aboushelib *et al.*, 2006; Fischer *et al.*, 2009), and proper matching of CTEs is essential to prevent failure after porcelain firing. Incompatibility in CTEs is aggravated by improper burning or rapid cooling since the low thermal conductivity of zirconia can cause excessive tensile stresses in the feldspathic ceramic veneer (Guazzato *et al.*, 2004; Tinschert *et al.*, n.d.; Benetti *et al.*, 2010; Komine *et al.*, 2010; Bulpakdi *et al.*, 2009).

Interestingly, the stresses generated in ceramic veneers in the presence of an incomplete bond between the veneer and the zirconia framework have not been extensively examined (Vagkopoulou *et al.*, 2009; De Jager *et al.*, 2006). In the single study in which simulated failures in this interface were investigated, the stresses in the ceramic veneer were increased by up to 12 times compared to conditions of perfect bonding between the materials (Rocha *et al.*, 2011).

Another aspect to consider is the structure supporting the restoration, since the stresses depend on whether the restoration is on a natural tooth or an osseointegrated implant (Pjetursson *et al.*, 2007). Implants and abutments have much higher elastic moduli than natural teeth (Burak Özcelik *et al.*, 2011), resulting in greater stress concentration and greater likelihood of failure if the bond between the two materials is incomplete. Failure rates in metal-ceramic prostheses are higher when they are mounted on implanted retainers compared to those mounted on natural teeth (Att *et al.*, 2012).

The aim of this study was to use three-dimensional nonlinear finite element analysis to evaluate the mechanical behavior of ceramic veneers, partially

debonded or bonded, over zirconia frameworks under two conditions of veneer/framework bond integrity and support by implant or natural tooth partially or completely bonded. The hypothesis was that the partially debonded between ceramic veneer and zirconia framework would increase stresses in ceramic veneer independently of framework material and full crown support.

MATERIALS AND METHODS

Models of a total crown on a central incisor were constructed in which the crown was supported by either a natural tooth or an implant. The factors studied included the frictional coefficient (0.3 or completely bonded), used to describe the condition of the bond between the veneer and the framework, the framework material (zirconia or palladium/silver), and the type of support (tooth or implant). The groups were created with the crowns partially bonded (0.3 frictional coefficient) or completely bonded): C - Crown with silver/palladium framework cemented onto natural tooth; Cz - Ceramic crown with zirconia framework cemented onto natural tooth; Ci - Crown with silver/palladium framework cemented on implant morse taper; CZI - Ceramic crown with zirconia framework cemented onto implant morse taper. Oblique loads were applied and analyzed using non-linear finite element analysis software to determine the maximum principal stress (σ_{max}), the shear stress (τ_{max}) and deformation (μ_{max}) for the veneer and the von Mises stress (σ_vM) for the frameworks.

Finite Element Model Design

Computerized tomographic (CT) images of a human edentulous maxilla were used to construct the virtual model. The CT images were exported to MIMICS 13.1 software (Materialise, Leuven, Belgium) for 3D model construction. The resulting model was exported to the SolidWorks 2012 software (Dassault

Systèmes SolidWorks Corp, Concord, MA, EUA) for geometry simplification and design refinement, sorting the cortical (2mm) and trabecular bone.

The crown cemented onto tooth was modeled using images from a CT scan of a central incisor. The images were transformed into dicom solid models using the InVesalius software (CTI, Campinas, São Paulo, Brazil). All tooth structures (enamel, crown and root dentin, dental pulp, and the periodontal ligament) were included in the solid model. Using the SolidWorks 2012 software, the tooth was reduced to 2.0 mm in thickness on the buccal and lingual surfaces and 3.0 mm in thickness on the incisal surface. The ceramic veneer and framework thickness was 2.0 mm and 0,4 mm (Figure 1).

The crown cemented onto implants was modeled using de same crown cemented onto tooth. The CAD models of the implant (Titamax Ex, 4x13mm, Neodent, Curitiba, Brasil) and prosthetic platform were obtained from the manufacturer (Figure 2).

All crowns were cemented onto the tooth or abutment with resin cement (Panavia, Kuraray, Tokyo, Japan) in a layer 0.09 mm thick.

Material Properties

The CAD models were exported to the Ansys Workbench 14.0 FEA software (Swanson Analysis Inc, Houston, PA, USA) as IGES files. All structures were considered isotropic and homogeneous. Material properties such as elastic modulus and Poisson's ratio were obtained from the literature (Table 1). The mesh was constructed through convergence of analysis (5%) that was determined in all models using a tetrahedral element of 0.8 mm size. The models had 29,665 (C and Cz) and 68,673 (Ci and Czi) elements. The number of nodes were 55,651 (C and Cz) and 121,061 (Ci and Czi) (Figure 3).

Interface conditions

All structures were considered bonded (linear) except the veneer/framework interface. This interface was considered perfectly bonded or with a friction coefficient of 0.3 (Rocha *et al.*, 2011).

Loading and boundary conditions

The models were defined by fixing the mesial and distal exterior surfaces of the bone segment in all directions. The models were loaded using an initial distributed loading of 49 N (Att *et al.*, 2012) applied to the lingual surface at an angle of 45 degrees from the long axis of the tooth followed by an axial load of 25.5 N (Caglar *et al.*, 2009) distributed across the incisor face. The maximum principal stress (σ_{max}), the shear stress (τ_{max}) and deformation (μ_{max}) for the ceramic veneer and the von Mises stress (σ_vM) for the framework were obtained.

RESULTS

The maximum principal stresses (σ_{max}) and shear stresses (τ_{max}) in the ceramic veneer under load are presented in Table 2.

When the veneer/framework bond was incomplete (friction coefficient 0.3) the stress concentration was greater in all structures regardless of the framework material or crown support. The stresses were always located in the region of load application (middle third of the palate and incisal edge of the crown) (Figure 4).

Analogous to the maximum principal stress, the greatest shear stress (162.48 MPa) occurred in the CZI model on the inside of the ceramic veneer near the veneer/framework interface. (Figure 5)

Deformation of the ceramic veneer was greater in models in which the friction coefficient was 0.3 ($C = 0.036$ mm, $C_z = 0.035$ mm, $C_i = 0.042$ mm, and $CZI = 0.042$ mm). In completely bonded models (friction coefficient of 1.0), those mounted on teeth (C and C_z) underwent deformations three times smaller than

poorly-bonded models, while those mounted on implants (Ci and CZI) experienced deformations approximately one-half as great as in poorly-bonded models.

