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Gabriel Felipe de Bragança

Efeito dos materiais de cimentação, presença de preparo dental e carregamento funcional na distribuição de tensões em laminados cerâmicos: Análise por elementos finitos

Effect of luting materials, presence of tooth preparation and functional loading on stress distribution on ceramic laminate veneers: Finite element analysis

Dissertação apresentada à Faculdade de Odontologia da Universidade Federal de Uberlândia como requisito parcial para obtenção do Título de Mestre em Odontologia na área de Clínica Odontológica Integrada.

Uberlândia, 2019

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Orientador: Prof. Dr. Carlos José Soares

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Prof. Dr. Carlos José Soares
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Uberlândia, 2019

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Título do Trabalho: ***Effect of luting materials, presence of tooth preparation and functional loading on stress distribution on ceramic laminate veneers: Finite element analysis***

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As **quatorze horas** do dia **vinte e cinco de fevereiro de 2019** no Anfiteatro Bloco 4L Anexo A, sala 23 Campus Umuarama da Universidade Federal de Uberlândia, reuniu-se a Banca Examinadora, designada pelo Colegiado do Programa de Pós-graduação em janeiro de 2019, assim composta: Professores Doutores: Murilo de Sousa Menezes (UFU); Crisnicaw Veríssimo (UFG); e o orientador(a) do(a) candidato(a): **Carlos José Soares.**

Iniciando os trabalhos o(a) presidente da mesa **Dr. Carlos José Soares** apresentou a Comissão Examinadora e o candidato(a), agradeceu a presença do público, e concedeu ao Discente a palavra para a exposição do seu trabalho. A duração da apresentação do Discente e o tempo de argüição e resposta foram conforme as normas do Programa.

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“Faça o teu melhor, na condição que você tem, enquanto você não tem condições melhores, para fazer melhor ainda”.

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SUMÁRIO

RESUMO

RESUMO

O objetivo deste estudo foi avaliar o efeito da contração de polimerização, carregamento funcional e propriedades mecânicas de diferentes materiais de cimentação nas tensões de contração e tensões residuais em laminados cerâmicos (CLV) ultrafinos de 0,3 mm com e sem preparo dental. Três cimentos resinosos: RelyX Veneer (RV, 3M ESPE), Allcem Veneer APS (AV, FGM), Variolink Esthetic LC (VE, Ivoclar Vivadent) e uma resina composta fluída: Tetric N-Flow (TF, Ivoclar Vivadent) foram testados. Foram realizados testes para mensurar a contração pós-gel (Shr), dureza Knoop (KHN), módulo de elasticidade (E), compressão axial (CS) e tração diametral (DTS). Análise por elementos finitos foi realizada utilizando como parâmetro o critério de von Mises modificado (mvm) Discos de cerâmica reforçada por dissilicato de lítio (IPS e.max CAD) foram feitos para simular os efeitos de atenuação de luz. Oito modelos de elementos finitos bidimensionais (Marc-Mentat, MSC Software) de incisivo central superior foram gerados para avaliar as tensões de contração durante a fotoativação de diferentes materiais de cimentação para CLVs ultrafinos de 0,3 mm com e sem preparo dental e tensões durante carregamento funcional. Dados coletados de Shr, KHN e E foram testados por ANOVA 2 fatores e teste de Tukey (α=0,05). TF apresentou menor contração volumétrica pós-gel quando a cerâmica foi interposta (0,31%). TF e RV mostraram maiores e VE menor valor de KHN e E na presença de cerâmica (P>0,05). Ambas situações de preparo dental apresentaram distribuição de tensões similares quando avaliados contração e carregamento funcional apresentando aumento na concentração de tensões na borda incisal para ambos e também na região cervical para os modelos com preparo dental com cimento RV apresentando maiores e VE menores valores de tensão (MPa). Resina fluída apresentou propriedades mecânicas similares aos cimentos resinosos. A distribuição de tensão na contração e carregamento funcional foi similar para ambas técnicas com e sem preparo dental.

PALAVRAS-CHAVE: laminados dentários, cimentos resinosos, análise por elementos finitos, oclusão dentária, materiais dentários

Abstract

ABSTRACT

The purpose of this study was to evaluate the effect of the polymerization shrinkage, functional loading and mechanical properties of luting materials on the shrinkage stress and residual occlusal stress of ultrathin 0.3-mm ceramic laminate veneers (CLVs) with and without tooth preparation. Three resin cements: RelyX Veneer (RV, 3M ESPE), Allcem Veneer APS (AV, FGM), Variolink Esthetic LC (VE, Ivoclar Vivadent), and one flowable resin composite: Tetric N-Flow (TF, Ivoclar Vivadent) were tested. Post-gel shrinkage (Shr), Knoop hardness (KHN), elastic modulus (E), compressive strength (CS) and diametral tensile strength (DTS) were performed. Finite element analysis was performed using modified von Mises criterion (mvm). IPS e.max CAD discs 0.3-mm thick were made for simulating the effects of light attenuation. Eight two-dimensional finite element models (Marc-Mentat, MSC Software) of a maxillary central incisor were generated to evaluate the shrinkage stress during the light-activation of luting materials and the residual stress during functional loading. Data of Shr, KHN and E were submitted to 2-way ANOVA and Tukey test (α=.05). TF had lower Shr when interposing ceramic disc (0.31%). TF and RV showed the highest and VE the lowest KHN and E values (*P*>.05). Veneers with or without preparation showed similar shrinkage stress and functional residual stress. Stress concentration was observed on the incisal edge and also on cervical region. Models with RV presented the highest and VE the lowest stresses values (MPa). Flowable composite had similar mechanical properties than resin cements. The shrinkage and functional residual stresses were similar for veneer with or without tooth preparation.

KEYWORDS: dental cements, tooth preparation, dental stress analysis, dental veneers, finite element analysis

Introdução e Referencial teórico

1. INTRODUÇÃO E REFERENCIAL TEÓRICO

A realização de procedimentos restauradores tem crescido nas últimas décadas. Laminados cerâmicos foram introduzidos na odontologia na década de 80 (Horn, 1983; Calamia, 1983) e vem ganhando popularidade nos últimos anos com a crescente demanda estética do sorriso. Estas restaurações cerâmicas são construídas em espessura finas, podendo variar desde 0,1 mm (Friedman, 1991), a 0,5 mm denominadas de laminados cerâmicos ultrafinos (Strassler, 2007) e até 1,0 mm de espessura (Friedman, 1991; Strassler, 2007). Laminados cerâmicos têm basicamente três tipos de indicações (Belser *et al.,* 1997): Tipo 1 – Dentes resistentes ao clareamento: manchamento por tetraciclina, traumatismo dentoalveolar, restaurações antigas que não são submetidas ao processo de clareamento; Tipo 2 – Alterações morfológicas: dentes conoides, diastemas ou dentes curtos; Tipo 3 – Perda extensa de estrutura: fratura coronal extensa, distúrbios de desenvolvimento como amelogênese imperfeita.

Com o avanço da tecnologia, melhora dos sistemas de adesão, dos materiais de cimentação, das cerâmicas odontológicas, do processo de confecção e utilização de protocolos adequados por parte de Cirurgiões-Dentistas e técnicos em prótese dentária, existe a possibilidade de confecção destes laminados cerâmicos realizando mínimo preparo dental para estabilização da peça cerâmica (Sampaio *et al.,* 2017) ou até mesmo sem realização de nenhum preparo dental (Gurel *et al.,* 2013; Alavi *et al.,* 2017). No entanto, quando não é realizado preparo da estrutura dental, são necessários mais cuidados no processo de acabamento e polimento, pois na ausência destes alguns problemas clínicos como a dificuldade de obtenção de transição suave entre cerâmica e estrutura dental, deficiência na forma e estética natural, sobrecontornos que podem gerar acúmulo de biofilme, inflamação gengival, cáries na região marginal, além do risco de trincas e fraturas de margem de cerâmica que podem ocorrer. Com a fina espessura, gera-se ainda o risco de trincas durante o processo de fotoativação dos materiais de cimentação, em que alguns destes aspectos são minimizados quando se realiza a confecção de laminados cerâmicos com preparos (Zarone *et al.,* 2018).

Laminados cerâmicos são geralmente cimentados com cimentos resinosos fotoativados por conta do controle de tempo de trabalho, o que facilita a remoção de excessos. Nesse grupo de materiais com ausência de aminas terciárias, ganha-se com a estabilidade de cor, minimizando a interferência de cor com o processo de envelhecimento na boca (Ural *et al.,* 2016). Dentre os cimentos resinosos fotoativados existe ampla variedade de cores e cimentos de provas denominados "try-in", que permitem o teste de cor da restauração em boca previamente ao processo de cimentação (Archegas *et al.,* 2011). Porém, aproveitando as vantagens de resinas compostas e seu menor custo, existe a possibilidade de cimentação de laminados cerâmicos utilizando resinas compostas fluídas, que apresentam boa estabilidade de cor (Archegas *et al.,* 2012), contração de polimerização e espessura de filme similares aos cimentos resinosos (Sampaio *et al.,* 2017).

