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MINISTÉRIO DA EDUCAÇÃO
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FACULDADE DE ODONTOLOGIA
PROGRAMA DE PÓS GRADUAÇÃO

MARCEL SANTANA PRUDENTE

RESTAURAÇÕES INDIRETAS UNITÁRIAS OBTIDAS PELA TECNOLOGIA CAD/CAM CHAIRSIDE: AVALIAÇÃO LABORATORIAL

Tese apresentada à Faculdade de
Odontologia da Universidade de Uberlândia,
como requisito parcial, para obtenção do Título de
Doutor em Odontologia na Área de
Clínica Odontológica Integrada

Uberlândia, 2017

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Orientador: Prof. Dr. Flávio Domingues das Neves
Banca Examinadora:
Prof. Dr. Carlos José Soares
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Ata da defesa de TESE DE DOUTORADO junto ao Programa de Pós-graduação em Odontologia da Faculdade de Odontologia da Universidade Federal de Uberlândia.

Defesa de: Tese de Doutorado nº 017 - COPOD
Data: 15/02/2017
Discente: **Marcel Santana Prudente; Matrícula 11313ODO007.**
Título do Trabalho: Restaurações indiretas unitárias obtidas pela tecnologia CAD/CAM chairside: avaliação laboratorial
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As **oito** horas do dia **quinze de fevereiro de 2017** 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 2017, assim composta: Professores Doutores: Carlos José Soares (UFU); Luis Henrique Araújo Raposo (UFU); João Paulo da Silva Neto (UEPB); Márcia Borba (UPF); Karla Zancopé (UFU) coorientador(a) do(a) candidato(a) **Marcel Santana Prudente.**

Iniciando os trabalhos o(a) presidente da mesa Dra. Karla Zancopé 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.

A seguir o senhor(a) presidente concedeu a palavra, pela ordem sucessivamente, aos(às) examinadore(a)(s), que passaram a argüir o(a) candidato(a). Finalizada a argüição, que se desenvolveu dentro dos termos regimentais, a Banca, em sessão secreta, atribuiu os conceitos finais.

Em face do resultado obtido, a Banca Examinadora considerou o(a) candidato(a) A provado(a).

Esta defesa de Tese de Doutorado é parte dos requisitos necessários à obtenção do título de Doutor. O competente diploma será expedido após cumprimento dos demais requisitos, conforme as normas do Programa, a legislação pertinente e a regulamentação interna da UFU.

Nada mais havendo a tratar foram encerrados os trabalhos às 14 horas e 00 minutos. Foi lavrada a presente ata que após lida e achada conforme foi assinada pela Banca Examinadora.

Profa. Dra. Márcia Borba – UPF

Prof. Dr. João Paulo da Silva Neto – UEPB

Prof. Dr. Carlos José Soares – UFU

Prof. Dr. Luis Henrique Araújo Raposo – UFU

Profa. Dra. Karla Zancopé – UFU
Coorientador(a)

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Dedico este trabalho a minha esposa Sara e a minha filha Alice, meus pais Marilda e Célio.

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"Para ter algo que nunca teve, é preciso fazer algo que nunca fez"
Chico Xavier

SUMÁRIO

Resumo 9

Abstract 10

1 Introdução e Referencial Teórico 11

2 Objetivos Específicos 15

3 Capítulos

Capítulo 1 16

Micro-CT marginal fit evaluation of chairside CAD/CAM crowns fabricated with different ceramic materials

Capítulo 2 28

Influence of scanner, powder application and adjustments on CAD/CAM crown misfit.

Capítulo 3 49

Influence of luting space settings on internal and marginal fit and polymerization shrinkage deformation of CAD/CAM ceramic crowns.

4 Conclusões 73

5 Referências 74

RESUMO

O sistema CAD/CAM na Odontologia é uma alternativa para a confecção de coroa totais cerâmicas. A adaptação marginal destas coroas depende da correta utilização do escâner, software e fresadora. O tipo do material cerâmico selecionado para a fabricação das coroas no sistema CAD/CAM, pode influenciar na qualidade final da adaptação marginal. Sabe –se que a seleção do material cerâmico é realizada considerando as propriedades mecânicas físicas e óticas e a região a ser reabilitada, porém identificar materiais que trazem melhor adaptação pode ser mais um fator importante nesta seleção (Capitulo 1). Além disso, novas tecnologias de aquisição de dados de diferentes escâneres podem impactar na adaptação marginal e o uso de técnicas devem ser estudadas para minimizar esta influência (Capitulo 2). Por fim, a variação dos parâmetros definidos no software, como o espaço de cimentação, determina a precisão de assentamento marginal e interno da coroa. Por consequência, a adaptação interna está correlacionada ao espaço ocupado pelo cimento resinoso e a variação deste pode influenciar a quantidade de cimento e fragilizar a restauração devido a contração de polimerização e deformação da coroa. Além disso, fatores relacionados com a espessura das cerâmicas, podem atenuar a irradiância e o comprimento de onda, que altera o padrão de polimerização e deformação da coroa (Capítulo 3). Portanto, o equilíbrio entre a utilização adequada da tecnologia do escâner, parâmetros do software, espessura do cimento resinoso e do material cerâmico devem ser consideradas para se obter boa adaptação marginal e interna das coroas.

Palavras chaves: CAD/CAM, adaptação marginal, contração de polimerização

ABSTRACT

CAD / CAM system in dentistry is an alternative to obtain all-ceramic crowns. The marginal adaptation of these crowns depends on the correct use of the scanner, software and milling machine. The type of ceramic material selected CAD / CAM crowns could influence the marginal adaptation. It is known that the selection of the ceramic material is carried out considering physical and optical properties and a region to be rehabilitated, but identifying the materials that bring the best fit may be another factor (Chapter 1). In addition, new data acquisition technologies of different scanners could minimize the marginal adaptation (Chapter 2). Finally, the range of the luting space parameters determines the degree of marginal and internal seating of the crown. Consequently, an internal fit is correlated to the space occupied by the resin cement and a variation could influence a quantity of cement and a crown resistance. In addition, the ceramics thickness could attenuate the irradiation and the wavelength, which alter the polymerization and deformation of the crown (Chapter 3). Therefore, the balance between the use of scanner technology, software, resin resin thickness and ceramic material should be considered to have a crowns with good marginal and internal fit.

Key words: CAD/CAM, fit, shrinkage deformation

1. INTRODUÇÃO E REFERENCIAL TEÓRICO

Os sistemas de desenho auxiliado por computador e de usinagem auxiliado por computador (CAD/CAMs) evoluíram consideravelmente durante os últimos anos e são usados por cirurgiões-dentistas e laboratórios de prótese ao redor do mundo. Essa tecnologia transformou a Odontologia moderna, criando novas possibilidades para obtenção de restaurações cerâmicas. Atualmente, existem diferentes tipos de sistemas CAD/CAM e uma das preocupações é uma melhor adaptação marginal dessas restaurações (Hamza *et al*. 2013; Neves *et al*., 2014[A], 2014[B], 2015; Prudente *et al.,* 2015). Infelizmente não existe consenso quanto a um valor referencial de adaptação, que fosse aceitável clinicamente e que pudesse ser adotado para análise de resultados *in vitro* e *in vivo* de próteses. A adaptação aceitável na literatura é variável: 120 µm (McLean & von Fraunhofer, 1971) 100 µm (Holmes *et al.,* 1992) 75 µm(Hung *et al.,* 1990). Porém, apesar destes valores, sempre busca-se coroas com menor desadaptação minimizando a doença periodontal e cáries secundárias, por isso valores de 75 µm podem ser referência (Neves *et al*., 2014[A], 2014[B], 2015, Prudente et al. 2015).

O sistema CAD/CAM é formado pelo CAD, estruturado pela união de dois componentes (escâner e software) e o CAM por um equipamento de manufatura, normalmente uma fresadora (Kayatt & Neves, 2012; Beuer *et al*., 2008). Nos equipamentos de consultório, o primeiro componente do CAD, se baseia na captura de imagens por meio de um escâner intra-oral e o segundo é composto por um software de planejamento ou desenho, no qual parâmetros podem ser definidos, como seleção do espaço de cimentação, extensão da restauração e tipo de material cerâmico. As informações geradas pelo software são enviadas para uma máquina fresadora (CAM), que executará o processo de usinagem das peças diminuindo o tempo clínico e laboratorial (Kayatt & Neves, 2012; Prudente *et al*., 2015).