The framework results are depicted in Table 3. Stresses in frameworks cemented to teeth were greater than those in frameworks cemented to implants. This effect was more evident in models with partially debonded between the structures (Figure 6).

DISCUSSION

The ceramic systems widely used to achieve excellence for aesthetic restorations need to be covered by feldspathic ceramic (Lin *et al.*, 2012) in order to decreased the opacity of the framework (Lin *et al.*, 2012).

The use of zirconia as a framework material increases the resistance of metal-free prostheses, however it is clear that failures in the bond between these two materials can reduce clinical success. Several studies have indicated that the primary cause of failure is a weak bond between the veneer and framework that may be the result of the difference in the thermal expansion coefficients (CTEs) of the two materials, and that proper matching of CTEs is essential to prevent failure after firing (Fischer *et al.*, 2009; Fischer *et al.*, 2007; Komine *et al.*, 2010). The incompatibility of CTEs is aggravated by improper burning or rapid cooling due to the low thermal conductivity of zirconia, which can cause tensile stresses in the veneer and eventual failure of the infrastructure/veneer bond.

In our study a failure of the infrastructure/veneer bond was simulated by a frictional contact of 0.3 using the non-linear finite element method. The test finite element has given up due to the impossibility establish the same coefficients for two models in a physical test. This coefficient was previously used, and the study reported a 12-fold increase in stress in ceramic crowns due to poor veneer/structure bonds (Rocha *et al.*, 2011), results similar to our a findings. Assuming a flexural strength for feldspathic porcelain of 40 MPa (Kim *et al.*, 2007),

inadequate bonding can result in stress values greater than the strength of the material.

The flaws propagate a ceramic with a low modulus of elasticity and a low level of resistance to a ceramic with a high modulus of elasticity and a higher resistance (Lecturer and Prostodoncia, 2012) which refers us to observe that higher values of stress were always found ceramics coverage with lower levels of tension in the infrastructure regardless of the material used. Beside this, studies have shown that a thin layer of ceramic veneer fired upon a material of framework significantly reduces the resistance of the bilayer crown. Although the critical load for the fracture is strongly influenced by the total thickness of the crown and is much less dependent on the veneer/core thickness of ceramic, porcelain veneer is still likely to be the weakest link compromising the strength of the whole two-layer system (Lin *et al.*, 2012).

From a qualitative perspective, the stresses were concentrated at the location of the applied load and the stress distributions appeared similar. The coefficient of friction affected the magnitude of the stress on the crown but did not modify the behavior stress distribution (Figure 1) (Rocha *et al.*, 2011).

The shear stress between the veneer and framework was calculated in order to evaluate the effect of varying the coefficient of friction at the interface between the two structures. Increasing the friction between the materials permitted tangential micro detachment, increasing the stress concentration compared to a perfectly bonded interface (Taskonak *et al.*, 2008). Similar behavior was observed in the offset values for the veneer, which increased 3-4-fold in models with less effective bonding.

The metal-ceramic prostheses with complete bond exhibited higher stress values, similar to the compression test results of Lecturer (2012). However, zirconia restorations can fracture under less stress and at greater frequency than metal-based restorations due to poor bonding between the framework and veneer (Silva *et al.*, 2012). The regions of stress concentration were similar for all applied loads and materials, in agreement with previous studies (Rocha *et al.*, 2011).

Frameworks cemented on implants exhibited higher stress concentrations due to the high elastic moduli of the implant and prosthetic compared to natural teeth (Burak Özcelik *et al.*, 2011), which have a periodontal ligament act to improve the distribution of stresses arising from occlusal forces. However, it was observed a high stress concentration in frameworks cemented on natural teeth. This may be explained by the model geometry, in which teeth were modeled with an average thickness of 0.4 mm and framework cemented on implants was described as a solid body, which may have significantly reduced stresses. Other study comparing different thicknesses of framework would be beneficial in confirming the stress concentrations in thinner structures and the real role of the periodontal ligament in stress distribution. It should be noted that the non-linearity increased tensile stresses in the framework but that the increased stresses were not sufficient to compromise the strength of the materials (Borba *et al.*, 2011).

Finally, attention should be paid to the fact that our methodology focused only on static analysis, and other studies of factors such as thermal and mechanical fatigue are required to explain the observations that differed from previous investigations of the resistance of prostheses employing zirconia frameworks.

Is important to explain that the simulated failures through the nonlinear analysis by finite element method are failures that can occur at the interface between the two materials, such as pore formation or blisters. And these failures can be minimized by establishing correct the heating and cooling ceramics cycle and by following the manufacturer instructions.

CONCLUSION

Within the limitations of the study, it was concluded that the bond integrity between the ceramic veneer and framework affects the mechanical performance of the ceramic veneer, independent of the framework material or crown support used.

Table 1: Mechanical properties of the materials. Elastic modulus (E) and Poisson's ratio (ν).

Materials	Elastic modulus (E) (Gpa)	Poisson's ratio (ν)	Reference
PALLADIUM/SILVER	95	0.33	(Cruz <i>et al.</i> , 2009)
CERAMIC VENEER	70	0.19	(Coelho <i>et al.</i> , 2009)
ZIRCONIA	205	0.22	(Coelho <i>et al.</i> , 2009)
DENTIN	20	0.31	(Dejak and Mlotkowski, 2008)
PULP	0.002	0.45	(Lin <i>et al.</i> , 2001)
PERIODONTAL LIGAMENT	0.0689	0.45	(Asmussen <i>et al.</i> , 2005)
RESIN CEMENT	18.3	0.33	(Li-li <i>et al.</i> , 2006)
CORTICAL BONE	13.6	0.26	(Cruz <i>et al.</i> , 2009)
TRABECULAR BONE	1.36	0.31	(Cruz <i>et al.</i> , 2009)
IMPLANT (TI)	110	0.33	(Cruz <i>et al.</i> , 2009)

Table 2: Maximum Principal Stress ($\sigma_{\max}$) and the Shear Stress ($\tau_{\max}$) for ceramic veneer.

Model	FriccionAl Coeficient	Maximum Principal Stress (Mpa)	Shear Stress (MPa)
C	0.3	602.06	140.22
	1.0	35.464	7.2781
CZ	0.3	674.48	159.39
	1.0	33.374	6.9906
CI	0.3	346.12	152.93
	1.0	41.281	7.1687
CZI	0.3	355.91	162.48
	1.0	40.619	7.086

Table 3: von Mises (σ_vM) stress for frameworks.