Frente ao procedimento adesivo realizado com materiais de cimentação que são materiais poliméricos, o conceito de contração de polimerização é inerente e importante de ser analisado (Soares *et al.,* 2017). Materiais resinosos, quer seja resinas compostas fluidas ou cimentos resinosos, são materiais viscosos que com a ativação pela luz, há o desencadeamento do processo de polimerização, e com ele a vitrificação ou o desenvolvimento do módulo de elasticidade do material (Anusavice *et al.,* 2013). Para a formação de cadeias poliméricas, ocorre a aproximação de moléculas e a redução de volume que gera a contração de polimerização. Quando existe a contração, e o material está aderido a uma estrutura, tensões de contração são geradas no interior das estruturas e nas interfaces. A tensão causada pela contração pós-gel é diretamente proporcional a alteração dimensional e ao módulo de elasticidade do material que é utilizado. Quando existe a adesão, qualquer alteração dimensional do compósito será transferida para a estrutura dental na qual está aderido, causando tensões residuais, neste caso proveniente da contração do material, então chamada de tensões de contração (Soares *et al.,* 2013). Estas tensões podem se concentrar na interface adesiva (Peumans *et al.,* 1999), no material de cimentação (May & Kelly, 2013). Tensões de contração podem gerar microinfiltração (Haralur, 2018), trincas no material cerâmico (Cao *et al.,* 2017) e sensibilidade pós-operatória (Gresnigt *et al.,* 2012). Tensões não são possíveis de se medir experimentalmente e nem clinicamente. Para avaliar tensões o método de elementos finitos tem sido amplamente utilizado na Odontologia, por meio de modelos bidimensionais ou tridimensionais (Rosatto *et al.,* 2015; Soares *et al.,* 2016; Soares *et al.,* 2017).

Neste aspecto, poucos estudos foram encontrados sobre a avaliação de tensões em laminados cerâmicos (Zarone *et al.,* 2005; Liu *et al.,* 2009; Li *et al.,* 2014; Ustun *et al.,* 2018) quer seja modulado pela espessura do material cerâmico ou pelo tipo de material de cimentação. No conhecimento dos autores deste estudo, não foi encontrado estudo que avalie a influência das tensões de contração e tensões residuais frente a carregamento funcional em laminados cerâmicos realizados com e sem preparo dental utilizando diferentes materiais de cimentação. Portanto, se faz importante a busca pelas respostas sobre a utilização de diferentes materiais de cimentação para laminados cerâmicos ultrafinos e da distribuição de tensões quando realizado com mínimo preparo dental comparando com a técnica sem preparo dental, tendo em vista os aspectos clínicos mencionados anteriormente.

Capítulo

2. CAPÍTULO 1

ARTIGO 1

Effect of luting materials, presence of tooth preparation and functional loading on stress distribution on ceramic laminate veneers: Finite element analysis

***Artigo a ser enviado para o periódico The Journal of Prosthetic Dentistry**

Effect of luting materials, presence of tooth preparation and functional loading on stress distribution on ceramic laminate veneers: Finite element analysis

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Effect of luting materials, presence of tooth preparation and functional loading on stress distribution on ceramic laminate veneers: Finite element analysis

ABSTRACT

Statement of problem. It is unclear how the polymerization shrinkage, functional loading and mechanical properties of luting materials affect the shrinkage and residual stresses of ceramic laminate veneers (CLVs) with and without tooth preparation.

Purpose. The purpose of this study was to evaluate the effect of the polymerization shrinkage, functional loading and mechanical properties of different luting materials on the shrinkage stress and residual occlusal stress of ultrathin 0.3-mm CLVs with and without tooth preparation.

Material and methods. Three resin cements: RelyX Veneer (RV), Allcem Veneer APS (AV), Variolink Esthetic LC (VE), and one flowable resin composite: Tetric N-Flow (TF) were tested for post-gel shrinkage (Shr) using strain-gauge test, Knoop hardness (KHN) and Elastic modulus (E) using hardness indentation, compressive strength (CS) and diametral tensile strength (DTS). IPS e.max CAD discs 0.3-mm thick were made for simulating the effects of light attenuation. Eight two-dimensional finite element models (Marc-Mentat, MSC Software) of a maxillary central incisor were generated to evaluate the shrinkage stress during the light-activated polymerization of different materials for luting ultrathin 0.3-mm CLVs with or without tooth preparation and the stress during functional loading. Results were evaluated by modified von Mises criterion (mvm). Collected data from Shr, KHN and E were submitted to 2-way ANOVA and Tukey test (α=.05).

Results. TF had lower volumetric post-gel shrinkage (%) when interposing ceramic disc (0.31%). TF and RV showed the highest and VE the lowest KHN and E values with the

presence of ceramic (*P*>.05). Both situation of tooth preparation showed similar stress distribution for shrinkage or functional loading with increased stress concentration on the incisal edge and also on cervical for tooth preparation models with RV presenting the highest and VE the lowest stresses values (MPa).

Conclusions. Flowable composite had similar mechanical properties than resin cements. The stress distribution from shrinkage and functional loading was similar for both techniques with or without tooth preparation.

CLINICAL IMPLICATIONS

Flowable composites and resin cements could be used to luting ceramic laminate veneers. Due to many clinical complications that can be occur on no preparation technique, minimal tooth preparation should be recommended since this technique do not increase significantly stress concentration.

INTRODUCTION

The expectation for harmonic and esthetic smiles has been increasing in contemporary dentistry. Anterior teeth color and shape alteration associated with oral health deficiency, reflect on the self-esteem and consequently on social aspects of patients.[1] Some advances in dental technology and ceramics led to the possibility of esthetic treatments with minimal[2] or without any tooth preparation.[3,4] Minimally invasive or unprepared veneers are usually made in ultrathin thickness of 0.3-0.5 mm[5], which have been increasingly used due the improved digital workflow in CAD/CAM systems[6] and industrially fabricated ceramic blocks.[7]

The clinical success rate for ceramic veneers after 15 years has been reported around 93%.[8] The long-term prognosis of the ceramic laminates is influenced by several factors such as tooth surface, ceramic thickness, cementation material, tooth preparation[9], and parafunctional habits.[10] Failures in CLVs have been related to micro-cracks and fracture of ceramic or tooth structure, microleakage, debonding of ceramic to the tooth preparation, periodontal problems and esthetic dissatisfaction.[9, 11, 12, 13] The veneers without tooth preparation requires more careful and skills on finishing and polishing due to difficulty in obtaining a natural shape, smooth transition, avoiding detrimental and overhangs. Furthermore, the thin margins are exposed to high risk of failure by chipping at dental office and dental laboratory, besides the high risk of cracking due to shrinkage during the light polymerization of luting materials.[14] A careful evaluation of the occlusal contacts is always considered necessary and essential to guarantee longevity for the restorative procedures.[15]

Ceramic veneers are usually cemented by using light-activated resin cements since they present longer working time, which facilitates the removal of excesses, improved color stability, and also due the availability of try-in systems.[16] To take advantage of the properties of composite resins and their cost-effectiveness compared with resin cements, some clinicians have used flowable resin composites to cement CLVs, however the absence of try-in has to be considered.[17, 18] The use of flowable resin composites in this technique has shown proper color stability[16], with similar polymerization shrinkage and film thickness to resin cements.[2]

Polymerization shrinkage stress is still an important concern during the light-activation of the resin-based materials.[19, 20, 21] Polymerization shrinkage of the luting resin cement may create stress concentration at the ceramic, tooth structure and interfaces.[22] Concentration of tensile stress is observed at the margins of ceramic veneers[23], which may lead to marginal gap with consequent marginal staining, microleakage[24], microcracks[15], and postoperative sensitivity.[25] Stress and strain generated during the functional mandibular movements in the incisal edge may interfere in the performance of CLVs. Finite element analysis has become a great valuable tool when examining the magnitude and distribution of shrinkage stresses using two or three-dimensional models.[26, 27, 19] Few studies have evaluated the stresses in ceramic veneers[28, 29, 30, 31, 32]. However, in the knowledge of the authors of this study, none associating the interaction of the polymerization shrinkage stress and residual stresses caused by functional loading in ultrathin CLVs in teeth with and without preparation.

Therefore, the aim of this study was to evaluate the effect of light attenuation caused by ceramic interposition on mechanical properties of luting materials and the shrinkage and residual stresses by functional loading on tooth restored with ultrathin 0.3-mm CLV with and without tooth preparation. The null hypotheses tested were that: 1 – The mechanical properties would not be affected by light attenuation caused by ceramic interposition; 2 - The stress distribution on tooth restored with CLV would not be affected by different luting materials, tooth preparation and functional loading with antagonist tooth.

MATERIAL AND METHODS

In order to simulate the effect of the CLV on light transmittance during light-activated polymerization which may affect the mechanical properties of the cementation materials, IPS e.max CAD (Ivoclar Vivadent, Schaan, Liechtenstein) HT/A1/C14 ceramic blocks were cut in 0.3-mm thick slices using a precision saw (Isomet 1000, Buehler, Lake Bluff, IL, USA), crystallized in dental furnace (Programat EP 3010, Ivoclar Vivadent, Schaan, Liechtenstein). Then, the ceramic discs were interposed between the light curing unit and the cementation materials on tests.

Four cementation materials including three resin cements (RelyX Veneer, 3M-ESPE, St. Paul, MN, USA; Allcem Veneer APS, FGM, Joinville, SC, Brazil; Variolink Esthetic LC, Ivoclar Vivadent, Schaan, Liechtenstein) and one flowable resin composite (Tetric N-Flow, Ivoclar Vivadent, Schaan, Liechtenstein) were tested in this study. The information about the luting materials are shown on Table 1. All luting materials were tested for post-gel shrinkage (Shr), Knoop hardness (KHN) and Elastic modulus (E). Compressive strength (CS) and diametral tensile strength (DTS) were tested and used to determine the modified von Mises stresses (mvm) by finite element analysis.

Light transmittance test was performed using MARC Resin Calibrator (BlueLight Analytics, Halifax, NS, Canada) was made to evaluate irradiance and spectrum of light curing unit with 1400 mW/cm² LED (Bluephase G2, Ivoclar Vivadent, Schaan, Liechtenstein) only and with interposing the ceramic discs which can affect the both blue and violet wavelength irradiance (mW/cm²).[33] LED was positioned in contact with the top sensor using a specific holder for keeping static during the tests and irradiance and spectrum were measured for 20 seconds five times with and without ceramic discs (Fig.1).