Um dos sistemas CAD/CAM mais utilizados dentro dos consultórios é o Sistema Cerec, que na sua terceira versão passou a ser muito aceito na comunidade odontológica pela precisão da adaptação (Prudente *et al.,* 2015). Neste equipamento pode-se obter rapidamente coroas em cerâmica vítreas livres de metal. Estas cerâmicas são disponibilizadas em blocos de diferentes materiais a base de feldspática, leucita, dissilicato de lítio e também como materiais híbridos como polímeros, polímeros reforçados por cerâmica e cerâmicas não vítreas como as zircônias (Li, Chow & Matinlinna, 2014) . Estes materiais estão comercialmente disponíveis por diferentes empresas. Ocorre que a seleção do material cerâmico é realizada levando em consideração as propriedades físicas e óticas e a região a ser reabilitada (Stawarczyk *et al*., 2015), porém identificar materiais que trazem melhor adaptação pode ser mais um fator a ser considerado durante a seleção.

Existe na literatura dados deficientes sobre a variação do tipo de cerâmica e sua influência na adaptação. Este fato ocorre, pois os dado apresentados em diferentes artigos utilizaram diferentes metodologias para análise de discrepância marginal, com número de medidas, parâmetros/tipo do software, tecnologia de fresagem, morfologia e qualidade do preparo dentário diferentes (Keshvad *et al*., 2011). Assim, a padronização do escâner, software e fresadora poderia responder esta questão, utilizando o material cerâmico como única variável.

Considerando os tipos de escâneres comercializados pelo sistema Cerec, duas formas de aquisição de dados estão disponíveis e recebem o nome de Bluecam e Omnicam (Prudente *et al*., 2015; Boeddinghaus *et al.,* 2015). O escâner Bluecam realiza a captura dos dados por meio de imagens – fotografias, que só podem ser obtidas após aplicação de uma fina camada de um pó opacificador - dióxido de titânio. Após a captura, as imagens são agrupadas e o modelo 3D é gerado (Boeddinghaus *et al.,* 2015). A literatura demonstrou que a aplicação do referido pó, previamente ao escaneamento é fundamental para a qualidade da imagem capturada por este escâner (Neves *et al*., 2014a, 2014b, 2015). Estudo recente mostrou que coroas de dissilicato de lítio obtidas pelo sistema Cerec com escâner Bluecam apresentou linha de cimentação marginal média de 39,2 µm (Neves *et al.,* 2014).

Em 2012, a Sirona disponibilizou comercialmente um escâner chamado Omnicam para o Sistema Cerec. Esta tecnologia captura os dados por meio de vídeo, sem a necessidade da aplicação de pó nas estruturas a serem escaneadas. Assim, os modelos 3D são gerados em cores e em tempo real (Boeddinghaus *et al.,* 2015). Até o presente momento, pouco tem sido relatado sobre esta câmera. Um artigo recente usou 110 µm de parâmetro para o espaço de cimentação e encontrou coroas com 82.1 µm de desajuste marginal (Renne *et al.,* 2015). No entanto, de acordo com as instruções do fabricante, é indicado o ajuste do parâmetro em 80 µm (Manual do operador 4.2 software 4.2.x). Assim fica uma lacuna na literatura para ser estudada em relação a este novo escâner e ao espaço de cimentação adequado.

A questão é: se selecionado valores menores no software para o parâmetro do espaço de cimentação (como sugerido pelo fabricante), o assentamento da coroa pode ficar prejudicado, o que resultaria em desajuste vertical (Nakamura *et al.,* 2003, Contrepois *et al.,* 2014). Em contrapartida, maior espaço interno gera camada de cimento resinoso mais espessa, o que promove estresse no remanescente dentário e também nos materiais restauradores devido contração de polimerização (May *et al.,* 2012, 2013; Soares *et al.,* 2016). Isto pode levar a falhas do processo de cimentação e risco de fratura (May *et al.,* 2013). Esta contração gerada pela polimerização depende de múltiplos fatores, tais como a intensidade da luz, o tempo de fotoativação, o tempo decorrido entre a cimentação da coroa e a ativação da luz, o módulo elásticidade do cimento resinoso e a estrutura remanescente do dente (Tantbirojn *et al.,* 2004, Bicalho *et al.,* 2015 parte I, Pereira *et al.,* 2015, Soares *et al.,* 2016).

Além disso, é importante compreender a característica da fonte de fotoativação e seu uso, minimizando a contração do cimento resinoso e deformação da coroa. Porém, sabe-se que o tipo de cerâmica e sua espessura pode levar a atenuação da fotoativação e afetar o grau de polimerização do cimento e gerar microdeformação (O'Keefe *et al.,* 1991, Lopes *et al.,* 2015). Esta polimerização inadequada, caracterizada por baixo grau de conversão, diminui as propriedades mecânicas e aumenta a sorção da água, a solubilidade, o aumento da quantidade de monômeros residuais livres, podendo causar irritação à polpa e pulpite irreversível (Jung *et al.,* 2001, Lee *et al.,* 2011, Lopes *et al.,* 2015). Por outro lado, uma fonte de luz com alta irradiância pode aumentar a contração do cimento, deformação da coroa e trincas embos materiais e estruturas remanescentes.

Portanto, o equilíbrio entre a utilização adequada da tecnologia do escâner, parâmetros do software, espessura do cimento resinoso e do material cerâmico devem ser consideradas para se obter boa adaptação marginal vertical, horizontal e interna das coroas, minimizando a contração de polimerização do cimento e a deformação da cora e das estruturas dentárias remanescentes.

3- OBJETIVOS ESPECÍFICOS

I- Avaliar a discrepância marginal (vertical e horizontal) das coroas obtidas pelo sistema CAD/CAM Cerec chairisde com diferentes materiais cerâmicos, usando microtomografia computadorizada.

II- Investigar a influência de duas tecnologias diferentes de escâneres intraorais (Omnicam e Bluecam) na adaptação vertical, horizontal e interna das coroas, antes e após ajustes internos. Além disso, analisou-se a influência da aplicação de pó anteriormente ao escaneamento com a Omnicam na adaptação das coroas produzidas usando microtomografia computadorizada.

III- Avaliar coroas obtidas com a câmera intraoral Cerec Omnicam, utilizando diferentes valores do parâmetro para o espaço de cimentação no software 4.2.5, com relação ao ajuste marginal e interno por meio da microtomografia computadorizada e à deformação da coroa durante a polimerização por meio de extensiometria. Além disso avaliar a irradiância e comprimento de onda da luz, produzida pela unidade de fotoativação e capturadas por um sensor localizado abaixo de diferentes espessuras de cerâmica, equivalentes a face oclusal, lingual e vestibular, utilizando “MARC resin calibrator”.

CAPÍTULO 1

Marcel Santana Prudente, Letícia Resende Davi, Célio Jesus do Prado, Karla Zancopé, Thiago de Almeida do Prado Naves Carneiro, Carlos José Soares, Gustavo Mendonça, Flávio Domingues das Neves. **Micro-CT marginal fit evaluation of chairside CAD/CAM crowns fabricated with different ceramic materials.** Journal of Applied Oral Science.

ABSTRACT

Objective: The aim of this study was to evaluate the marginal fit of Cerec chairside crowns CAD/CAM system fabricated with different ceramic materials, using micro-computed tomography (μ-CT). Materials and Methods: One human premolar was prepared for all-ceramic crowns. Five different digital impressions with Cerec 3D Bluecam were made for each ceramic material group by applying a thin layer of titanium dioxide powder on the master model. For each virtual model obtained, the crowns were designed. The ceramic materials milled were divided into: D group (lithium disilicate), L group (leucite) and F group (feldspathic). Each crown (n=5) was fixed to the cast and scanned using μ-CT for measuring vertical and horizontal misfit. Data were statistically analyzed by 1-way ANOVA, followed by the Tukey honestly significant difference test (a=.05). Results: The mean values of vertical misfit were 39.1±37.0 μm for D group, 52.0±56.9 μm for L group, which were significantly lower values than for the F group at 62.5±65.1 μm (P<0.001). Both types of horizontal misfit (underextended and overextended) were 50.7% for D group, 51.1% for L group, and 63.1% for F group. Conclusion: The selection of the ceramic material could influence the fit of produced crowns, when using Cerec 3D Bluecam scanner chairside CAD/CAM system. Lithium disilicate and leucite crowns exhibited significantly smaller vertical misfit than feldspathic crowns.

INTRODUCTION

Nowadays, aesthetic dental restorations have become very popular in contemporary dentistry offering several advantages like biocompatibility with the oral environment, high strength to support masticatory forces, and good aesthetics due to its translucency and biomimetic color and reduced discoloration[9,15,24]. Recently, with the evolution of the computer-aided design (CAD) and computer-aided manufacturing (CAM) systems, the use of several ceramic materials has been increased[1] and monolithic crowns with feldspathic, leucite and lithium disilicate are largely used and the choice based on mechanical, aesthetic properties and marginal discrepancy[24].