MODEL	FRICCIONAL COEFICIENT	VON MISES STRESS (ΣVM)
C	0.3	868,03
	1.0	18,63
CZ	0.3	1050,3
	1.0	25,469
CI	0.3	167,23
	1.0	17,283
CZI	0.3	182,88
	1.0	25,118

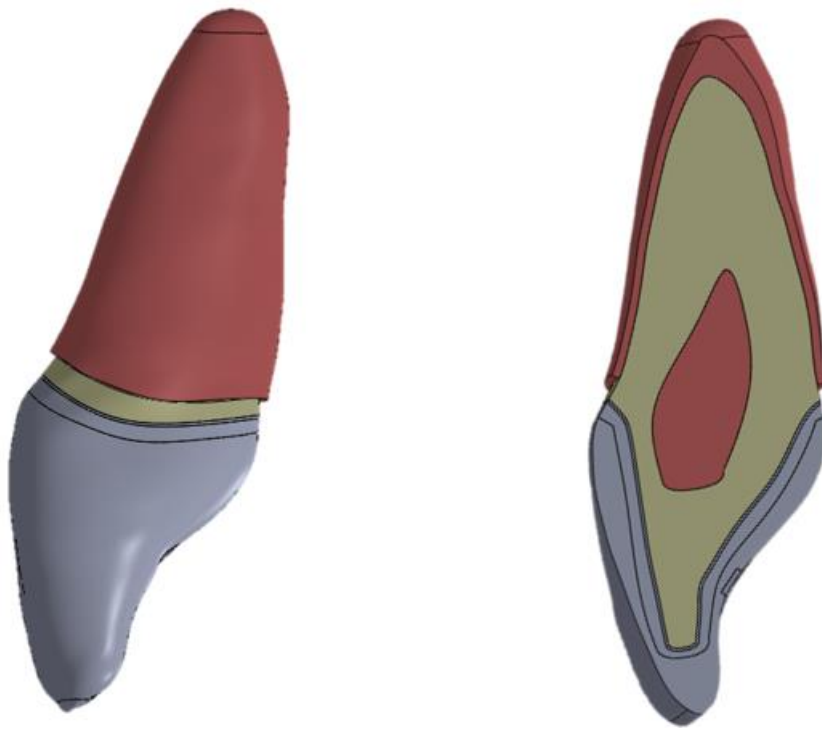


Figure 1: Tooth model with ceramic veneer and framework, cement layer, dentin, dental pulp, and the periodontal ligament



Figure 2: Implant model with ceramic veneer and framework, abutment, cement layer, screw and implant.

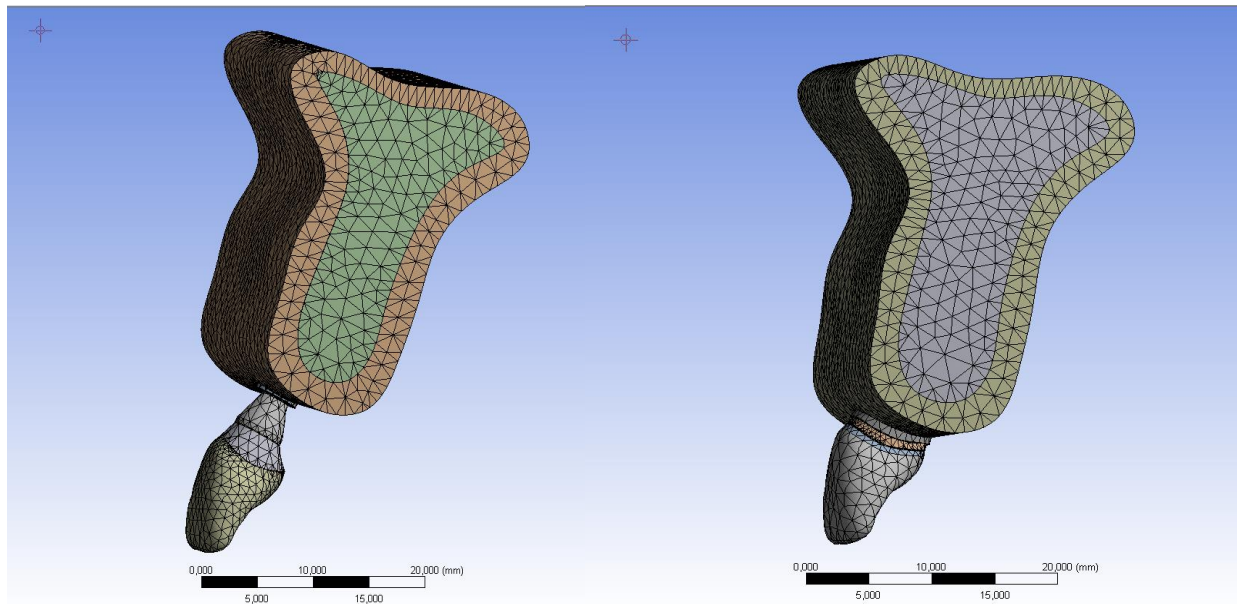


Figure 3: The models using a tetrahedral element of 0.8 mm size.

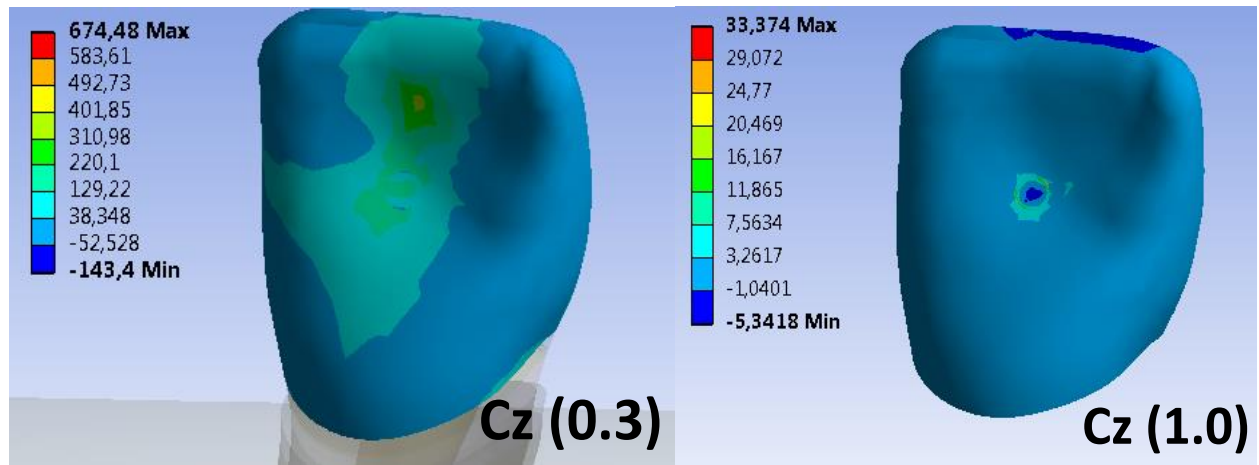


Figure 4: Maximum Principal Stress distribution at ceramic veneer.