Post-gel linear shrinkage (Shr) was measured using strain gauge method.[34] The luting material (n=5) was placed on top of a biaxial strain gauge (CEA-06-032WT-120, Measurements Group, Raleigh, NC, USA) that measured shrinkage strains in two perpendicular directions. Ceramic discs were placed on top of an apparatus with 2-mm height, limiting this height for luting materials, and between luting material and LED touching the ceramic disc, the same height was placed without ceramic disc (Fig. 2). All tests were made without any ceramic treatment, only touching the luting materials. When the material was light-activated, the polymerization shrinkage causes a strain on the strain gauge that is recorded by acquisition system (ADS0500IP, Lynx Electronic Technology) which is converted by electrical resistance changes in the strain gauge to voltage changes through a quarter-bridge circuit with an internal reference resistance. The values were collected for ten minutes. The mean post-gel shrinkage strain made with 0.3-mm ceramic interposition was used as linear post-gel shrinkage input for the finite element analysis and could be converted to volumetric post-gel shrinkage (VS) percentage by multiplying by 3 and 100%.[27]

For characterizing the compression and tensile strength of each cementation material the axial compressive strength (CS) and diametral tensile strength (DTS) test were performed (n=5). The materials were placed into a stainless-steel mold for the CS (6-mm height, 3-mm diameter) and for DTS (2-mm height, 4-mm diameter) and were light polymerized in increments of 1 mm, according to the instructions of manufacturer, and without interposing ceramic disc in this method considering the thickness of the specimens and to achieve the best conditions of materials at this step. The specimens were stored at dry conditions for 24h at 37°C, and were submitted to CS and DTS in universal testing machine (DL2000, EMIC) at a crosshead speed of 0.5 mm/min until failure occurred. CS values (N) were calculated by dividing the fracture load (F) by the cross-sectional area (πr^2) using equation = F/ πr^2, where 1 N/mm^2 is equal to 1 MPa. DTS values (N) were calculated by the equation = $2F/\pi dh$, where F is the fracture load, d is specimen diameter, h is the height of the specimen and using MPa scale. The CS and DTS data are presented on Table 2.

The four luting materials were put into cylindrical Teflon molds (6-mm diameter, 1-mm thickness) (n=5) with and without 0.3-mm thickness ceramic discs above it with polyester strip between them and below the luting materials. Another Teflon mold was used to input the LED tip and keep it in the same position for all the tests. The specimens were light-activated according to manufacturer's instructions. The two polyester strips used caused a drop of 2.51 J/cm^2 on total energy and 128 mW/cm^2 on maximum irradiance. After 24h dry storage at 37°C the specimens were submitted to Knoop indentations (MicroMet 5104, Buehler, Lake Bluff, IL, USA), obtaining 25 measurements per specimen for Knoop hardness (KHN) (Fig.3). The Knoop indentations were also used to determine the Elastic modulus (E).[35, 27] The decrease in the length of the indentation diagonals caused by elastic recovery of a material is related to the hardness/elastic modulus ratio (H/E) according to the following empirical relationship: $b'/a' = b/a - \alpha 1\ (H/E)$, where b/a is the ratio of the diagonal dimensions a and b, in the fully loaded state, given by a constant 0.140647. b'/a' is the ratio of the altered dimensions when fully recovered, and $\alpha 1 = 0.45$ is a proportionality constant.[27]

To evaluate polymerization shrinkage stresses during light-activated polymerization and the residual stresses during the functional loading on envelope of border movement or Posselt's envelope, eight 2-dimensional finite element models were created to simulate ultrathin 0.3-mm CLVs with and without tooth preparation according to the four luting materials. The models were created by using a sagittal cross-sectional tomography image as a template. Maxillary and mandibular intact central incisors were measured using medical software (Mimics 16.0, Materialise, Leuven, Belgium) to set the scale. This image was imported to ImageJ software (The National Institutes of Health, Bethesda, MD, USA) where coordinates were drawn, the scale was set and imported to MSC.Marc/Mentat software (MSC Software Corporation, Santa Ana, CA, USA). The mesh using four-node isoparametric quadrilateral elements was created manually. Butt joint or incisal bevel preparation of 0.3 mm and CLV with the same thickness were created at maxillary incisor and luting material film thickness of 150 μm was created. For the models without preparation the CLV and luting material were created (Fig. 4). Plane strain condition was assumed for tooth and CLV and plane stress elements for the luting materials.[26, 21] Polymerization shrinkage was simulated by thermal analogy reducing temperature by 1°C while linear post-gel shrinkage value made with 0.3-mm ceramic interposition was entered as the coefficient of linear thermal expansion.[26, 21] After polymerization shrinkage simulation the models were submitted to a non-linear analysis of the loading of 100N simulating envelope movement between maxillary and mandibular incisors simulating an anterior bite movement.

Since the materials tested are brittle, a failure criterion should take strength differential effect (SDE), which is represented by compressive/tensile strength as that most dental materials have higher strength in compression than in tension, that is SDE ≠ 1.[36] Note that original von Mises criterion is obtained for SDE = 1, so the modified von Mises equivalent stress (mvm) was chose for this analysis. The mvm expresses the stress conditions using the ratio between compressive and tensile strength which were calculated on the experimental tests. The stresses values are visualized using a linear color scale in which blue indicates the lowest stress values, and yellow and light gray the highest values (MPa). The SDE data is presented on Table 2. The compressive and tensile strengths of enamel were 384.0 and 10.3MPa and for dentin 297.0 and 98.7MPa, respectively.[37]

The Shr (%), KHN (N/mm²) and E (GPa) were tested for normal distribution (Shapiro-Wilk) and equality of variance (The Levene Test), followed by parametric statistical tests. Two-way ANOVA was performed for Shr, KHN and E. Multiple comparisons were made using The Tukey Test. All tests employed α=0.05 significance level and all analyses were performed using Sigma Plot 12.5 (Systat Software Inc, San Jose, Ca, USA).

RESULTS

The light transmittance test shown that interposing 0.3-mm ceramic disc causes a significant drop of total energy (22.82 J/cm² to 11.71 J/cm²), maximum irradiance (1148.75 mW/cm² to 589.40 mW/cm²), violet spectrum range - 360-420nm (2.71 J/cm² to 1.26 J/cm²) and blue spectrum range energy - 420-540nm (20.12 J/cm² to 10.52 J/cm²).

The linear post-gel shrinkage curves and the volumetric post-gel shrinkage (%) means and standard deviations are shown respectively on Fig. 5, Table 3 and Table 4. The two-way ANOVA showed no significant overall effect of luting material (*P*=.072) neither for presence of tooth preparation (*P*=.078), but was observed significant overall effect of the interaction between luting material and presence of ceramic (*P*=.019). When interposing 0.3-mm ceramic disc VE and TF had lower post-gel shrinkage than AV and RV.

Knoop hardness (N/mm²) and Elastic modulus (GPa) means and standard deviations measured in specimens made with or without interposition of the ceramic disc are shown in Table 5, 6 and 7. The two-way ANOVA found significant overall effect of luting material

(P<.001) and interposition of ceramic disc (P<.001), and for the interaction between luting material and interposition of ceramic disc (P<.001). Analyzing the luting materials when interposing ceramic discs, TF and RV showed the highest and VE the lowest KHN and E values. In general, KHN and E values decreases when interposing ceramic discs.

Fig. 6A and 6B shown qualitatively modified von Mises stress distribution at shrinkage, incisal contact and final movement moments on finite element models with 0.3-mm CLVs with and without tooth preparation, respectively. The stress distribution pattern at shrinkage polymerization moment on models with or without tooth preparation (Fig. 6A and 6B) is the almost the same, concentrating higher stresses at incisal of enamel, internal incisal of ceramic and at cervical preparation, however models without preparation showed less stress concentration at cervical area. RV showed the highest and VE the lowest stress concentration regardless of tooth preparation. When the models have incisal contact the stress distribution pattern remains similar but the stresses decrease at the incisal area of enamel, regardless of tooth preparation, with RV presenting the highest and VE the lowest stress concentrations (Fig. 6A and 6B). At the final movement moment, stresses at incisal of enamel have increased regardless of tooth preparation (Fig. 6A and 6B). Stresses have slightly increased at cervical preparation (Fig. 6A) on models with tooth preparation, what is not strongly evidenced on models without tooth preparation (Fig. 6B).

Fig. 7A and 7B shown the quantitative stress distribution (MPa) at most critical interfaces of enamel and ceramic at shrinkage moment. Higher stress concentration was verified at the incisal area of enamel regardless of tooth preparation, with RV presenting the higher and VE the lowest stresses values, with slightly higher stress on models with tooth preparation (about 1MPa). Models with tooth preparation showed higher stress values at the cervical preparation region (Fig. 7A). Fig. 7C and 7D shown quantitative stress distribution on luting materials at the interface with enamel and ceramic at shrinkage moment. Higher stress concentration was observed at the cervical area regardless of tooth preparation, being higher on models with tooth preparation (Fig. 7C). RV showed the highest and VE the lowest stress values on these interfaces.

DISCUSSION

The present study evaluated the effect of light attenuation caused by ceramic interposition on mechanical properties of different luting materials and the shrinkage and residual stresses by functional loading on tooth restored with ultrathin 0.3-mm CLV with and without tooth preparation. The results showed that ceramic interposition affected the mechanical properties of luting materials and the different luting materials, presence of tooth preparation and functional loading modified the stress distribution on tooth restored with CLV, rejecting the first and second null hypotheses.