All-ceramic crowns present some risk of fracture because ceramic is a brittle material. However, recent advances have enhanced its mechanical properties and **a**esthetic**s**. Therefore most choice is a feldspathic ceramic with fine crystalline structure, which ensures mismatching of tooth color and better enamel appearance[26]. Historically, the feldspathic ceramic could be used on anterior teeth given its low flexural strength of 94.08 ± 14.21 MPa and fracture toughness of 1.37 ± 0.22 MPa•m½[4,16,24]. Another option of aesthetic CAD/CAM ceramic material is a leucite glass-ceramic which presented flexural strength of 120 to 151 MPa, almost indicated for anterior crowns[3,24]. Considering the necessity to have a material indicated for both anterior and posterior crowns, the lithium disilicate CAD/CAM ceramic was introduced to the market with pre-crystallyzed blocks in a bluish color to facilitate the milling process with initial flexural strength of 130 MPa and after the heat crystallization process increases its strength to 360 MPa[16,24,25] and the fracture toughness is 0.9-1.1 MPa•m½[25]. This material is indicated for both anterior and posterior crowns and widely used for CAD/CAM users.

Although the mechanical and aesthetic properties of these ceramic materials are well established by dentists, another pivotal issue to the success of monolithic crowns is the marginal fit of CAD/CAM crowns. The literature presented in the study aims to show the accuracy of the crowns produced with different ceramic materials available for the CAD/CAM system. However, few studies presented isolated marginal discrepancy information with one type of ceramic produced by the widely used Cerec CAD/CAM system. The monolithic feldspathic crowns produced presented marginal discrepancy that ranged from 53 to 164 micrometers with Cerec 3[2,8,15,17,19]. However, the leucite ceramic material lacked information on marginal discrepancy, only regarding internal discrepancy, between 302 and 342μm[17]. Besides, a recent study presented for lithium disilicate crowns 39.2μm of marginal discrepancy[20].

The different results presented in the literature hinge upon several methodologies used for the type of marginal discrepancy analysis, number of measurements, cement space settings, scanning or milling technology, tooth preparation morphology and quality, operator and material experience[14]. However, all results are comparable with several acceptable values of vertical marginal discrepancy: 120 μm[18], ≤ 100 μm[12], and ≤ 75 μm[7,13,20,21] and few studies presented the horizontal misfit information which is an important issue to avoid periodontal disease and secondary caries[2,5]. To verify the marginal discrepancy, micro-computed tomography (μ-CT), which is a nondestructive method[11], was recently used to measure the marginal discrepancy of crowns with 3D reconstruction in several points without any damage to the crowns[8,22].

Therefore, the aim of this study was to evaluate the marginal discrepancy (vertical and horizontal) of crowns obtained from Cerec chairside CAD/CAM system with different ceramic materials using μ-CT. The null hypothesis was that the material used would not influence the marginal fit of the crowns.

MATERIAL AND METHODS

A human mandibular left first premolar positioned with adjacent artificial teeth on a master model typodont (Ethics Committee approval 381/06) were prepared with diamond burs (1014, 3145, 3098, and 3098F, KG Sorensen, São Paulo, Brazil), suitable for all-ceramic crowns. The preparation for an all-ceramic crown was free from undercuts, the angles were rounded, and the walls were tapered 6 degrees to the occlusal surface. The margins were prepared with shoulders and rounded axiogingival line angles.

A thin layer of titanium dioxide powder was applied to the surface of the preparation, the adjacent teeth, and the surrounding soft tissues (Cerec powder, VITA-Zahnfabrik, Bad Säckingen, Germany) and five different digital impressions were taken. Prior to each scan, a new powder layer was applied, simulating a clinical situation. This optimizes image quality by creating a matte finishing to the surface. Impressions of the prepared tooth were generated using a Cerec 3D Bluecam scanner (Sirona Dental Systems GmbH, Bensheim, Germany), in a standardized way. The crowns were designed in Cerec 3D software (version 4.0) with luting space and adhesive gap set to 70 µm.

An experienced operator designed all the crowns, and made some manual adjustments at the margin line automatically generated by the software. Finally, a Cerec inLab MC XL milling unit was used for CAM processing of all designed crowns, on the standard milling mode. Each crown, respectively, was milled with ceramic material. Three experimental groups (n = 5) were based on the material: group D: lithium disilicate crowns (IPS e.max, Ivoclar Vivadent AG, Schaan, Liechtenstein); group L: leucite glass-ceramic crowns (IPS Empress CAD, Ivoclar Vivadent AG, Schaan, Liechtenstein); and group F: feldspathic ceramic crowns (VITABLOCS Mark II, VITA-Zahnfabrik, Bad Säckingen, Germany).

No internal adjustments were made to the ceramic crowns before marginal-fit measurements. The prepared tooth was removed from the typodont and each crown was fixed to the same tooth using silicone material (Fit Checker, GC Dental Industrial Corp, Tokyo, Japan), through digital pressing. To obtain images for marginal-fit measurements, all specimens were scanned using µ-CT (Scanco CT40, Scanco Medical AG, Zürich, Switzerland). Imaging was performed at 70 kVp and 112 µA with resolution of 1024x1024 pixels. Pixel size and slice width were both 8 µm and the scan time was approximately 1 hour.

Thirteen images from the sagittal set and thirteen images from the coronal set were selected to evaluate all the sample extension in two different planes. The thirteen selected images were equally distributed between the first and the last images that contained the cervical margin[7,20,21]. For each image two measurements of horizontal fit and two of vertical fit were performed at 400x magnification using CTAn processing software (Version 1.12.0.0, Skyscan, Kontich, Belgium).

For vertical fit, the measurements were taken from the external crown margin to the outermost point of the tooth; for horizontal fit, the measurements were taken from the outermost point at the prepared margin of the tooth to the crown margin, according to previously methodology[7,20,21].

Statistical analyses were performed with Sigma Plot statistical software (version 12.0, Systat Software Inc., San Jose, CA, USA). The values of vertical measurements were submitted to statistical analysis through one-way analysis of variance (ANOVA) followed by Tukey's post hoc test for pair-wise comparisons ($\alpha = .05$). Vertical marginal fits were grouped according to the following values: 1) ≤ 75 µm[7,13,20,21], 2) 75–100 µm[12], 3) 100–120 µm[18], and 4) > 120 µm[6]. The maximum acceptable vertical marginal discrepancy was set to 75 µm. In addition, horizontal marginal discrepancy values were placed into three categories[7,20,21]: 1) underextended, 2) equally extended, and 3) overextended.

RESULTS

The mean and standard deviation of vertical misfit values (µm) are shown in Table 1. Significant difference ($P < 0.05$) was found among group F and the other groups. Group F showed significantly higher vertical misfit values than the other 2 groups. Additionally, no difference was detected between D and L groups. For each of the 3 techniques, vertical misfit values for the lithium disilicate crowns were most often <75 µm (Table 2).

Horizontal marginal discrepancy values were also calculated for each group (Fig. 1).

DISCUSSION

The null hypothesis that the material used would not influence the marginal fit of the crowns was rejected. The results revealed statistically significant differences in the marginal fit of ceramic crowns produced by feldspathic ceramic compared to the other~~s~~ ceramic materials. The results of vertical and horizontal discrepancy favored the use of lithium disilicate and leucite crowns for manufacturing ceramic samples.

The present study presented values of vertical discrepancy of feldspathic crowns according to Nakamura, et al.[19] (2003) that presented values of marginal discrepancy between 53-66 µm, when the luting space was set to 30 µm. Demir, Ozturk and Malkoc,[8] (2014), presented similar vertical marginal discrepancy between 50 to 60 µm. Another study[20] that analyzed the marginal discrepancy of lithium disilicate crowns also presented a marginal discrepancy (39.2 µm) similar to that of the present study. These differences in marginal discrepancy could be justified by the physical properties of each material, different software, several methodologies used in the type of marginal discrepancy analysis, number of measurements, cement space settings[14]. In the present study, the cement space settings were selected with 70 µm, considering the manufacturer instructions for Cerec system software 4.0 and milled in a MCXL machine. It is pivotal that all studies present this information in the future researches.

In previous studies it was shown that ~~as~~ the brittleness index of a ceramic material and milling vibration increase~~s~~ the potential for marginal chipping defects on porcelain margins, justifying the mean of group F[14,23]. Although the feldspathic ceramic presented the lowest mechanical properties[4,16,24] and influenced the marginal discrepancy, the use of leucite could be an option to avoid failures of marginal discrepancy because it offers the best mechanical properties[3,24]. Another aspect is the milling process of crystalized ceramic blocks, which could jeopardize the feldspathic crowns margin. Therefore, the precrystalized state of the lithium disilicate allows the block to be milled easily without excessive diamond bur wear, avoiding damage to the material and margin chipping because it yielded 130 Mpa in the pre-crystallized presentation[16,24,25]. However, the leucite and lithium disilicate ceramic-presented very similar aesthetic characteristics to the feldspathic ceramic enamel appearance[26].