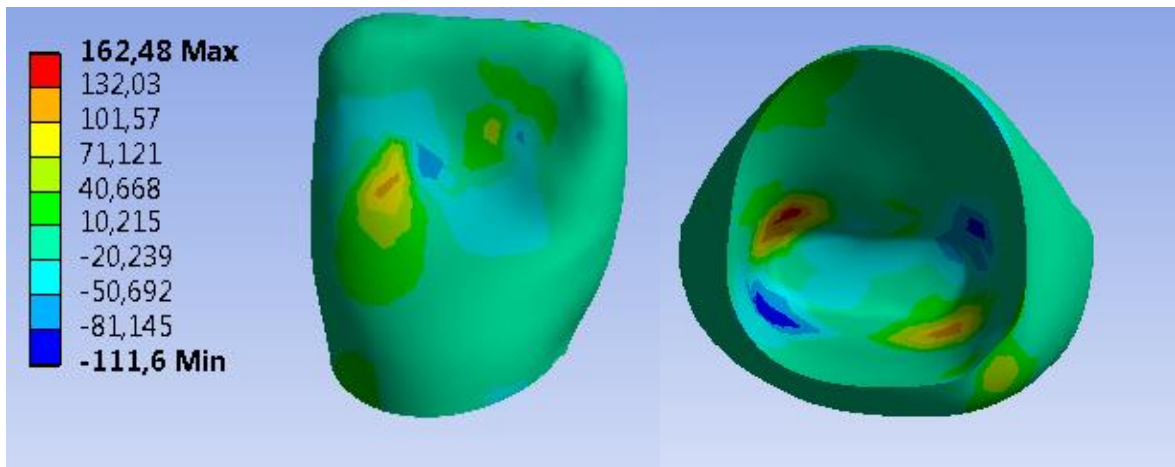


Figure 5: Shear Stress (MPa) for Czi model was located at internal interface ceramic veneer/framework.

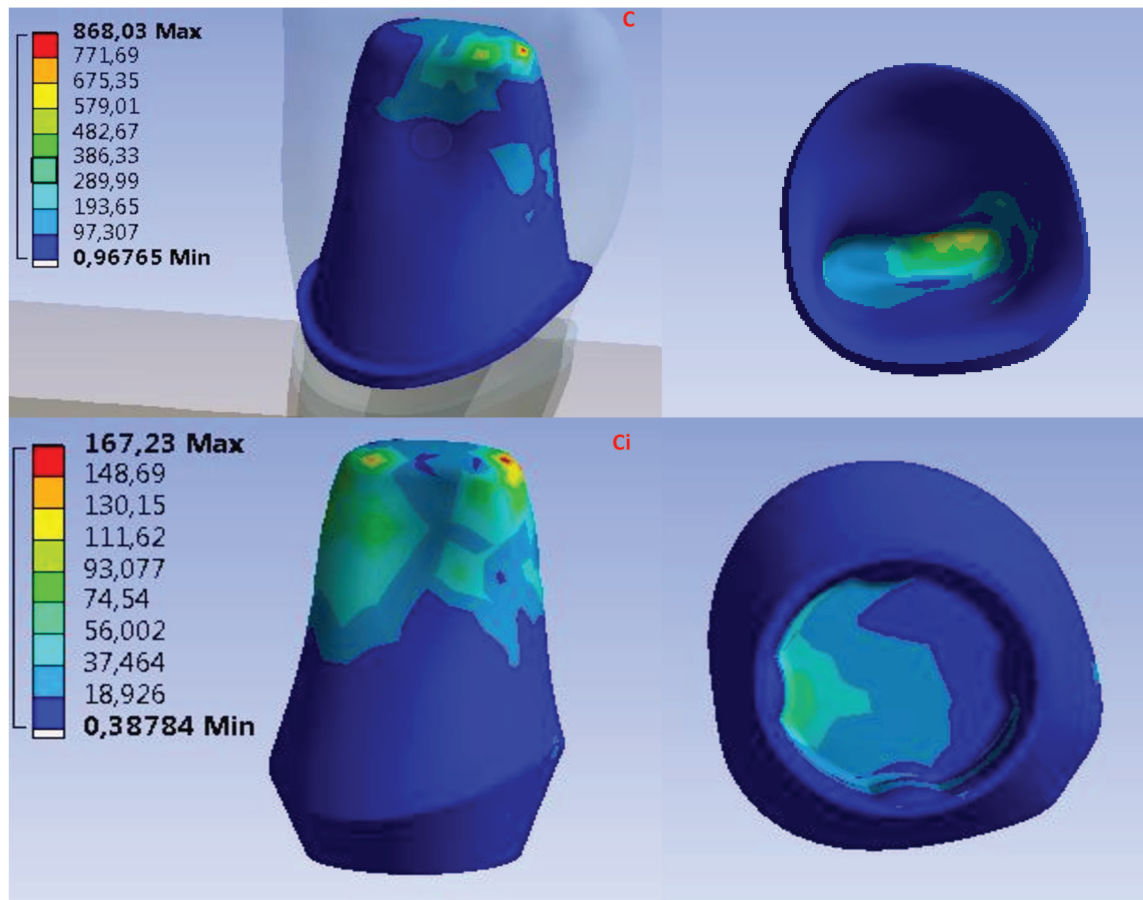


Figure 6: von Mises stress (σ_M) for the framework with frictional coefficient 0.3.

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CONCLUSÃO

Dentro das limitações do estudo, podemos concluir que a união deficiente entre a cerâmica de cobertura e a infraestrutura da prótese pode afetar a performance mecânica da cerâmica de cobertura, tornando-a susceptível a falhas independente do material usado como infraestrutura ou do suporte da coroa total.