The characterization of the mechanical properties and post-gel shrinkage of luting materials, which were used as input of finite element analysis is an important aspect of this study. The use of 0.3-mm ceramic interposed between the LED and the luting materials for preparation of the specimens simulated closer clinical conditions of the effect of the light attenuation on the mechanical properties of the luting materials, as well on the stress distribution on finite element analysis, which had not been simulated in previous studies using finite element analysis.[29, 30, 31] The thin lithium disilicate ceramic thickness caused a significant reduction on irradiance and energy delivered by LED showing that it would be an important aspect to be used in laboratorial tests.

Not all shrinkage generates stresses, but stresses are generated when the composite material becomes solid enough to transfer stresses which occurs in post-gel moment, a portion of total polymerization shrinkage that causes stress.[20, 21] Post-gel shrinkage was calculated for all luting materials in the real clinical conditions modulated by ceramic thickness. When interposing ceramic discs VE and TF presented lower post-gel shrinkage values. It suggests that Norrish type I photoinitiator, as Lucerin-TPO and the new germanium-based photoinitiator commercially known as Ivocerin present on TF and VE respectively, causes a higher effect on post-gel shrinkage due to the lowest irradiance emitted in the violet spectrum by Bluephase G2 in a situation where light is attenuated by ceramic. This probably occurred since the absorption peak of TPO is set into the violet spectrum (380-420 nm) and Ivocerin absorption peak is also set in the violet spectrum but slightly extended to the blue spectrum range (420-455 nm).[33] It also can explain why TF had slightly lower Shr than VE when interposing ceramic discs. Despite these results, VE and TF showed almost the same mechanical properties on this condition. This study showed that the flowable composite TF had the highest compressive-tensile strength ratio (SDE) which means that tensile strength is very similar to others luting materials but presented higher compressive strength. TF has camphorquinone (CQ) as photoinitiator, which can explain why this luting material presented high mechanical properties, probably due to a satisfactory polymerization because of the two CQ and TPO photoinitiators. Although TF presented high mechanical properties and similar stress distribution as the resin cements tested, the absence of try-in pastes is an important limitation for using these materials as luting agents.[18] However, this material can be used as an alternative material for cementation of CLV. The KHN and E values in general decreased when a 0.3-mm ceramic thickness was interposed, showing that a decrease in light transmittance have an influence on mechanical properties of luting materials. However, more studies which analyses degree of conversion of these materials under these conditions are required.

Two-dimensional finite element models present a simplification of what occurs in reality where more factors are involved and is just one slice of a more complex three-dimensional structure, but it is clearly possible to predict the most critical regions of failure, the stress distribution and the behavior of different luting materials on CLV in a computational methodology. The modified von Mises criterion used to evaluate failure is also a more appropriated method of analyses for porcelain material owing to its brittleness.[28]

During the light-activated polymerization of the luting materials higher stress concentration was verified on incisal edge and cervical regions of CLV models with tooth preparation, which is the weakest region of the interface.[12, 29] However, the cervical region of the models without tooth preparation had lower stress concentration which is possibly explained by the fact of the preparation leave a thin layer of cervical enamel very close to the dentin, and when shrinkage occurs at this thin structure with high Elastic modulus, it accumulate more stress than the same thicker structure without any preparation. The internal incisal edge was also the region that concentrated higher stress on the models without tooth preparation which is also the most common location of ceramic fracture. Since stresses can generate micro-cracks and with increasing stresses and loading cycles the micro-cracks can be extended causing ceramic fractures[13], this statement may explain the ceramic failures observed clinically related to stress magnitude and distribution.

The functional loading expressed by the antagonist biting maintained the same locations of the stress distribution observed during the polymerization shrinkage. The presence of tooth preparation did not influence the stress distribution of CLV. However, CLV without tooth preparation need to have the correct indications and even with the highest technologies as 3D scanning systems, CAD/CAM systems, 3D printing among others, there is a difficulty in delimiting the ceramic margins for obtaining a smooth transition between tooth structure and ceramic. Besides that, clinicians need to be careful with the finishing of restoration so that there are no cracks of ceramic margin, exposure of luting materials or overhangs occurs. Once overhangs exist, problems as gingival inflammation or accumulation of biofilm can generate caries in this region.

However, a limitation of this study is that 2-dimensional finite element models uses only a slice of the entire structure and some surfaces as proximal areas preparation were not investigated. Future studies should focus on a 3-dimensional finite element analyses to complement these findings and in laboratorial luting on enamel or dentin substrates to verify the mechanical behavior for both techniques with and without tooth preparation as luting materials.

CONCLUSION

Within the limitations of this laboratorial and finite element study, the following conclusions can be drawn:

1. The light attenuation caused by interposing ceramic disc affected the mechanical properties of luting materials;
2. The flowable composite resin showed similar mechanical properties than resin cements;
3. The shrinkage and residual stresses levels were similar for models with and without tooth preparation.

REFERENCES

1. Grzić R, Spalj S, Lajnert V, Glavicić S, Uhac I, Pavicić DK. Factors influencing a patient's decision to choose the type of treatment to improve dental esthetics. Vojnosanit Pregl 2012;69:978-85.
   https://doi.org/10.2298/VSP111027026G
2. Sampaio CS, Barbosa JM, Cáceres E, Rigo LC, Coelho PG, Bonfante EA, Hirata R. Volumetric shrinkage and film thickness of cementation materials for veneers: An in vitro 3D microcomputed tomography analysis. J Prosthet Dent 2017;117:784-91.
   https://doi.org/10.1016/j.prosdent.2016.08.029
3. Gurel G, Sesma N, Calamita M, Coachman C, Morimoto S. Influence of enamel preservation on failures rates of porcelain laminate veneers. Int J Periodontics Restorative Dent 2013;33: 31-9.
   https://doi.org/10.11607/prd.1488
4. Alavi AA, Behroozi Z, Nik Eghbal F. The shear bond strength of porcelain laminate to prepared and unprepared anterior teeth. J Dent 2017;18:50-5.
5. Strassler HE. Minimally invasive porcelain veneers: indications for a conservative esthetic dentistry treatment modality. Gen Dent 2007;55:686-94.
6. Miyazaki T, Hotta Y, Kunii J, Kuriyama S, Tamaki Y. A review of dental CAD/CAM: current status and future perspectives from 20 years of experience. Dent Mater J 2009;28:44-56.
   https://doi.org/10.4012/dmj.28.44
7. Li RW, Chow TW, Matinlinna JP. Ceramic dental biomaterials and CAD/CAM technology: state of the art. J Prosthodont Res 2014;58:208-16.

https://doi.org/10.1016/j.jpor.2014.07.003

8. Friedman MJ. A 15-year review of porcelain veneer failure--a clinician's observations. Compend Contin Educ Dent. 1998;19:625-8
9. Peumans M, Van Meerbeek B, Lambrechts P, Vanherle G. Porcelain veneers: a review of the literature. J Dent 2000;28:163-77. https://doi.org/10.1016/S0300-5712(99)00066-4
10. Granell-Ruíz M, Agustín-Panadero R, Fons-Font A, Román-Rodríguez JL, Solá-Ruíz MF. Influence of bruxism on survival of porcelain laminate veneers. Med Oral Patol Oral Cir Bucal. 2014;19:426-32. https://doi.org/10.4317/medoral.19097
11. da Costa DC, Coutinho M, de Sousa AS, Ennes JP. A meta-analysis of the most indicated preparation design for porcelain laminate veneers. J Adhes Dent 2013;15:215-20.
12. Zarone F, Epifania E, Leone G, Sorrentino R, Ferrari M. Dynamometric assessment of the mechanical resistance of porcelain veneers related to tooth preparation: a comparison between two techniques. J Prosthet Dent 2006;95:354-63. https://doi.org/10.1016/j.prosdent.2006.03.003
13. Chai SY, Bennani V, Aarts JM, Lyons K. Incisal preparation design for ceramic veneers: A critical review. J Am Dent Assoc 2018;149:25-37. https://doi.org/10.1016/j.adaj.2017.08.031
14. Zarone F, Leone R, Di Mauro MI, Ferrari M, Sorrentino R. No-preparation ceramic veneers: a systematic review. J Osseointegr 2018;10:17-22.
15. Cao X, Fleming GJP, Addison O. The impact of resin-coating on sub-critical crack extension in a porcelain laminate veneer material. Dent Mater 2017;33:498-504.

https://doi.org/10.1016/j.dental.2017.02.004

16. Archegas LR, Freire A, Vieira S, Caldas DB, Souza EM. Colour stability and opacity of resin cements and flowable composites for ceramic veneer luting after accelerated ageing. J Dent 2011;39:804-10. https://doi.org/10.1016/j.jdent.2011.08.013
17. Archegas LR, de Menezes Caldas DB, Rached rN, Soares P, Souza EM. Effect of ceramic veneer opacity and exposure time on the polymerization efficiency of resin cements. Oper Dent 2012;37:281-9. https://doi.org/10.2341/11-134-L
18. AlGhazali N, Laukner J, Burnside G, Jarad FD, Smith PW, Preston AJ. An investigation into the effect of try-in pastes, uncured and cured resin cements on the overall color of ceramic veneer restorations: an in vitro study. J Dent 2010;38:78-86. https://doi.org/10.1016/j.jdent.2010.08.013
19. Soares CJ, Faria-E-Silva AL, Rodrigues MP, Vilela ABF, Pfeifer CS, Tantbirojn D, Versluis A. Polymerization shrinkage stress of composite resins and resin cements - What do we need to know? Braz Oral Res 2017;31(suppl 1):e62. https://doi.org/10.1590/1807-3107bor-2017.vol31.0062
20. Soares CJ, Bicalho AA, Tantbirojn D, Versluis A. Polymerization shrinkage stresses in a premolar restored with different composite resins and different incremental techniques. J Adhes Dent 2013;15:341-50.
21. Bicalho AA, de Souza SJ, de Rosatto CM, Tantbirojn D, Versluis A, Soares CJ. Effect of temperature and humidity on post-gel shrinkage, cusp deformation, bond strength and

shrinkage stress - Construction of a chamber to simulate the oral environment. Dent Mater 2015;31:1523-32.
https://doi.org/10.1016/j.dental.2015.09.023