To ensure accuracy of the results, the present study had only one prepared tooth to eliminate the possible variations of preparation and took five different digital impressions to obtain fair results[14]. This fact determined the real influence of material on marginal discrepancy of the crowns and to show the results are presented clearly by percentile (Table 2), to express the percentage of values classified into each category. The authors of the present study believe that the limit of an acceptable marginal discrepancy should be 75µm[7,13,20,21]. According to the percentage of values up to 75µm, lithium disilicate, leucite and feldspathic ceramic crowns could be used to obtain clinically acceptable crowns.

Additionally, dental crowns with significant horizontal discrepancy on the margin could have retention of food and bacteria, leading to periodontal inflammation and secondary caries, reducing restoration longevity[2,5]. In this study, most values obtained for lithium disilicate and leucite crowns presented no horizontal mismatches, decreasing disease risk. It is important to note that no adjustments were made to fit the crowns before the measurement procedure. Therefore, it is important that horizontal discrepancies such as crown overhangs could be adjusted with diamond burs before cementation to avoid disease[5].

All these results could be easily obtained using the µ-CT[8,11,22] and have been used for recent studies[7,8,20,21]. In future studies, the position of the samples has to be undertaken with a specific device inside the CT scanner to standardize the measurements and determin~~ed~~ the specific point of marginal discrepancy. Long-term clinical data are required to validate the results of this in vitro study.

Considering the limitations of this study, the Cerec 3D Bluecam chairside CAD/CAM system provided accurately fitting of crowns with software 4.0 and cement space of 70 micrometers. The ceramic material indeed influences the fitting of monolithic crowns produced by Cerec CAD/CAM system. Leucite and lithium disilicate crowns presented statistically lower vertical and horizontal discrepancy than feldspathic crowns. According to the percentage of values up to 75µm, all-ceramic materials tested in the present study can be used to obtain clinically acceptable crowns. Several Cerec users all over the world produce all-ceramic crowns with Bluecam scanner using the software 4.0 and MCXL milling unit. It is important to understand the impact of using different materials to produce dental restorations in the final fit justifying this research. New materials, scanning technologies, software and milling units are now available in the market and should be tested and evaluated to verify the influence of each one on marginal discrepancy.

CONCLUSION

Within the limitations of this study, the selection of the ceramic material could influence the fitting of produced crowns, when using Cerec 3D Bluecam scanner chairside CAD/CAM system. Lithium disilicate and leucite crowns fabricated exhibited significantly smaller vertical misfit than feldspathic crowns.

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Tables

Table 1 – Mean values and standard deviation of vertical marginal gap in μm.

Lithium dissilicate	Leucite	Feldspathic
39.1±37.0 A	52.0±56.9 A	62.5±65.1 B

Different upper case letters represent significant differences (α<0.05).

Table 2 – Ranges of vertical misfit for each group.

	Up to 75μm	75μm–100μm	100μm–120μm	Over 120μm
Lithium Disilicate	83.8%	10.7%	2.3%	3.2%
Leucite	73.0%	9.6%	4.2%	13.2%
Feldspathic	71.5%	9.6%	3.8%	15.1%

FIGURE LEGENDS

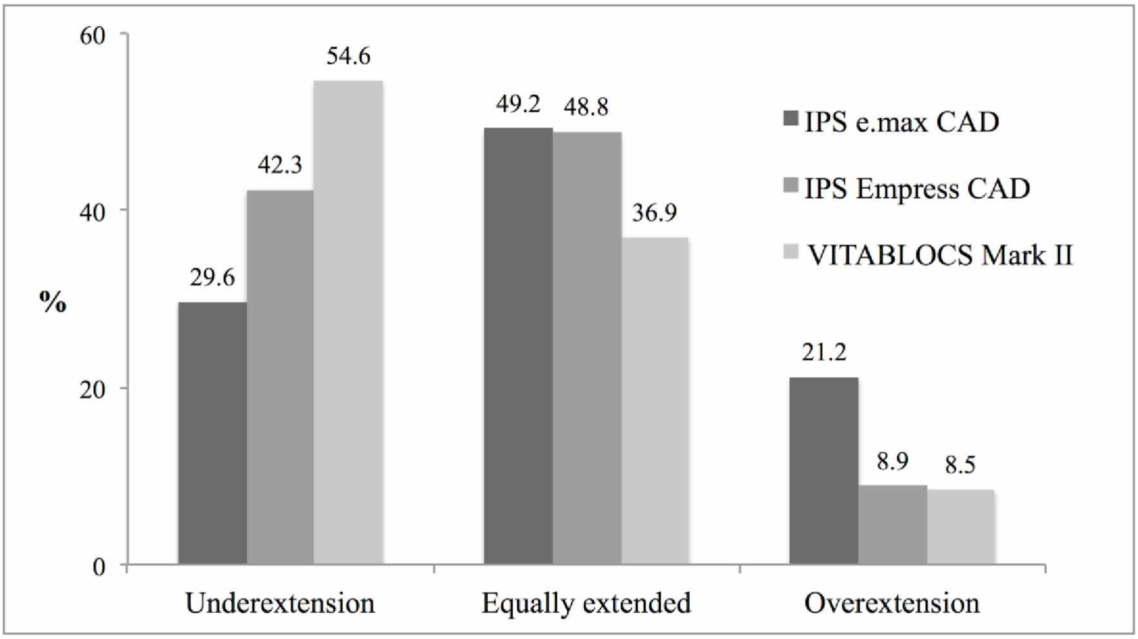

Fig. 1. Percentage of underextended, equally extended, or overextended crowns fitted to the prepared tooth.

CAPÍTULO 2

Marcel Santana Prudente, Letícia Resende Davi, Célio Jesus do Prado Karla Zancopé, Leandro Maruki Pereira, Kemmilly de Oliveira Nabbout, Flávio Domingues das Neves. **Influence of scanner, powder application and adjustments on CAD/CAM crown misfit. Journal of Prosthetic Dentistry.**

ABSTRACT

Statement of problem. The manufactures of CAD/CAM systems emphasize that new technologies improve marginal discrepancy. However, data supporting such a statement is limited.

Purpose. The purpose of this study was to investigate the influence of: (1) different intraoral optical scanners, (2) powder application and (3) adjustments in the intaglio surface, on crowns marginal discrepancy.

Methods. Single human premolar was fixed on typodont and prepared to receive Cerec CAD/CAM crowns. Three fabrication techniques were used: digital impressions with Bluecam scanner with titanium dioxide powder (TDP), digital impressions Omnicam scanner without TDP and digital impressions with Omnicam scanner with TDP. Five experimental groups (n=10) were designated: Bluecam (Group B), Bluecam with adjustments (Group BA), Omnicam (Group O), Omnicam with adjustments (Group OA) and Omnicam with powder (Group OP). Specimens were scanned with micro-computed tomography to measure vertical, horizontal, internal fit and volumetric 3D internal fit value of each luting space. Paired t-test was used to evaluate mean marginal fit change after adjustments, within the same group. One-way ANOVA and post hoc test were used for comparison among B, O and OP groups (α=.05).

Results. Mean vertical fit values and standard deviation were: B= 29.5(13.2)µm; BA= 26.9(7.7)µm; O= 149.4(64.4)µm; OA= 49.4(12.7)µm and OP= 33.0(8.3)µm. Adjustments in the intaglio surface and powder application statistically influenced the vertical fit of Group O. The percentage of vertical fit values < 75 µm were: B=89.3%, BA=92.7%, O=31.0%, OA=73.5% and OP=92.0%. Mean horizontal fit values were: B= 56.2(21.5)µm; BA= 85.8(44.4)µm; O= 77.5(11.8)µm; OA= 102.5(16.2)µm and OP=

91.4(19.4)μm. Group B presented significant difference from the other tested groups (*P*<.05). The percentages of horizontal misfit were: B= 61.2%, BA= 73.5%, O= 88.1%, OA= 92.4% and OP=85.0%. Volumetric 3D internal fit values were: B= 9.4(1.3)mm^3, BA= 10.7(1.0)mm^3, O= 11.8(2.1)mm^3, OA= 11.0(1.3)mm^3 and OP= 9.6(0.9)mm^3. B and OP presented significantly better results than O group.

Conclusions. Different intraoral optical scanners, powder application and internal adjustments influenced crowns marginal discrepancy. Crowns fabricated by Omnicam had significantly higher vertical discrepancy and internal volume than Bluecam scanner with powder. Adjustments of the intaglio surface improved the vertical fit of Omnicam crowns. However, powder application before Omnicam scanning improved the vertical fit and internal fit 3D value of luting space of crowns.

CLINICAL IMPLICATIONS:

Powder application before Omnicam scanning improves the vertical fit of crowns and decreased 3D luting space.