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APÊNDICE 1 – Ilustrações de Materiais e Métodos

1. Construção do modelo tridimensional da maxila:

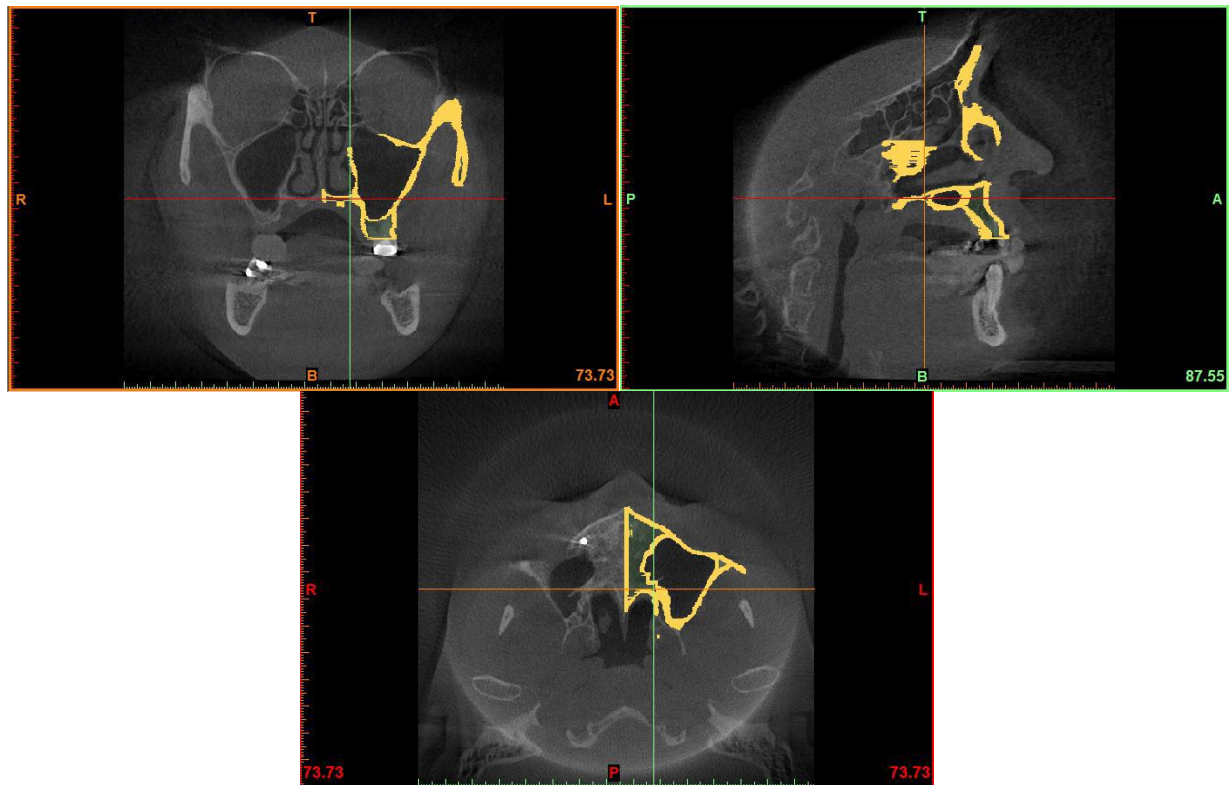


Figura 1: Imagens de tomografia computadorizada de um paciente desdentado total superior. Os cortes tomográficos foram importados para o *software* Mimics, onde foram classificados de acordo com a densidade do osso em graus de cinza.

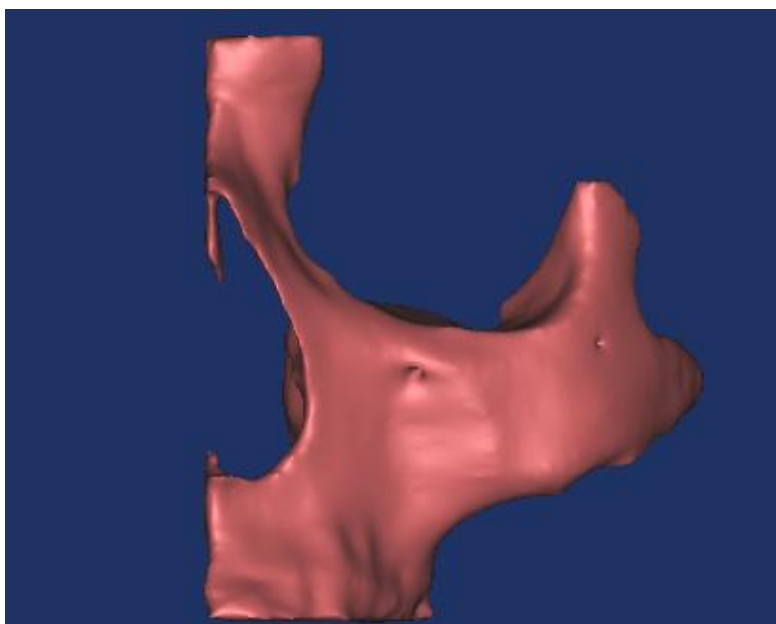


Figura 2: Primeira reconstrução da maxila até o osso zigomático utilizando o *software* Mimics.

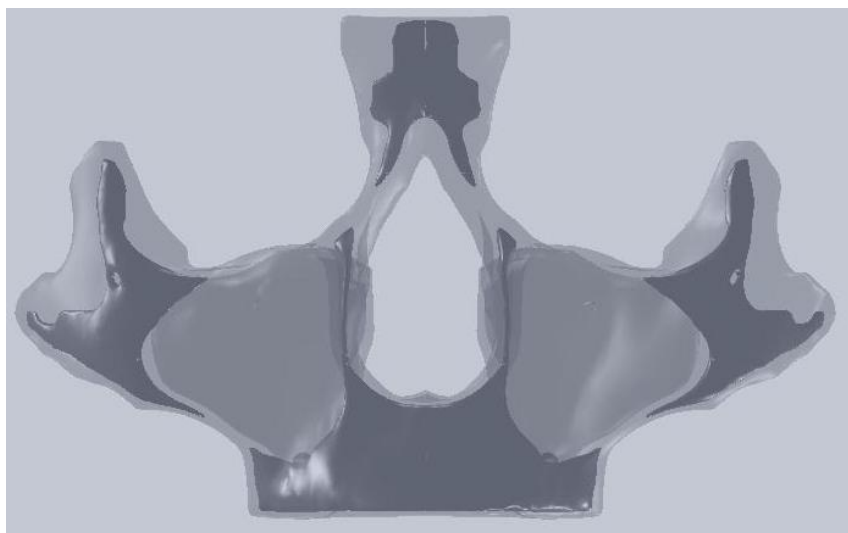


Figura 3: O modelo inicial foi exportado para o *software* SolidWorks (SOLIDWORKS 2009, SOLIDWORKS CORPORATION, MA, EUA) a fim de que o modelo final apresentasse osso cortical e medular.