22. Peumans M, Van Meerbeek B, Yoshida Y, Lambrechts P, Vanherle G. Porcelain veneers bonded to tooth structure: an ultra-morphological FE-SEM examination of the adhesive interface. Dent Mater 1999;15:105-19.
https://doi.org/10.1016/S0109-5641(99)00020-2
23. May LG, Kelly JR. Influence of resin cement polymerization shrinkage on stresses in porcelain crowns. Dent Mater 2013;29:1073-9.
https://doi.org/10.1016/j.dental.2013.07.018
24. Haralur SB. Microleakage of porcelain laminate veneers cemented with different bonding techniques. J Clin Exp Dent 2018;10:166-71
25. Gresnigt MM, Kalk W, Özcan M. Clinical longevity of ceramic laminate veneers bonded to teeth with and without existing composite restorations up to 40 months. Clin Oral Investig 2013;17:823-32.
https://doi.org/10.1007/s00784-012-0790-5
26. Rosatto CM, Bicalho AA, Veríssimo C, Bragança GF, Rodrigues MP, Tantbirojn D, et al. Mechanical properties, shrinkage stress, cuspal strain and fracture resistance of molars restored with bulk-fill composites and incremental filling technique. J Dent 2015;43:1519-28.
https://doi.org/10.1016/j.jdent.2015.09.007
27. Soares CJ, Bicalho AA, Verissimo C, Soares P, Tantbirojn D, Versluis A. Delayed photo-activation effects on mechanical properties of dual cured resin cements and finite

element analysis of shrinkage stresses in teeth restored with ceramic inlays. Oper Dent 2016;41:491-500.
https://doi.org/10.2341/15-090-L

28. Magne P, Douglas WH. Design optimization and evolution of bonded ceramics for the anterior dentition: a finite element analysis. Quintessence Int. 1999;30:661-72.
29. Zarone F, Apicella D, Sorrentino R, Ferro V, Aversa R, Apicella A. Influence of tooth preparation design on the stress distribution in maxillary central incisors restored by means of alumina porcelain veneers: a 3D-finite element analysis. Dent Mater 2005;21:1178-88.
https://doi.org/10.1016/j.dental.2005.02.014
30. Liu HL, Lin CL, Sun MT, Chang YH. Numerical investigation of macro- and micro-mechanics of a ceramic veneer bonded with various cement thicknesses using the typical and submodeling finite element approaches. J Dent 2009;37:141-8.
https://doi.org/10.1016/j.jdent.2008.10.009
31. Li Z, Yang Z, Zuo L, Meng Y. A three-dimensional finite element study on anterior laminate veneers with different incisal preparations. J Prosthet Dent 2014;112:325-33.
https://doi.org/10.1016/j.prosdent.2013.09.023
32. Ustun O, Ozturk AN. The evaluation of stress patterns in porcelain laminate veneers with different restoration designs and loading angles induced by functional loads: A three-dimensional finite element analysis study. Niger J Clin Pract 2018;21:337-42.
33. Delgado AJ, Castellanos EM, Sinhoreti M, Oliveira DC, Abdulhameed N, Geraldeli S, et al. The use of different photoinitiator systems in photopolymerizing resin cements

through ceramic veneers. Oper Dent 2018 Dec 5. doi: 10.2341/17-263-L. [Epub ahead of print]
https://doi.org/10.2341/17-263-L

34. Sakaguchi RL, Versluis A, Douglas WH. Analysis of strain gage method for measurement of post-gel shrinkage in resin composites. Dent Mater 1997;13:233-9.
https://doi.org/10.1016/S0109-5641(97)80034-6

35. Marshall DB, Noma T, Evans AG. A simple method for determining elastic-modulus-to-hardness ratios using Knoop indentation measurements. J Am Ceram Soc 1982;65:175-6.
https://doi.org/10.1111/j.1151-2916.1982.tb10357.x

36. Versluis A, Tantbirojn D, Douglas WH. Why do shear bond tests pull out dentin? J Dent Res 1997;76:1298-307.
https://doi.org/10.1177/00220345970760061001

37. Versluis A, Versluis-Tantbirojn D. Filling cavities or restoring teeth? J Tenn Dent Assoc 2011;91:36-42.

Table 1. Luting materials used in this study

Material	Code	Shade	Type	Light activation time	Composition	Filler (wt%)	Manufacturer
RelyX Veneer	RV	TR	Light-cured resin cement	20 s	Bis-GMA, TEGDMA, zirconia/silica filler	66.0	3M ESPE, St Paul, MN, USA
Allcem Veneer APS	AV	Trans	Light-cured resin cement	40 s	Methacrylic monomers, aluminosilicate glasses, silicon oxide	63.0	FGM, Joinville, SC, Brazil
Variolink Esthetic LC	VE	Neutral	Light-cured resin cement	20 s	UDMA, Bis-GMA, HEMA, TEGDMA, GDMA, barium glass, zirconia/silica filler	60.0-68.0	Ivoclar Vivadent, Schaan, Liechtenstein
Tetric N-Flow	TF	T	Light-cured flowable	20 s	UDMA, Bis-GMA, Bis-EMA, TEGDMA, barium glass,	63.0	Ivoclar Vivadent, Schaan, Liechtenstein

	resin composite	ytterbium trifluoride, mixed oxide, silicon dioxide

Table 2. Mean and SD of compressive strength, diametral tensile strength and stress differential effect

Luting Materials	Compressive strength (MPa)	Diametral tensile strength (MPa)	Strength differential effect (SDE)
Allcem Veneer APS	169.6 (11.3)	37.4 (1.7)	4.5
RelyX Veneer	202.5 (15.4)	37.1 (2.6)	5.5
Variolink Esthetic LC	100.2 (8.9)	22.2 (1.7)	4.5
Tetric-N Flow	274.0 (8.9)	36.5 (2.7)	7.5

Table 3. Two-way ANOVA for volumetric post-gel shrinkage

Source of Variation	**Sum of Squares**	***df***	**Mean Square**	**F**	***P***
Luting material (A)	0.115	3	0.0384	17.319	<.001
Presence of ceramic veneer (B)	0.0534	1	0.0534	24.097	<.001
A x B	0.0597	3	0.0199	8.989	<.001
Error	0.0709	32	0.00222		

Table 4. Mean and standard deviation of volumetric post-gel shrinkage (%).

Luting Materials	Without ceramic veneer	With 0.3mm ceramic veneer
Allcem Veneer APS	0.49 (0.05) Aa	0.52 (0.05) Ab
RelyX Veneer	0.54 (0.05) Aa	0.51 (0.03) Ab
Variolink Esthetic LC	0.50 (0.06) Ba	0.37 (0.03) Aa
Tetric-N Flow	0.48 (0.04) Ba	0.31 (0.04) Aa

Different uppercase letters indicate significant difference between the presence of ceramic. Different lowercase letters indicate significant difference between luting materials for each experimental condition of light polymerization ($P < 0.05$).

Table 5. Two-way ANOVA for Knoop Hardness.

Source of Variation	Sum of Squares	*df*	Mean Square	F	*P*
Luting material (A)	2416.950	3	805.650	486.664	<.001
Presence of ceramic veneer (B)	28.025	1	28.025	16.929	<.001
A x B	24.021	3	8.007	4.837	.007
Error	52.975	32	1.655		

Table 6. Two-way ANOVA for Elastic Modulus.

Source of Variation	Sum of Squares	*df*	Mean Square	F	*P*
Luting material (A)	85.818	3	28.606	28.558	<.001
Presence of ceramic veneer (B)	1.057	1	1.057	1.055	.312
A x B	6.651	3	2.217	2.213	.106
Error	32.054	32	1.002		

Table 7. Means and standard deviation of Knoop Hardness (N/mm2) and Elastic Modulus (GPa) of the luting materials light activated without and with interposing 0.3 mm ceramic veneer.

Luting Materials	Knoop Hardness (N/mm^2)		Elastic Modulus (GPa)	
	Without ceramic veneer	With 0.3mm ceramic veneer	Without ceramic veneer	With 0.3mm ceramic veneer
Allcem Veneer APS	33.8 (1.2) Ab	31.0 (0.9) Bb	4.1 (0.4) Ab	3.4 (1.0) Ab
RelyX Veneer	35.2 (1.3) Ab	34.8 (1.9) Aa	6.3 (1.0) Aa	5.0 (1.8) Aa
Variolink Esthetic LC	17.1 (1.4) Ac	17.3 (0.8) Ac	2.2 (0.3) Ac	1.9 (0.2) Ac
Tetric-N Flow	38.6 (1.0) Aa	35.1 (1.5) Ba	5.0 (0.5) Aa	6.0 (1.2) Aa

Different uppercase letters indicate significant difference between the presence of ceramic; and different lowercase letters indicate significant difference between luting materials ($P < 0.05$).