INTRODUCTION

The computer assisted design/computer assisted technology (CAD/CAM) revolution in dentistry permitted the production of ceramic restoration in a reduced time with acceptable fitting accuracy in dental laboratories and offices.[1,2,3] This technology was developed for dental offices (chairside CAD/CAM) and becomes an alternative to the traditional techniques.[4,5]

Historically each step and upgrade in the CAD/CAM system, from optical impression to machining influenced the marginal discrepancy of restorations.[3] The first feldspathic ceramic inlays produced by Cerec (Sirona Dental Systems GmbH) chairside

CAD/CAM in 1984 presented marginal gap between 140 and 256 μm.[6-9] In 1988, the upgrades of software started to produce onlays and veneers.[8] Later, in 1994, the new Cerec 2 presented additional cylinder diamond, enabling the grinding of partial coverage and complete crowns with margin fit range 50 to 150 μm.[10] In 2000, the Cerec 3 included an enhanced intraoral optical camera that reproduce more details, a scaled depth and the wheel was skipped in the CAM, and introduced two-bur-system[9]. All data acquisitions using Cerec 1, 2 and 3 generated 2D images.[8]

In 2003 the new generation of Cerec 3 was updated with a charge-coupled device (CCD) camera that can take a three-dimensional image.[8,11] According to recent studies, the Cerec Bluecam system presented 39.2 μm of crowns marginal fit with 3D image capturing with a titanium powder application before scanning.[12,13] The powder application improved the image quality, creating a matte surface in different materials improving the crowns fit.[12-14]

Recently, Cerec introduced the new camera Omnicam, which generates a 3D model with real color and in real time by video camera without powder application before scanning.[15] Omnicam scanning process should be in dry conditions and the camera holding as close to the specimen to acquire accurate digital intraoral scans.[16] Software upgrades minimize the possible errors on scanning[17] and the evolution of CAD/CAM system reduced marginal discrepancy.[8] New technologies of camera are attractive but should have similar or better results than others existed technologies, to be cost effective.[18] The real accuracy of scanning, designing and milling steps of CAD/CAM technology was tested to ensure the health of tissues.[19]

Therefore, the aim of this study was to (1) investigate the influence of two different technologies of intraoral optical scanners (Omnicam and Bluecam), (2) investigate the influence of the intaglio surface adjustments, and (3) the influence of powder application previously to the Omnicam scanning, in the vertical, horizontal and internal discrepancy of crowns. The null hypothesis of this study was that vertical, horizontal and internal fit of crowns would not be influenced by different technologies of intraoral optical scanners, intaglio surface adjustments and previously powder application.

MATERIAL AND METHODS

Preparation of teeth

A premolar was fixed on typodont (Ethics Committee approval 381/06) and was prepared to receive a ceramic crown with 6 degrees total angle of convergence to the occlusal surface, shoulder margins with 1.5 mm wide and rounded axiogingival angles. The 5 experimental groups (n=10) used lithium disilicate (IPS e.max CAD; Ivoclar Vivadent AG) to obtain crowns according to Table I.

Scanning procedures

For the Bluecam (B) and Adjusted Bluecam (BA) groups, powder was applied to the preparation surface of typodont with an aerosol (Cerec powder; Vita-Zahnfabrik). An intra-oral scanner (Cerec 3D Bluecam scanner; Sirona Dental Systems GmbH) was used to obtain optical impressions. Single 3D frames were captured, creating a 3D model in the software (version 4.0; Sirona Dental Systems GmbH).

The Omnicam (O) and Adjusted Omnicam (OA) groups had the surface of the preparations and surrounding teeth scanned with a powder-free camera. The camera was positioned perpendicular and as close to the specimen as possible, rather than at a 45° angle and dry conditions (Omnicam; Sirona Dental Systems GmbH)[16] and a another software was used (Cerec 4.2.5; Sirona Dental Systems GmbH). This new technology of camera and software allows for the capture of several 3D frames per second, generating the 3D model in real time and real color, decreasing the scanning time.[15]

The Omnicam Powdered (OP) group was also scanned with a camera (Omnicam; Sirona Dental Systems GmbH), but a thin layer of powder (Cerec powder; Vita-Zahnfabrik) was applied to the surface of the preparation and surrounding teeth of the typodont.

Crown design and milling process

The Bluecam crowns were designed with 4.0 software with a luting space for adhesive cementation of 70 micrometers according to the manufacturer's instructions. The Omnicam crowns were designed in the 4.2.5 software, and the luting space for adhesive cementation was set at 80 micrometers according to manufacturer's instructions. A milling unit (Cerec inLab MC XL; Sirona Dental Systems GmbH) was used to mill the crowns of all groups.

No internal adjustments, glazing or polishing were made in the crowns of the B, O and OP groups before the marginal fit measurements.

Scanning procedures

Each crown was fitted and fixed with the silicone-based material on premolar (GC Fit Checker; GC Dental Industrial Corp.) and were scanned using micro-computed tomography (µ-CT; Skyscan 1272) in CPBio (Research Center of Biomechanics, Biomaterials and Cell Biology) to obtain images for measurements of the marginal[12-14] and internal discrepancy.[11,17]

µ-CT scanning was performed at 100 kV and 100 µA, with a pixel size of 9.4 µm, Filter Cu 0.11 mm and resolution of 1632x1092 pixels. The selected scanning was performed at 0.4 degrees of rotation step at 360 degrees; to diminish artifacts, an average of 2 frames were collected with 20 pixel random movements, resulting in a scanning time of 2 hours per specimen.

Adjustments of the intaglio surface

After scanning of the crowns for B and O groups, the thin layer of silicone-based material was checked, guiding the adjustments of the intaglio surfaces of the crowns. After adjustments the crowns for BA and OA groups were created and scanned.

Images reconstruction

The μ-CT images needs to be reconstructed before analyses. In this step, images' artifacts could be eliminated. The reconstruction of images was obtained by software (NRecon, version 1.6.8.0; SkyScan), and the following parameters were used: smoothing of 5, ring artifact correction of 10 and beam hardening correction of 5%. After that, another software (Data viewer software, version 1.5.0.2; SkyScan) obtained sagittal and coronal images dataset. Next, 13 images from the sagittal set and 13 images from the coronal set were selected to illustrate specimen extension in 2 different planes, according to previous studies.[12-14] The 13 selected images were evenly distributed between the first and last images that presented the tooth cervical margin. Thirteen coronal and thirteen sagittal images, equally distributed between the first and last image selected, were analyzed.

Measurements procedures

In each image selected the measurements for vertical, horizontal fit were performed at 300x magnification using the processing software (CTAN, version 1.12.0.0; SkyScan).

Fifty-two measurements per specimen were performed according to previous studies and mean was calculated.[12-14] The maximum acceptable vertical fit was set to 75 μm and percentage number was recordable.[12-14] The horizontal fit was calculated considering all values as positive, however the percentage of underextended, equally extended, and overextended data was performed.

Internal fit between the crown and prepared tooth was also evaluated using μ-CT. The central image of all selected coronal and sagittal cuts was selected, and 6 points were measured for both images: 2 axial, 2 occlusal and 2 internal margins, according to Figure 1.

The space between the intaglio surface of the crown and the prepared tooth is known as luting space. To obtain the volumetric 3D internal fit value of luting space of each specimen, the software (CTAN, version 1.12.0.0; SkyScan) was used and all images without cement were excluded. One by one, the luting space was identified manually and determined with binary selection based on the gray scale indexes. A morphometric analysis was performed based on the individual 3D object analysis, so the volumetric 3D internal fit value of each cement space was recorded.

Statistical analyses were performed with statistical software (SigmaPlot v12.0; Systat Software Inc.). The means and standard deviation were calculated in each group. Paired t-test was used to evaluate mean marginal gaps change after adjustments (B and BO) and (O and OP), within the same group. One-way ANOVA and post hoc test were used for comparison among B, O and OP groups (α=.05).

RESULTS

Considering the groups of scanners tested, the mean data, standard deviation, percentage of values <75 μm and coefficient of variation of the vertical fit, horizontal fit and volumetric 3D internal fit values (µm) are shown in Table 2 and Figure 2. B and OP presented significantly better results than O group, considering vertical fit and volumetric 3D internal fit values. Considering horizontal fit, group B presented significant difference from the other tested groups. The internal fit measured, showed intaglio contact of the Omnicam crowns to the prepared teeth on point M5 of axial wall (Table 3). The powder application statistically influenced group O, and vertical fit and 3D internal volume fit presented values similar than Bluecam, except in horizontal fit.

Adjustments in the intaglio surface for Bluecam groups with powder, negatively affected the horizontal fit ($P=.015$) and 3D internal volume ($P=.029$) and no influenced on vertical fit ($P=.579$) (Table 4). For Omnicam group, the adjustments statistically improved the vertical fit of crowns ($P<.001$), however higher horizontal misfit was recorded ($P=.005$). Considering 3D internal volume, no difference was presented after crowns intaglio surface adjustments ($P=.270$) (Table 5).