2. Construção dos modelos tridimensionais do dente:

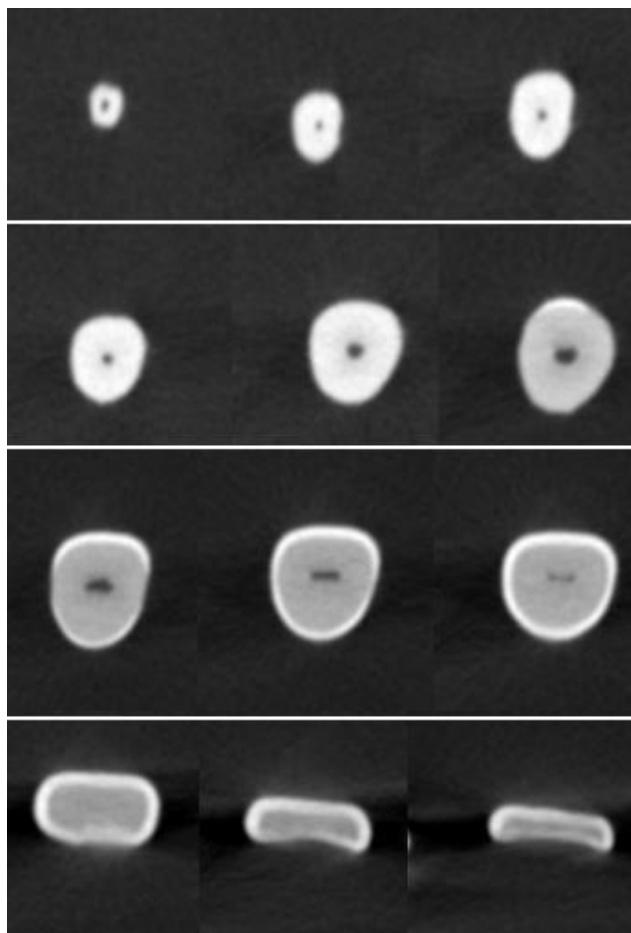


Figura 4: Sequência de imagens da microtomografia computadorizada (Tomógrafo Computadorizado de Feixe Cônico – KODAK 9000 3D) de um incisivo central hígido.

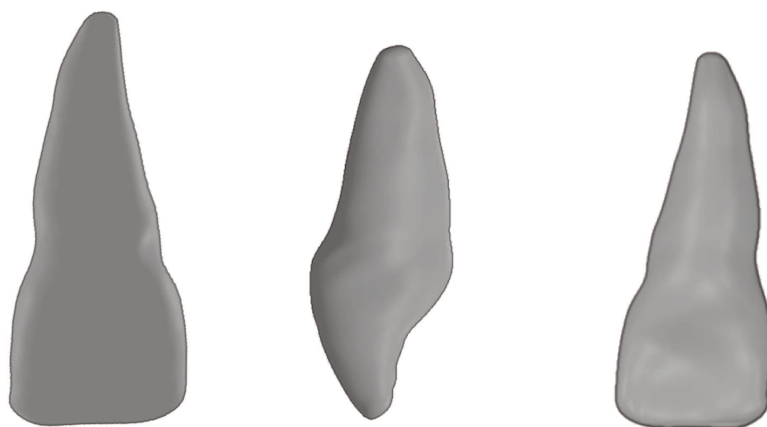


Figura 05: As imagens DICOM foram importadas para o *software* InVesalius (CTI – Renato Archer) para a reconstrução tridimensional.

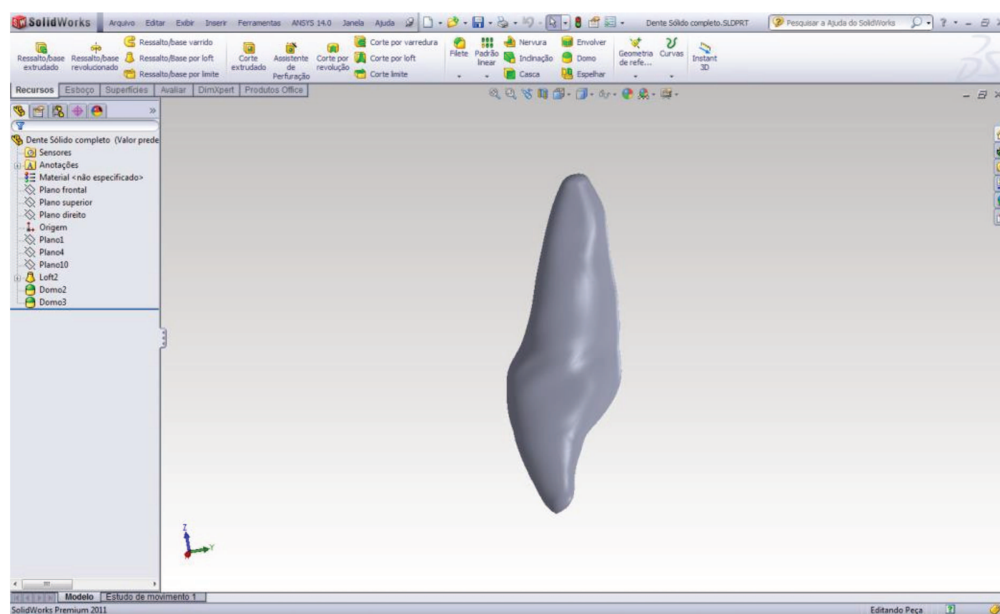


Figura 06: Interface do *software* SolidWorks utilizado para alteração dos modelos tridimensionais.