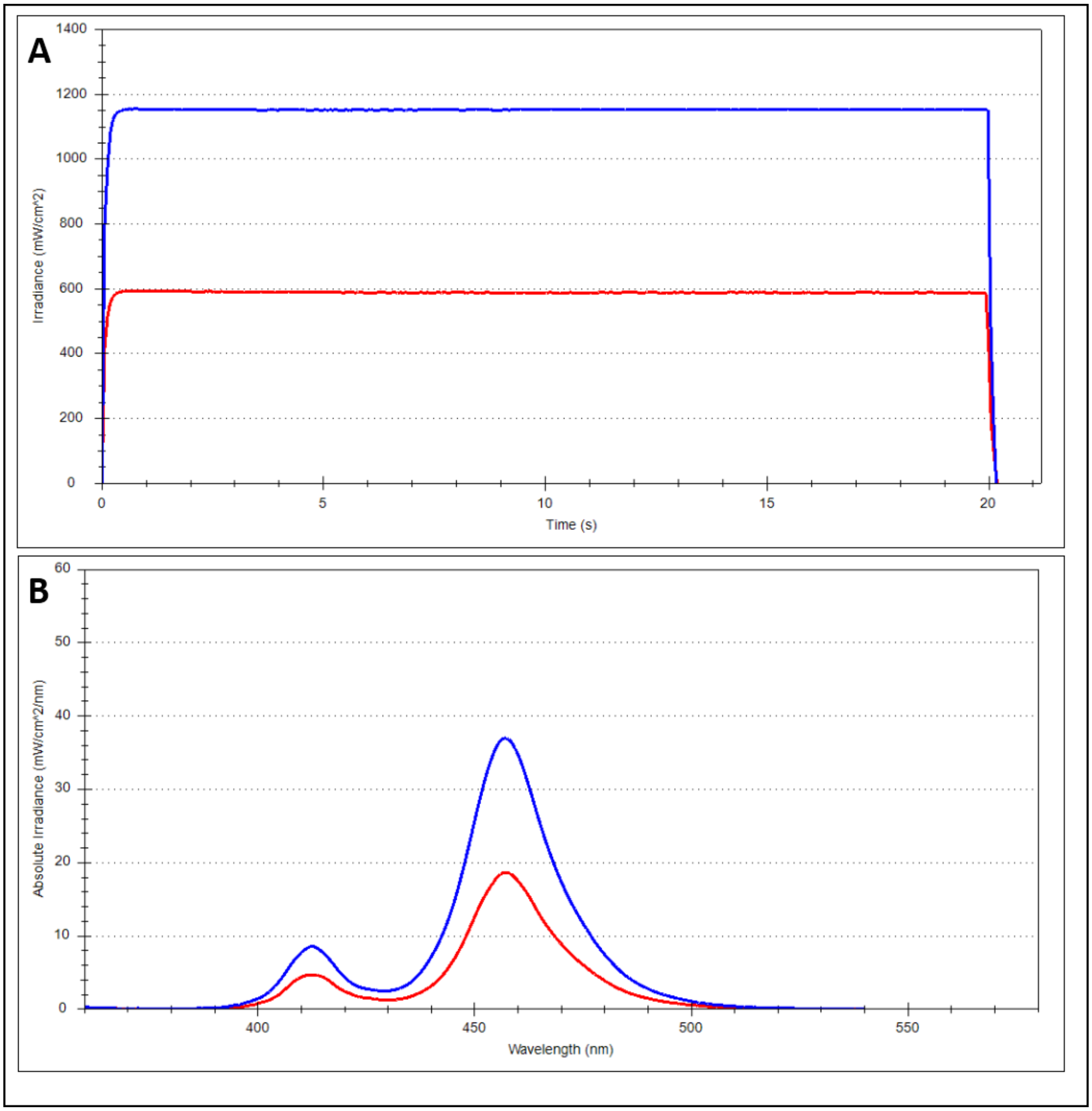

Fig. 1. Light transmittance test on MARC Resin Calibrator measured with Bluephase G2 with (red line) or without (blue line) 0.3-mm thickness of the e.max CAD ceramic disc; A) Irradiance (mW/cm^2); B) Spectrum (nm).

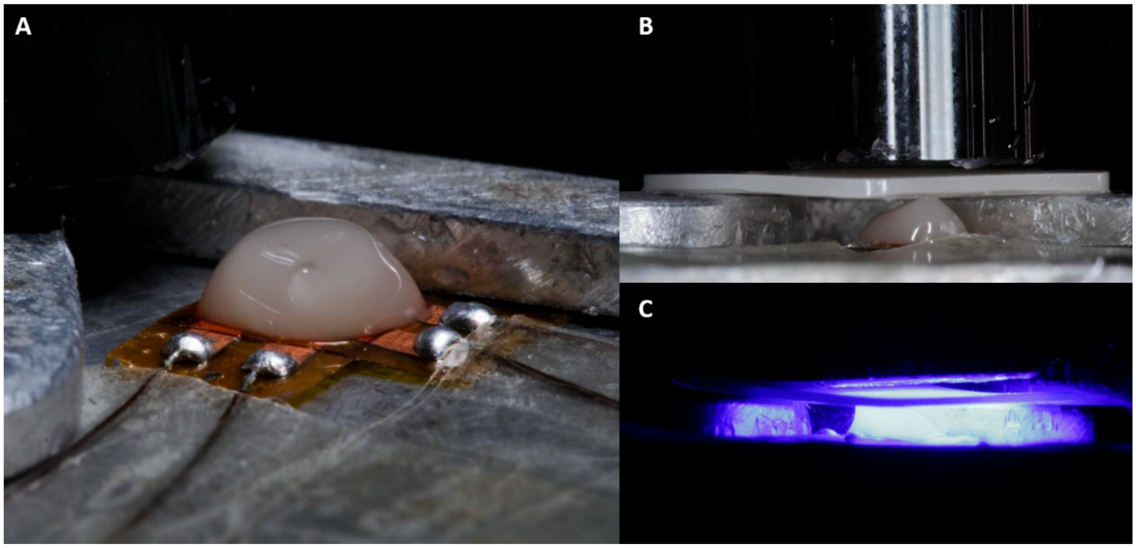

Fig. 2. Strain gauge method used for post-gel calculation of cementation materials. A) Cementation material inserted over strain-gauge; B) Lateral view of the apparatus used for stabilizing the ceramic disc positioned over the cementation material and LCU touching the upper surface of the 0.3mm ceramic disc; C) Light activation the cementation material through the ceramic disc.

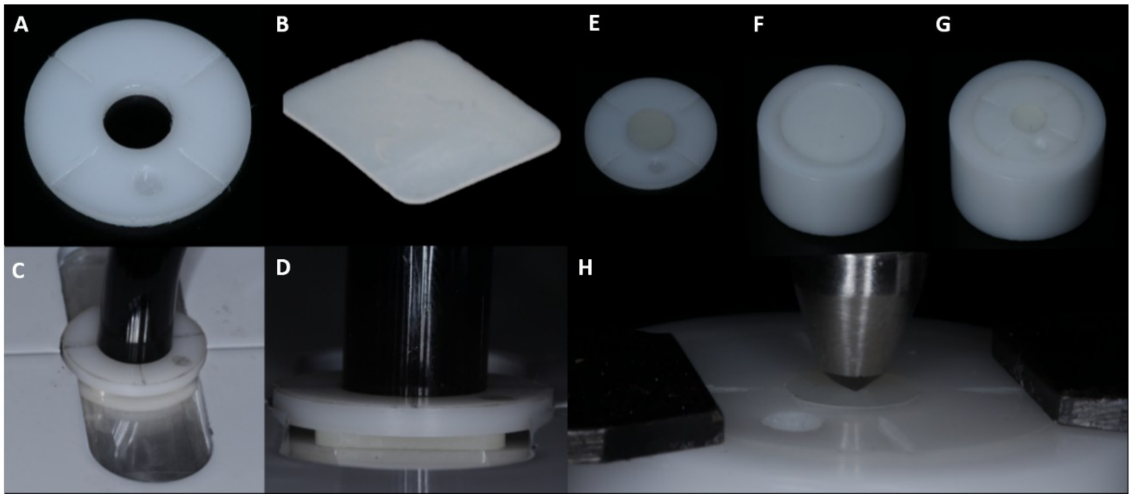

Fig. 3. Specimens for Knoop hardness and Elastic modulus calculation. A) Teflon mold; B) 0.3 mm-thickness ceramic discs; C) Light activation of cementation material; D) Lateral view from the set; E) Cementation material inside Teflon mold; F) Apparatus for holding cylindrical teflon mold for micro-hardness test; G) Cylindrical teflon mold inside apparatus; H) Indentations made at micro-hardness indenter.