The percentages of horizontal fit values were also calculated for each group (Fig. 3). The underextended and overextended values were added to represent the horizontal fit of each group. The horizontal fit were 61.2% of the B group, 73.5% of the BA group, 88.2% of the O group, 92% of the OA group and 85% for the OP group. The best result was presented for Bluecam group.

DISCUSSION

The null hypothesis of this study was rejected. Vertical fit, horizontal fit and 3D internal volume of crowns was influenced by different technologies of intraoral optical scanners, intaglio surface adjustments and previously powder application.

Different intraoral optical chairside scanners and its software influence the vertical and internal volume of lithium disilicate crowns discrepancy. Considering the vertical and internal fit, the results favored the Bluecam scanner and Omnicam with powder application. Bluecam is based on blue-light scanning technologies, which use short wavelengths, resulting in high levels of accuracy.[18] Other important aspect is that Bluecam scanning process is dependent a thin layer of powder to generate a matte finishing on the surface and prevent reflections during image capture.[5] This characteristic could improve the marginal fit of the crowns because the finish line of the preparation is easily detectable.[12-14] However, the Omnicam scanner technology is based on optical 3D video scanners that capture data on in real time and color without powder application. The similar technology of capture data by video permit to have several 3D images per second without powder application.[5] In the present study, the crowns produced by this system presented higher fit of 149.4 µm with software 4.2.5. This finding corroborated with recent study that presented similar results of 149 µm with software 4.2.1.[15]

This alternative method evaluated (group OP) was the application of titanium dioxide powder on the prepared tooth to improve the marginal fit of the crowns made with Omnicam scanner. A previous study indicated that E4D (E4D laser scan, D4D Technologies) chairside CAD/CAM (a powder free scanner) exhibited significantly smaller vertical crown fit when powder was used before digital impressioning.[14] Based on the present results, the powder application improved the vertical fit and internal volume and should be considered an option to reduce the adjustments of the intaglio surface of the crowns. It was observed that the OP groups reduced the coefficient of variation of data (Table 2) and improved the percentage of values less than 75µm: for the group O was 31% and for OP 92%. These numbers emphasizes the benefit of powder application before scanning, improving the marginal discrepancy of crowns made with Omnicam scanner, reducing the risk of microleakage, periodontal disease, and recurrent caries.[19]

The reduced value of 3D internal volume presented on group B and OP could optimize the fixation of crowns based on reduced cement, however the highest values presented by group O could present highest thickness of cement. The benefits of bonding are limited by the reduced cement thickness and could jeopardize the fixation of the crowns due to the increasing influence of polymerization shrinkage stresses.[20] Polymerization shrinkage can cause tensile stresses in the intaglio surface of crowns, that would be enough to cause its fracture with thicker cement.[20] Cement shrinkage was also predicted to cause debonding of the cement from the ceramic.[20]

Influences of the scanning technology were presented by the horizontal fit (Group B 56.2 μm) and a recent study presented similar results (69.7 μm) for Bluecam crowns corroborating with this study.[21]

The adjustments of crowns intaglio surface were performed using a silicone material and diamond burs to improve the marginal fit. Clinically, the adjustment on the prepared tooth is recommended[22] to avoid ceramic damage [23] and clinical longevity. Moreover in the present study, the authors only used one prepared tooth for all specimens, so it was impossible to perform any adjustment on the tooth. This procedure reduced the vertical fit of crowns significantly for group O (149 μm) to OA (49.3 μm), however increased the horizontal fit (77.5 to 102.5) and did not influence the volumetric 3D internal fit. However, this procedure not affects positively the vertical fit, horizontal and volumetric 3D internal fit of group B to BA. It was observed that the coefficient of variation of data (Table 2) reduced after adjustments on intaglio surface of crowns and the percentage of values less than 75 micrometers for the group O was 31% and for group OA was 73.5%.

Another step that could be manually modified in the study was the internal luting space selection. All groups used the manufacturer's recommendations. Groups B and BA should be 70 μm in the software version 4.0; for groups O, OA and OP, were used 80 μm in the software version 4.2.5. These parameters were analyzed to verify the reproducibility between the luting space settings at the software and the measurements of the internal area. First, the 70 μm parameter selected in the software version 4.0 for group B generated a space ranging between 16-230 μm and 9.4 mm^3 of 3D volume, and the 80 μm parameter selected in the software version 4.2.5 for group O ranged between 0-276.9 μm and 11.81 mm^3 of 3D volume. Another study determined that the selection of 30 μm for this parameter in the Cerec 3 software showed an internal gap that ranged between 116 and 162 μm.[11] However, the reproducibility of the defined space may not be exactly as expected, considering the results of the present study.

It was expected that the highest luting space could avoid crown intaglio surface contact with the tooth and reduce the marginal fit. However, group O had the highest values of marginal discrepancy, which could be from the reduced internal luting space at the M5 point of group O (Table 2). Group B, with 70 μm of luting space, had the lowest values of marginal discrepancy. When Omnicam with software version 4.2.5 was used, the luting space could probably be set higher than 80 μm to prevent the highest marginal gap. A previous study reported that different luting spaces influenced the marginal discrepancy.[11] However, recent study showed that differences between two cement space settings did not seem to affect the marginal accuracy of the Cerec Bluecam with software 3.8.[21]

The range at the horizontal fit between groups could be determined with the different technology in capture of the images or possible errors of operator in the selection of the preparation finish line. Other possible interference is the lack of reproducibility of design by the machine during the milling step. In the present study, images capture and design of preparation finish line was easily realized in the B and OP groups. These groups had previously undergone powder application on the preparation tooth. Clinically, the horizontal fit could be solved, promoting adjustments in the ceramic crown (overextented) or teeth (underextended).

It is important highlight that this study evaluated the vertical, internal and horizontal fits to establish or minimize possible clinical implications based on the risk of microleakage, periodontal disease, and recurrent caries.[19] The literature consider acceptable marginal fit within 120 µm.[24] However the value of 75 µm was considered acceptable by other authors and by the present study[12-14] determining the efficiency of intaglio surface adjustments or powder application technique.

In further studies, the variation of luting space parameters in the software should be verified whether it interferes with the fit of ceramic crowns obtained by CAD/CAM. New technologies could be available in the future improving the scanning, design (CAD) or manufacturing (CAM). Moreover, long-term clinical data are necessary to verify the efficacy and importance of these techniques.

CONCLUSIONS

Within the limitations of this in vitro study, the following conclusions could be drawn:

- Different intraoral optical scanners, powder application and internal adjustments influenced crowns marginal discrepancy.
- Crowns fabricated by Omnicam had significantly higher vertical discrepancy than Bluecam scanner.
- Adjustments of the intaglio surface improved only the vertical fit of Omnicam crowns.
- Powder application before Omnicam scanning improved the vertical fit of crowns and reduced the volumetric 3D internal fit.

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TABLES

Table 1. Groups' descriptions

Group	Abbreviation	Powder	Intaglio surface adjustment
Bluecam	B	Yes	No
Bluecam with adjustments	BA	Yes	Yes
Omnicam	O	No	No
Omnicam with adjustments	OA	No	Yes
Omnicam powdered	OP	Yes	No

Table 2. Vertical (µm), horizontal (µm) and volumetric 3D internal fit (mm^3) results without adjustments (N=10).

Group	Vertical	Coefficient of variation	Percentage < 75 µm	Horizontal	Volumetric 3D Internal Fit
B	29.5(13.2) A	44.7%	89.3	56.2(21.5) A	9.4(1.3) A
O	149.4(64.4) B	43%	31	77.5(11.8) B	11.8(2.1) B
OP	33.0(8.3) A	25%	92	91.4(19.4) B	9.6(0.9) A

B: Bluecam crown; O: Omnicam crown; and OP: Omnicam with powder crown. Values with same letter are not significantly different on columns based on One-way ANOVA test.

Table 3. Mean data of the internal fit values (μm) of vestibular/lingual and mesio/distal surface (N=10).

Group	M1		M2		M3		M4		M5		M6	
	VL	MD	VL	MD	VL	MD	VL	MD	VL	MD	VL	MD
B	83	49.7	29.9	85.7	129.7	230.9	132.4	161.6	16	74.1	69.7	55.1
BA	119.1	29	46.9	57.6	64.7	137.1	183.9	196.3	45.4	124.1	49.4	98.4
O	168.3	143	28.8	28.2	51.7	87.9	276.9	105.1	0	21.6	220.5	189.7
OA	217.9	100.8	76.9	65.1	55.6	111.5	256.2	95.9	26.2	55.8	128.8	171
OP	132.6	100.6	35.1	72.9	119.8	156.6	171.7	134.1	16	39.9	77.3	115

Table 4. Vertical (μm), horizontal (μm) and volumetric 3D internal fit (mm^3) Bluecam results before and after adjustments (N=10).