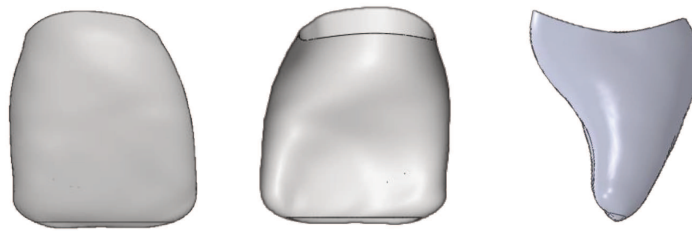


Figura 07: Modelagem das estruturas do dente. Vista vestibular, palatina e proximal do esmalte dental.

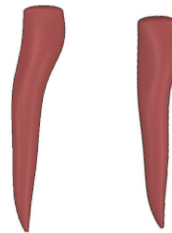


Figura 08: Vista proximal e vestibular da polpa dental.

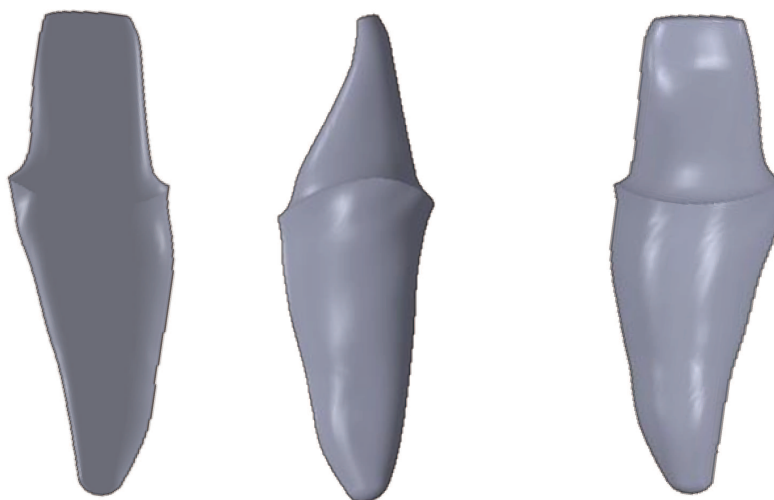


Figura 09: Vista vestibular, proximal e palatina do preparo para coroa total no incisivo central.

3. Modelos disponibilizados pela empresa Neodente.



Figura 10: Implante unitário cone morse (Titamax Ex, 4x13mm, Neodent, Curitiba, Brasil) e seu respectivo componente protético.

4. Montagem dos Modelos:

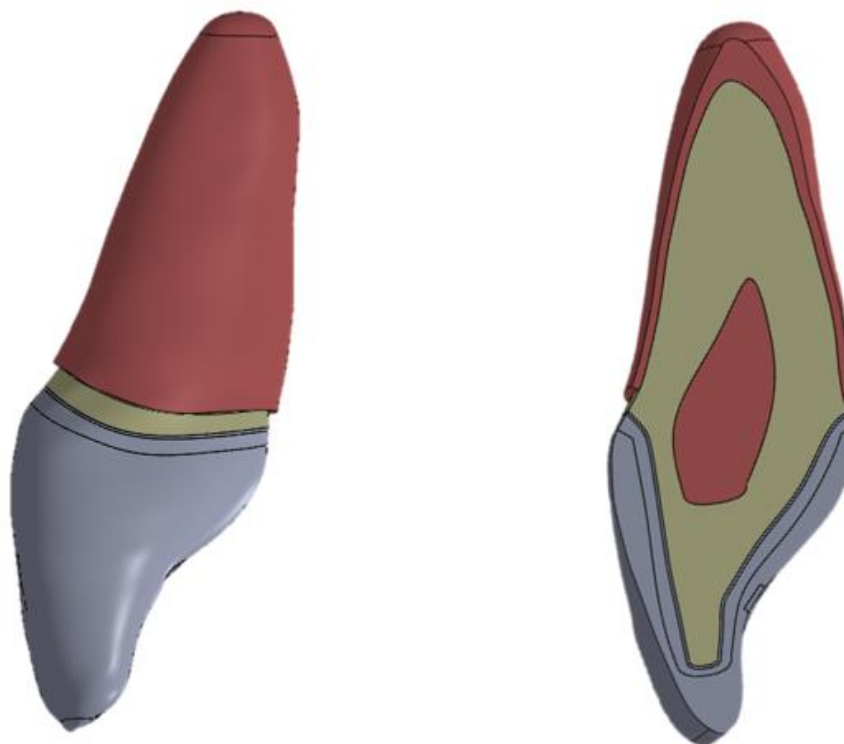


Figura 11: Modelo da coroa total cimentada sobre dente.

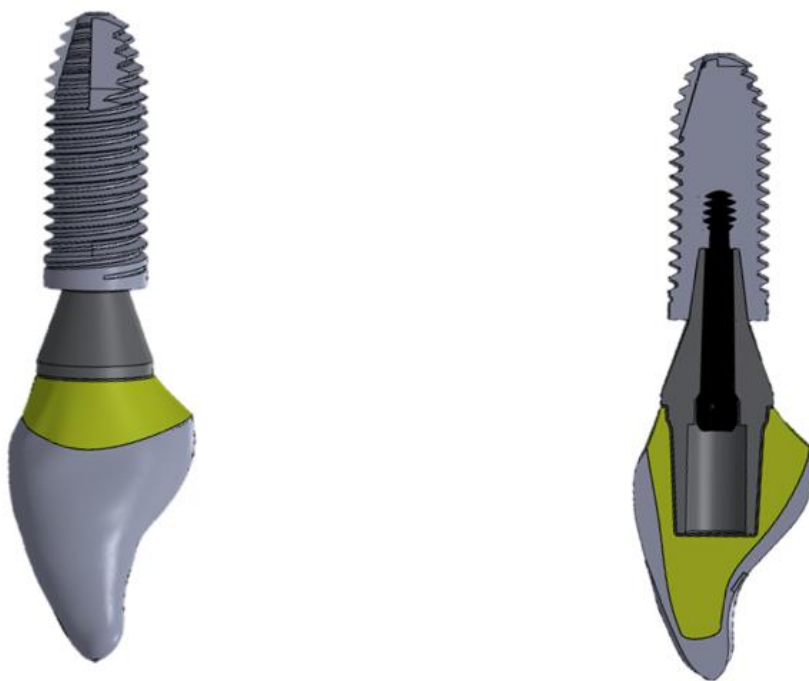


Figura 12: Modelos da coroa total cimentada sobre implante.