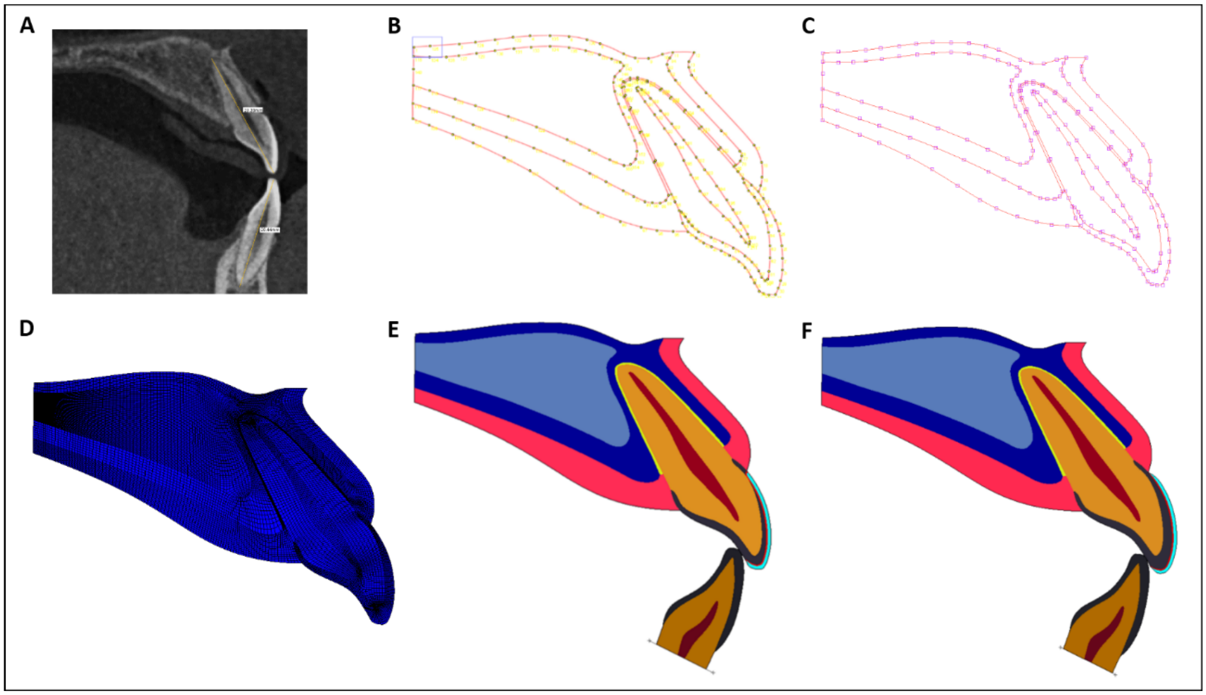

Fig. 4. Generation of two-dimensional finite element models. A) Sagittal cross-sectional tomography image used as template on Mimics; B) Coordinates points drawn on ImageJ; C) Curves generated from the coordinates points on MSC.Marc; D) Finite element mesh created manually; E) Two-dimensional model with 0.3 mm PLV with dental preparation; F) Two-dimensional model with 0.3 mm PLV without dental preparation.

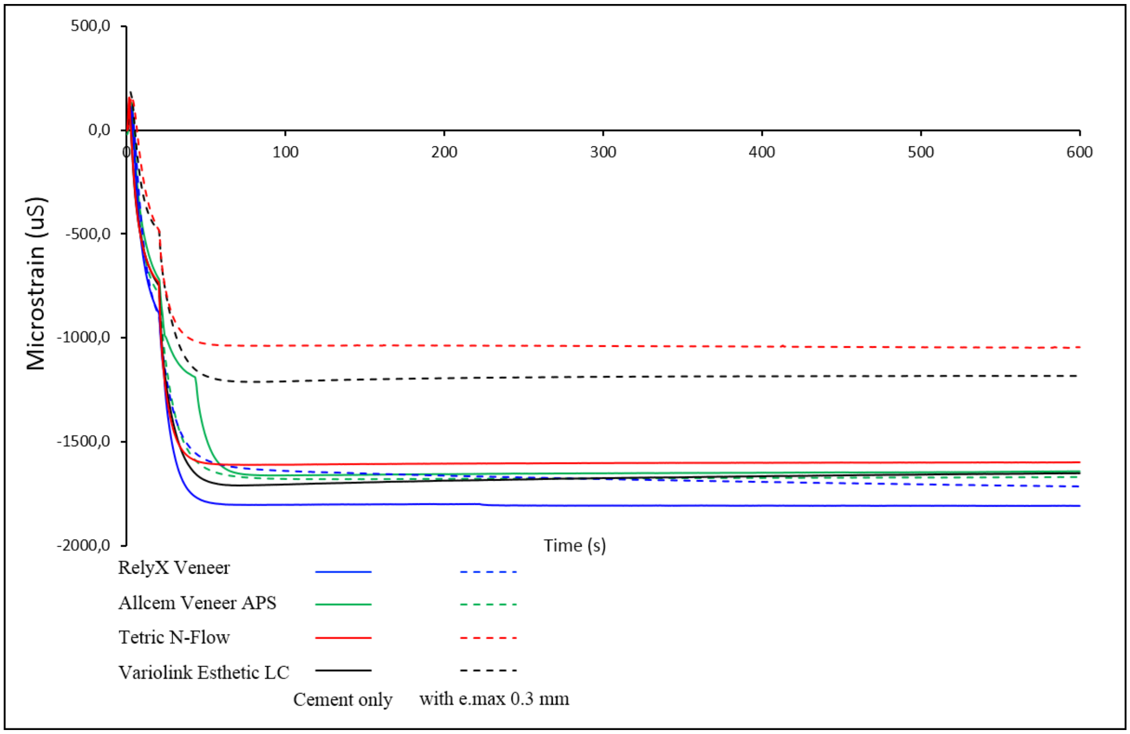

Fig. 5. Post-gel shrinkage curves obtained during light polymerization and after 10 minutes.

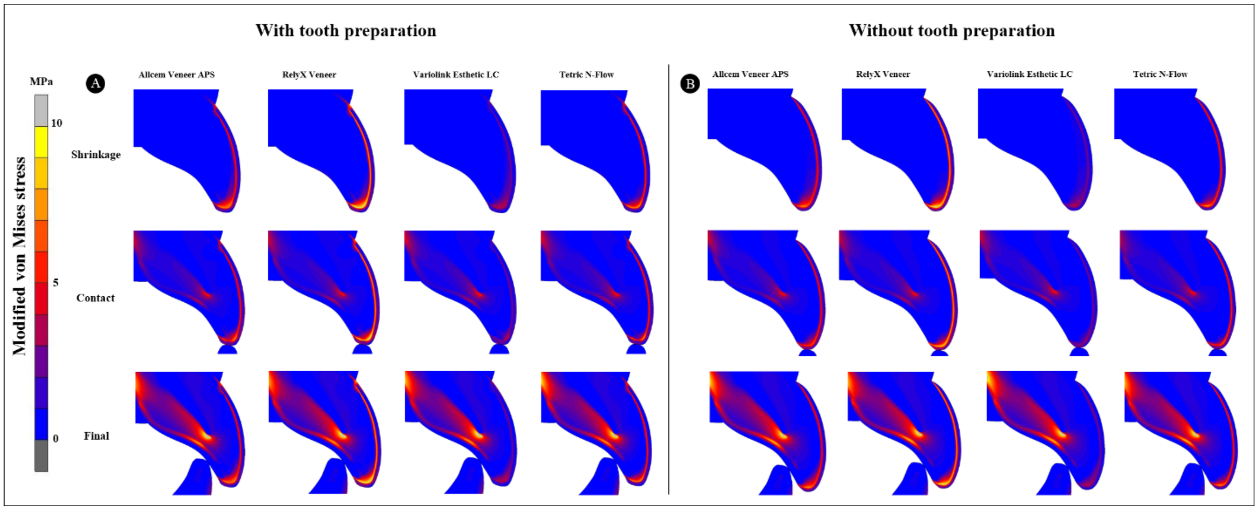

Fig. 6. Shrinkage stress generated during polymerization of cementation materials, and the residual stress at incisal contact and final occlusal movement A) ultrathin (0.3mm) ceramic veneer with tooth preparation; B) ultrathin (0.3mm) ceramic veneer without tooth preparation.

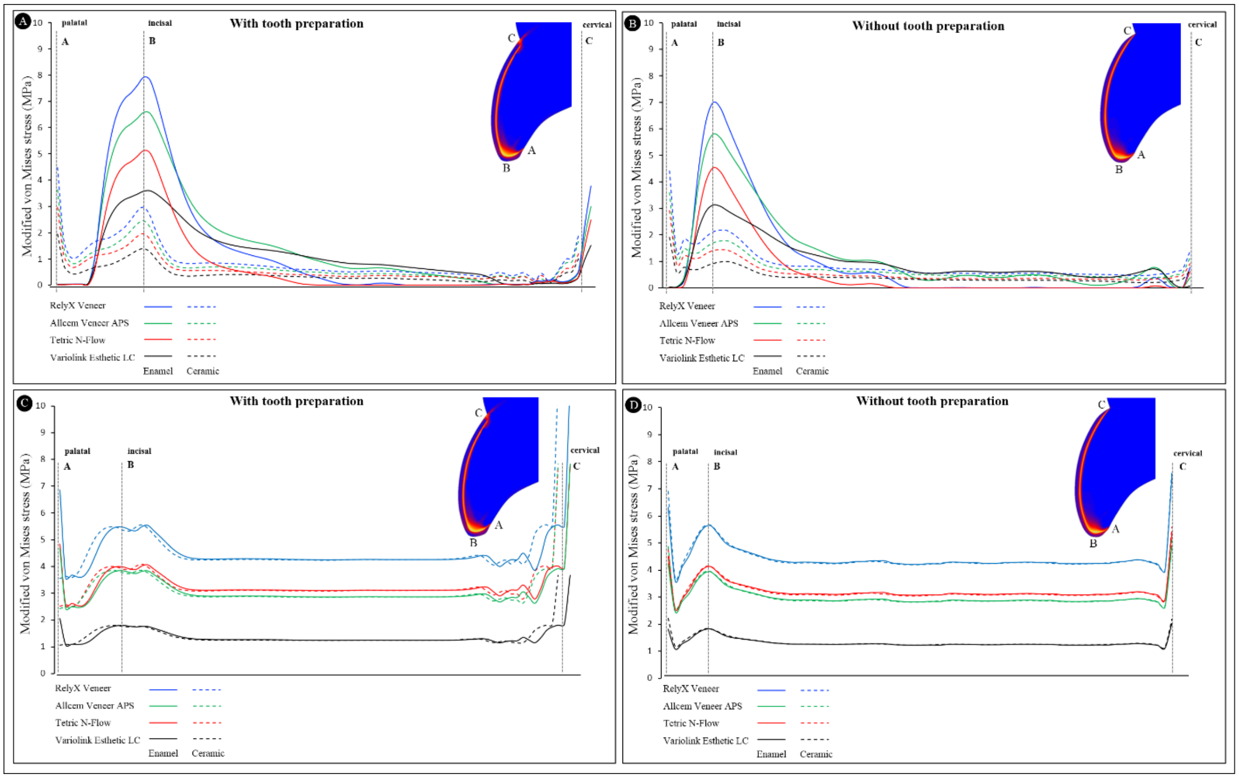

Fig. 7. Modified von Mises stress distribution on interfaces. Interfaces of enamel and ceramic on models: A) with dental preparation; B) without dental preparation. Interfaces of cement with enamel and ceramic on models: C) with dental preparation; D) without dental preparation.