Group	Vertical	Coefficient of variation	Percentage < 75 μm	Horizontal	Volumetric 3D Internal fit
B	29.5(13.2) A	44.7%	89.3	56.2(21.5) A	9.4(1.3) A
BA	26.9(7.7) A	28%	92.7	85.8(44.4) B	10.7(1.0) B

B: Bluecam crown; BA: Bluecam crown adjusted. Values with same letter are not significantly different on columns based on Paired t-test.

Table 5. Vertical (µm), horizontal (µm) and volumetric 3D internal fit (mm^3) Omnicam results before and after adjustments (N=10).

Group	Vertical	Coefficient of variation	Percentage < 75 µm	Horizontal	Volumetric 3D Internal fit
O	149.4(64.4) A	43%	31	77.5(11.8) A	11.8(2.1) A
OA	49.4(12.7) B	25.7%	73.5	102.5(16.2) B	11.0(1.3) A

O: Omnicam crown; and OA: Omnicam crown adjusted. Values with same letter are not significantly different on columns based on Paired t-test.

FIGURE LEGENDS

Fig. 1 – Six points used to measure the internal misfit.

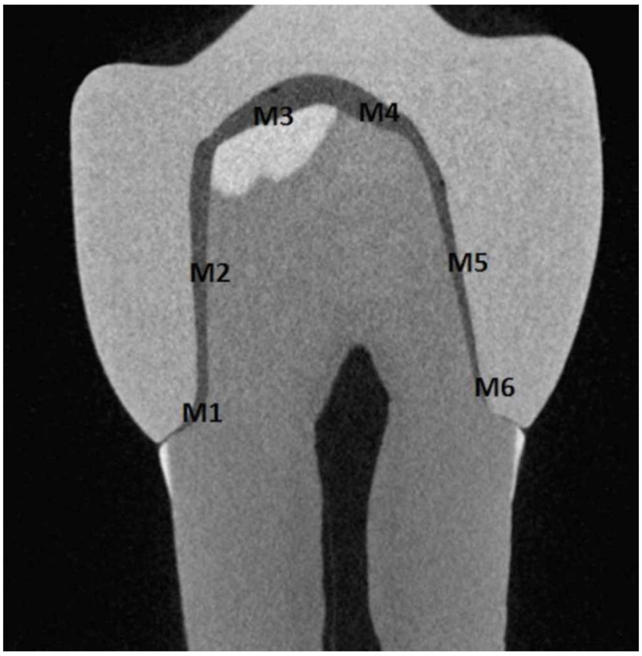


Fig. 2 – Scatter plot column means diagram of the vertical misfit (μm) for each group.

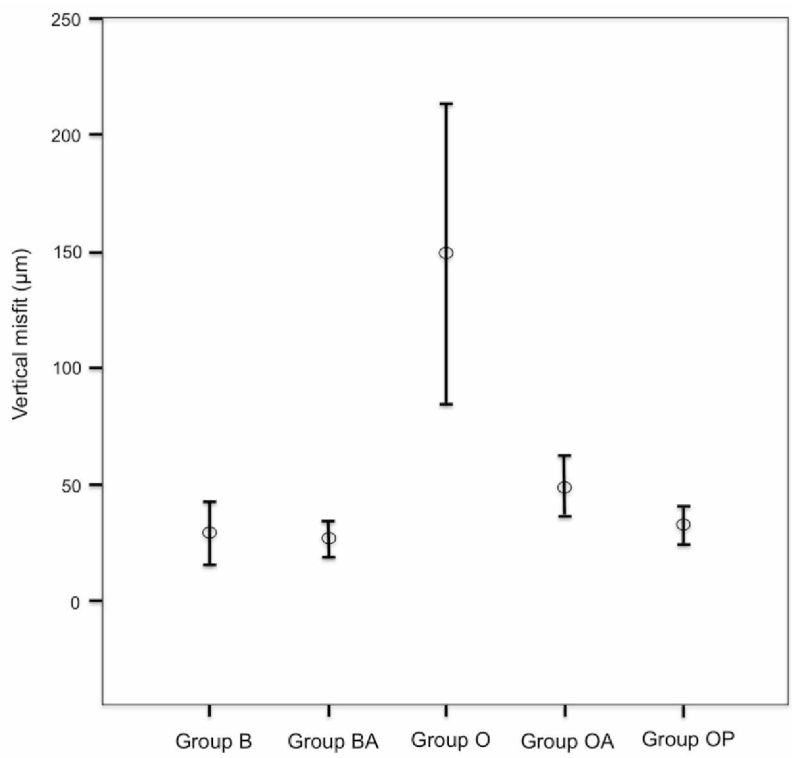
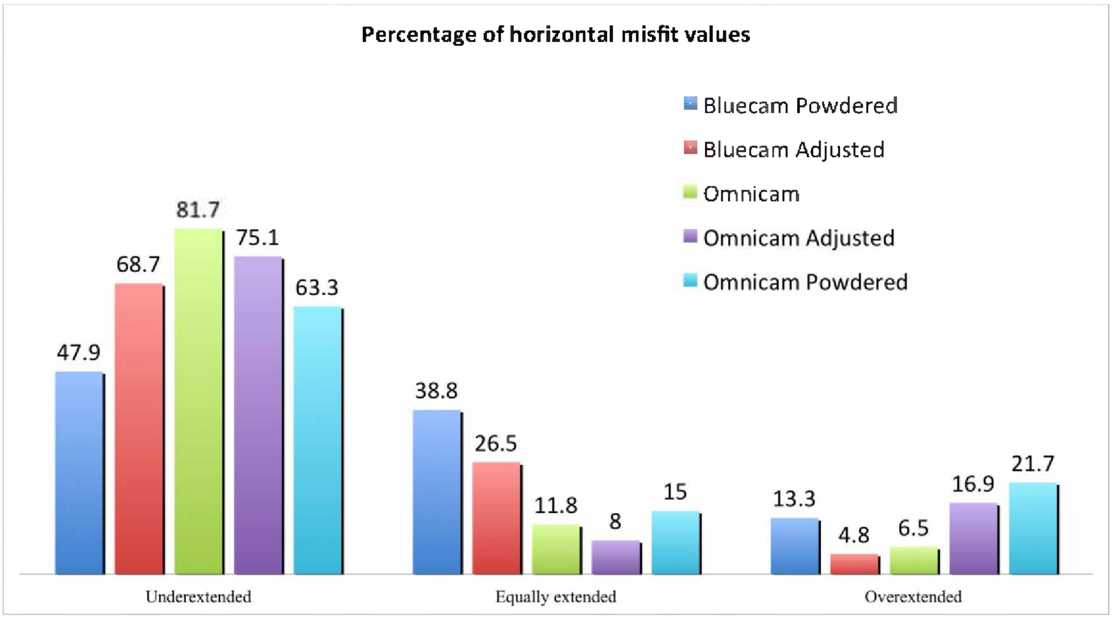


Fig. 3 – Percentage of the horizontal misfit values for each tested group.



CAPÍTULO 3

Marcel Santana Prudente, Rayssa Pereira Rodrigues, Leandro Maruki Pereira, Aline Aredes Bicalho, Carlos José Soares, Flávio Domingues das Neves.
Influence of luting space settings on internal and marginal fit and polymerization shrinkage deformation of CAD/CAM ceramic crowns.
Journal of Prosthetic Dentistry

ABSTRACT

Statement of the problem CAD/CAM crowns could be obtained with different luting space settings. The impact on internal and marginal fit, and crown deformation resulted by polymerization shrinkage of the resin cement, until is unclear.

Purpose To investigate the CAD/CAM crowns obtained with different luting space settings on internal and marginal fit, and deformation of ceramic crown resulted by polymerization shrinkage of the resin cement.

Material and Methods Thirty human molars were prepared and ten crowns were obtained with different luting space settings: LD40 - 40μm, LD80 - 80μm, LD160 - 160μm. Internal fit (IF) was analyzed on occlusal, axial, axiogengival points, and vertical fit (VF) were performed on each face (buccal, distal, lingual and mesial) using micro-computed tomography analysis. External crown deformation (ECD) was recorded on buccal and distal faces. Five light-curing protocols were realized to verify the wavelength spectrum peak (WSP) of the curing unit and irradiance delivered (ID) in two situations: with 0mm sensor distance and through the ceramic with different thickness. Data were statistically analyzed by 1-way ANOVA, followed by the Tukey honestly significant difference test (α=.05).

Results The highest IF was observed on occlusal and axial points of LD160 group ($P<.001$) and LD80 presented lowest values on axiogengival point ($p=.003$, $p=.006$). The highest and significantly VF was presented for group LD40 independent of region. LD 160 presented the highest ECD independent of buccal and distal strain gauge. The ID reduced significantly with the interposition of the ceramic block to the sensor. Statistically similar WSP was recorded.