5. Análise pelo Método dos Elementos Finitos:

5.1. Confeção da malha.

Tabela 1: Número de elementos e nós de cada modelo

	Coroa total sobre dente	Coroa total sobre implante
Elementos	29665	68673
Nós	55651	121061

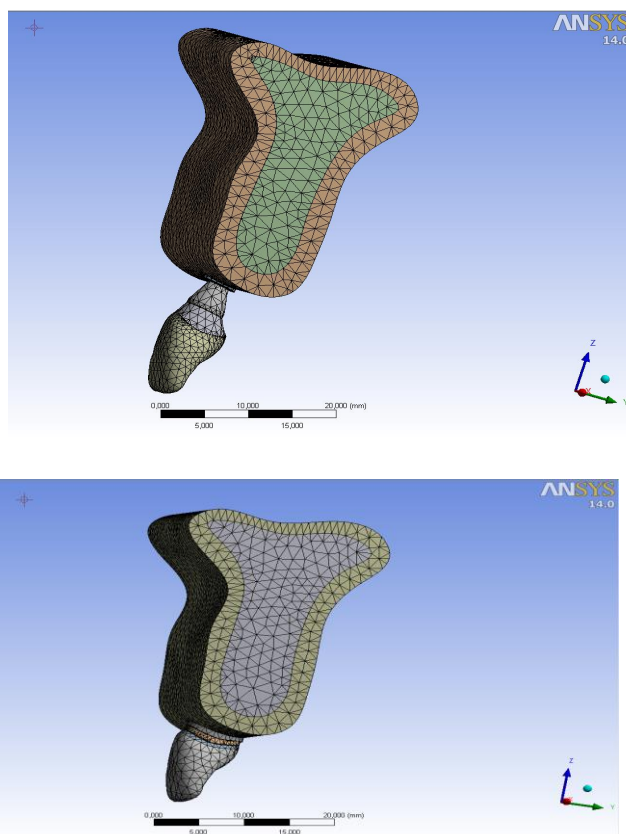


Figura 13: Confeção da malha através da convergência de análise à 5% determinada por elementos tetraédricos de 0,8 mm.

5.1: Carregamento

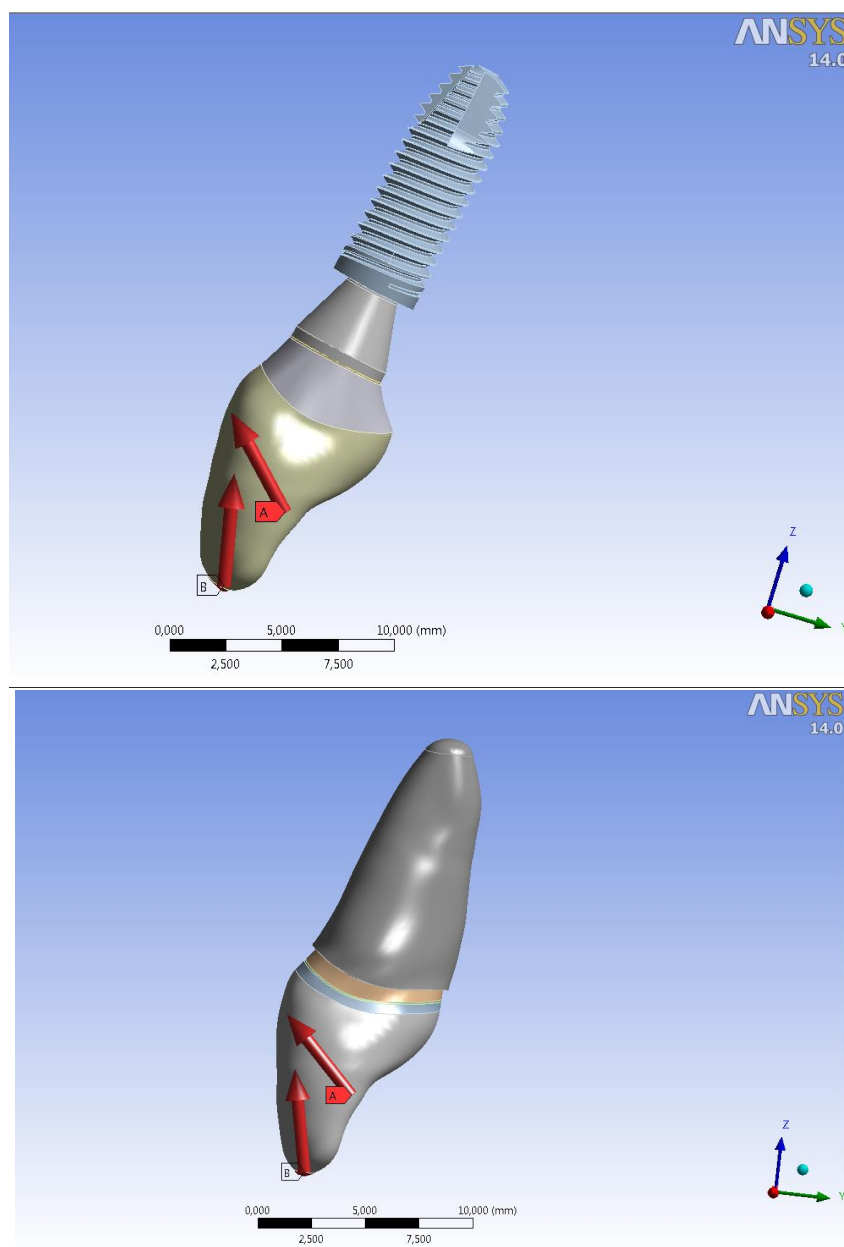


Figura 14: Carregamento realizado em 2 *steps*: 49N aplicado obliquamente (45°) no terço incisal da face palatina da coroa total e 25,5N aplicado perpendicularmente na face incisal da coroa total.

ANEXO 1

Fw: Submission Confirmation

De: **Profa. Altair A. Del Bel Cury** (altcury@fop.unicamp.br) Este remetente está na [lista de contatos](#).
Enviada: sexta-feira, 2 de agosto de 2013 14:02:23
Para: Bruno (brunosottomaior@gmail.com); Priscilla Cardoso Lazzari (pri_lazzari@hotmail.com)
1 anexo
Submission Confirmation.eml (2,8 KB)

--Anexo de Mensagem Encaminhado--
From: JPD@gru.edu
To: altcury@fop.unicamp.br
Date: Fri, 2 Aug 2013 15:45:41 +0100
Subject: Submission Confirmation

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