Conclusões

3. CONCLUSÕES

De acordo com as limitações deste estudo laboratorial e por elementos finitos, as seguintes conclusões podem ser obtidas:

1. A atenuação de luz causada pela interposição de disco cerâmico afetou as propriedades mecânicas dos materiais de cimentação;
2. A resina composta fluida apresentou propriedades mecânicas similares aos cimentos resinosos;
3. Os níveis de tensões de contração e residuais foram similares para os modelos com e sem preparo dental.

Referências

* De acordo com a Norma da FOUFU, baseado nas Normas de Vancouver. Abreviaturas dos periódicos com conformidade com Medline (Pubmed).

REFERÊNCIAS

Horn H. A new lamination, porcelain bonded to enamel. **N Y State Dent J.** 1983;49(6):401–3.

Calamia JR. Indications for porcelain veneers. Etched porcelain veneers: a new treatment modality. **N Y J Dent.** 1983;53(6):255–9.

Friedman MJ. Augmenting restorative dentistry with porcelain veneers. **JADA.** 1991;122:29–34. https://doi.org/10.14219/jada.archive.1991.0180

Strassler HE. Minimally invasive porcelain veneers: indications for a conservative esthetic dentistry treatment modality. **Gen Dent.** 2007;55(7):686-94.

Belser UC, Magne P, Magne M. Ceramic laminate veneers: continuous evolution of indications. **J Esthet Dent.** 1997;9(4):197-207. https://doi.org/10.1111/j.1708-8240.1997.tb00941.x

Sampaio CS, Barbosa JM, Cáceres E, Rigo LC, Coelho PG, Bonfante EA, et al. Volumetric shrinkage and film thickness of cementation materials for veneers: An in vitro 3D microcomputed tomography analysis. **J Prosthet Dent**. 2017;117(6):784-91. https://doi.org/10.1016/j.prosdent.2016.08.029

Alavi AA, Behroozi Z, Nik Eghbal F. The shear bond strength of porcelain laminate to prepared and unprepared anterior teeth. **J Dent.** 2017;18(1):50-5.

Gurel G, Sesma N, Calamita M, Coachman C, Morimoto S. Influence of enamel preservation on failures rates of porcelain laminate veneers. **Int J Periodontics Restorative Dent.** 2013;33(1): 31–9.

https://doi.org/10.11607/prd.1488

Zarone F, Leone R, Di Mauro MI, Ferrari M, Sorrentino R. No-preparation ceramic veneers: a systematic review. **J Osseointegr.** 2018;10(1):17-22.

Ural Ç, Duran İ, Tatar N, Öztürk Ö, Kaya İ, Kavut İ. The effect of amine-free initiator system and the polymerization type on color stability of resin cements. **J Oral Sci.** 2016;58(2):157-61.
https://doi.org/10.2334/josnusd.15-0619

Archegas LR, Freire A, Vieira S, Caldas DB, Souza EM. Colour stability and opacity of resin cements and flowable composites for ceramic veneer luting after accelerated ageing. **J Dent.** 2011;39(11):804-10.
https://doi.org/10.1016/j.jdent.2011.08.013

Archegas LR, de Menezes Caldas DB, Rached rN, Soares P, Souza EM. Effect of ceramic veneer opacity and exposure time on the polymerization efficiency of resin cements. **Oper Dent.** 2012;37(3):281-9.
https://doi.org/10.2341/11-134-L

Soares CJ, Faria-E-Silva AL, Rodrigues MP, Vilela ABF, Pfeifer CS, Tantbirojn D, et al. Polymerization shrinkage stress of composite resins and resin cements - What do we need to know? **Braz Oral Res.** 2017;31(suppl 1):e62.

Anusavice KJ, Phillips RW, Shen C, Rawls HR. **Phillips' Science of Dental Materials.** Elsevier/Saunders; 2013.

Soares CJ, Bicalho AA, Tantbirojn D, Versluis A. Polymerization shrinkage stresses in a premolar restored with different composite resins and different incremental techniques. **J Adhes Dent.** 2013;15(4):341-50.

Peumans M, Van Meerbeek B, Yoshida Y, Lambrechts P, Vanherle G. Porcelain veneers bonded to tooth structure: an ultra-morphological FE-SEM examination of the adhesive interface. **Dent Mater.** 1999;15(2):105-19.
https://doi.org/10.1016/S0109-5641(99)00020-2

May LG, Kelly JR. Influence of resin cement polymerization shrinkage on stresses in porcelain crowns. **Dent Mater.** 2013;29(10):1073-9.
https://doi.org/10.1016/j.dental.2013.07.018

Haralur SB. Microleakage of porcelain laminate veneers cemented with different bonding techniques. **J Clin Exp Dent.** 2018;10(2):166-71

Cao X, Fleming GJP, Addison O. The impact of resin-coating on sub-critical crack extension in a porcelain laminate veneer material. **Dent Mater.** 2017;33(5):498-504.
https://doi.org/10.1016/j.dental.2017.02.004

Gresnigt MM, Kalk W, Özcan M. Clinical longevity of ceramic laminate veneers bonded to teeth with and without existing composite restorations up to 40 months. **Clin Oral Investig.** 2013;17(3):823-32.
https://doi.org/10.1007/s00784-012-0790-5

Rosatto CM, Bicalho AA, Veríssimo C, Bragança GF, Rodrigues MP, Tantbirojn D, et al. Mechanical properties, shrinkage stress, cuspal strain and fracture resistance of molars restored with bulk-fill composites and incremental filling technique. **J Dent.** 2015;43(12):1519-28.
https://doi.org/10.1016/j.jdent.2015.09.007

Soares CJ, Bicalho AA, Verissimo C, Soares P, Tantbirojn D, Versluis A. Delayed photo-activation effects on mechanical properties of dual cured resin cements and finite element analysis of shrinkage stresses in teeth restored with ceramic inlays. **Oper Dent.** 2016;41(5):491-500.
https://doi.org/10.2341/15-090-L

Li Z, Yang Z, Zuo L, Meng Y. A three-dimensional finite element study on anterior laminate veneers with different incisal preparations. **J Prosthet Dent.** 2014;112(2):325-33.
https://doi.org/10.1016/j.prosdent.2013.09.023

Zarone F, Apicella D, Sorrentino R, Ferro V, Aversa R, Apicella A. Influence of tooth preparation design on the stress distribution in maxillary central incisors restored by means of alumina porcelain veneers: a 3D-finite element analysis. **Dent Mater.** 2005;21(12):1178-88.
https://doi.org/10.1016/j.dental.2005.02.014

Liu HL, Lin CL, Sun MT, Chang YH. Numerical investigation of macro- and micro-mechanics of a ceramic veneer bonded with various cement thicknesses using the typical and submodeling finite element approaches. **J Dent.** 2009;37(2):141-8.
https://doi.org/10.1016/j.jdent.2008.10.009

Ustun O, Ozturk AN. The evaluation of stress patterns in porcelain laminate veneers with different restoration designs and loading angles induced by functional loads: A three-dimensional finite element analysis study. **Niger J Clin Pract.** 2018;21(3):337-342.

Release para imprensa

RELEASE PARA IMPRENSA

Nos últimos anos a busca pela odontologia estética tem crescido fortemente. Cada vez mais a população tem buscado o sorriso ideal e dentes perfeitos. Vários tratamentos podem ser feitos visando a melhora estética do sorriso, dentre eles os laminados cerâmicos ou popularmente conhecidos como "lentes de contato dental", que nada mais são do que finas restaurações cerâmicas que são coladas aos dentes, buscando melhorar a cor e formato dos dentes. Estes procedimentos são realizados com mínimo desgaste dos dentes ou até mesmo sem nenhum desgaste. Porém na maioria das vezes a realização destes procedimentos sem desgaste, que a princípio seria uma vantagem, acaba gerando algumas complicações como restaurações insatisfatórias com algum degrau, margens espessas que pode gerar acúmulo de placa, inflamação gengival ou até mesmo cáries. Estas restaurações são cimentadas com cimentos resinosos ou resinas fluidas que são endurecidas pelo uso de luz azul. Ao ser ativada pela luz há a contração gerando tensões que podem gerar problemas futuros como trincas, fraturas, infiltração com manchamento e sensibilidade. Nesse nosso estudo simulamos em computador os efeitos de diferentes materiais usados para fixar essas restaurações. As características destes materiais foram medidas em laboratório e inseridas nos modelos computacionais onde foi simulado a contração de polimerização e um movimento de mordida de um alimento nos dentes anteriores. Nosso estudo mostrou que tanto a resina composta fluida quanto os cimentos resinosos, podendo ser utilizados para cimentação destas restaurações. Devido às várias complicações clínicas da técnica sem preparo dental, recomenda-se a realização de mínimo preparo dental desde que esta técnica não aumenta as tensões no dente e nem na cerâmica possibilitando melhor transição da restauração para o dente, minimiza riscos de degrau, trincas ou fraturas de cerâmica no momento de ajuste na boca.