Conclusion Luting space settings influenced on IF, VF and ECD of CAD/CAM ceramic by polymerization shrinkage. Ceramic thickness in different sites affected the ID by the curing unit and influenced the ECD.

Key- words CAD/CAM, crown, shrinkage, marginal fit, internal fit, shrinkage

Clinical Implications The intermediary luting space settings of 80 μm could be selected on the software 4.2.5 of CEREC to fabricated lithium disilicate CAD/CAM crowns with reduced internal fit, lower marginal fit and lower influence of shrinkage stress of the resin cement layer and ceramic deformation.

INTRODUCTION

Traditionally, to obtain all-ceramic crowns in the laboratory, the technician coats the die with spacer varnish and waxes the crown. Next, the waxed crown is included in an investment, the lost wax process is realized and the ceramic is pressed with hot-pressed system with accurate marginal adaptation.[1,2] The space between the inner surface of the crown and the die is known as luting space. Unlike the conventional technique, CAD/CAM systems can standardize the luting space as it could be set on the software that designs the crown.[1,3,4,5,6,7,8] The luting space of all-ceramic crowns is filled with resin cement that presents lower elastic modulus than ceramic and, normally, closer elastic modulus to that present in dentin, preventing fracture of the crown during chewing.[9,10] Considering the brittle characteristic of ceramic, choosing a reinforced ceramic for crowns, appropriated luting space and resin cement is vital for the success of the restoration.[3,6,7,10]

Different values of luting space settings for CAD/CAM all-ceramic crowns fabricated by Cerec system have been reported. They ranged from 0 to 50μm resulting in crowns with marginal fit between 39.2 to 164.0 μm and internal fit between 109.5 to 162.0 μm. [2,3,11,12,13,14] No reliable reproduction of the selected setting of luting space was observed after measurements of internal and marginal fit (Table I). According to an *in vitro* test, the ideal thickness of cement should range from 25 to 40 μm,[15] although these values are clinically rarely achieved. However, the lower values of the inner space may reflect on the difficulty of the crown setting, which may result in vertical marginal misfit. In addition, higher internal space generates thicker resin cement layer that generates stress within both restorative cavities and materials, and can lead to bonding failures.[4,5]

Polymerization shrinkage of resin material is directly associated with the structure deformation of ceramic materials and crown-tooth assembly.[16] Considering this aspect, the strain gauge method is used to evaluate the cuspal deformation generated during the shrinkage polymerization process of resin material restoring large cavities.[17] The shrinkage stress generated by polymerization shrinkage depends on multiple factors, such as curing light intensity, photoactivation time, time elapsing between crown cementation and light activation, elastic modulus of resin cement and remaining tooth structure.[18,19,20,21] Higher internal space accommodates a larger amount of resin cement that may be responsible for higher adjacent structure deformation, which can result in higher shrinkage stress transferred to the surface of the ceramic crowns.[4,5] Therefore, this method can also be adequate to verify the influence of the shrinkage process on all-ceramic crowns.

The irradiance emitted by the curing unit influences the capacity of the polymerization process of the resin cement.[22,23] If there is enough light to produce polymer network, polymerization shrinkage is a natural consequence.[21,22,24] The type of ceramics and their thickness could lead to some attenuation and affect the degree conversion of resin cement polymerization.[23,25] Inadequate polymerization, characterized by low degree of conversion, decreases the mechanical properties of cement and increases water sorption, solubility, and increased amount of residual monomers may cause pulp irritation, irreversible pulpitis and decrease the bonding of resin cements.[23,26,27] Therefore, characterizing the light-curing unit in the laboratory experiments simulating the experimental conditions is important issue to better describe and explain the phenomenon of polymerization shrinkage.

To date, little has been reported about the new Cerec system intraoral camera (Omnicam) that captures data by video in real time and color, without powder application.[28,29,30] A recent paper has used 110 μm of luting space settings with software 4.2.4 and found crowns with 82.1 μm of marginal fit.[28] However, according to the manufacturer's instructions, the setting of 80 μm of luting space to obtain all-ceramic crowns are indicated.[31] Therefore, the combination and balance between the lowest possible inner space that may reduce the shrinkage stress of the resin cement with the sufficient space to determine easily and adequate crown setting is recommended. To analyze the luting space settings and the influence of the luting resin cement thickness of CAD-CAM disilicate ceramic crowns generated by using the intraoral camera of Cerec Omnicam with software version 4.2.5 system was evaluated considering: (1) marginal and internal fit by μ-CT analyses and (2) crown deformation during the polymerization shrinkage of cement by strain gauge method (3) the amount of irradiance and light spectrum of the curing light unit through the ceramic. The null hypothesis was that the luting space settings do not influence internal fit, marginal fit and ceramic crown deformation resulted from polymerization shrinkage of the resin cement and no attenuation was observed in irradiance and light spectrum of the curing light unit through the ceramic.

MATERIALS AND METHODS

Teeth selection and preparation crown

Thirty human mandibular third molars were collected, selected (Ethics Committee approval 381/06) and fixed on the Typodont. The teeth were measured with a digital caliper (Mitutoyo, Digimatic®), obtaining coronal width varying between 9.5 mm and 10.7 mm. The teeth were randomly divided into 3 groups (n=10). Diamond burs (1014, 3145, 3098, and 3098F, KG Sorensen) with copious air-water spray were used to perform all ceramic crowns preparation, with rounded shoulder axiogingival angle.[32] Standardized digital impressions of the prepared teeth were generated using a

Cerec 3D Omnicam scanner (Sirona Dental Systems GmbH). The crowns were designed in Cerec 3D software (version 4.2.5) with different luting space settings: LD40 – 40 μm, LD80 – 80 μm, and LD160 – 160 μm (Fig. 1). The lithium disilicate blocks (IPS e.max, Ivoclar Vivadent AG) were milled using Cerec inLab MC XL milling unit (Sirona Dental Systems GmbH).

Scanning procedures – Internal and Marginal measurement procedures

Each provisional crown was fixed by using silicone-based material on each respectively tooth (GC Fit Checker, GC Dental Industrial Corp). To standardize the measurements, each specimen received four radiopaque lines on the cervical portion of the root to determine the buccal, distal, lingual and mesial faces. Each specimen was fixed in the same position on μ-CT (Brucker-Skyscan 1272) to obtain images for measurements of the marginal and internal fit. The μ-CT scanning was performed at 100 kV and 100 μA, with a pixel size of 9.4 μm, Filter Cu 0.11 mm and resolution of 1632x1092 pixels. The selected scanning was performed at 1 degree of rotation step at 360 degrees; to diminish artifacts, an average of 2 frames were collected with 20 random movements, resulting in a scanning time of 1 hour per specimen. Images of each specimen were reconstructed (NRecon v, Bruker-micro CT) providing axial cross-sections of their inner structure. Data Viewer v.1.4.4 software (SkyScan) was used to view the images in a 3-dimensional (3D) profile; 3D images of each specimen as well as axial images were qualitatively analyzed to verify an image quality obtained.

For internal marginal adaptation 2 axiogingival, 2 axial and 2 occlusal sites were measured in the central sagittal and coronal images of the crown and the mean were obtained for axiogingival, axial and occlusal (Fig. 2A).

Thirteen sagittal images were selected for measuring the buccal and lingual marginal fit. Thirteen coronal images were selected for measuring the mesial and distal marginal fit. For each image, vertical fit was performed at 300x magnification using CTAn processing software for marginal fit evaluation (Version 1.12.0.0, Skyscan,). For vertical fit, the measurements were taken from the external crown margin to the most external point of the tooth (Fig. 2B). The vertical fit examination in 13 sites of four areas (buccal, lingual, mesial and distal) resulted in 52 measurements per tooth and 520 per group.[33]

Crowns surface treatment

The intaglio surface of the ceramic crowns were etched with 5% hydrofluoric acid (Porcelain etchant; Bisco,) for 20 seconds followed by water spray for 10 seconds, and air dry for 20 seconds. The one coat of silane (RelyX Ceramic Primer; 3M ESPE), which was applied for 20 seconds using a microbrush was then air-dried for 10 seconds with room-temperature air.

Strain gauge fixation

Strain gauges were bonded to the buccal and distal ceramic crown surfaces (n=10) with cyanoacrylate adhesive (Super Bonder; Loctite,) and were connected to a data acquisition device (ADS0500IP; Lynx Tecnologia Eletrônica). The buccal strain gauge (PA-06-060CC-350L; Excel Sensores,) had an internal electrical resistance of 350 Ω, a gauge factor of 2.07, and a grid size of 7 mm^2. The distal strain gauge had an internal electrical resistance of 120 Ω a gauge factor of 2.137, and a grid size of 1.00 mm^2. The dimension of the face defined the size of the strain gauges and the flat area was selected to fix the strain gauge. The gauge factor is a proportional constant between electrical resistance variation and strain. In addition, two strain gauges were fixed to another intact tooth to compensate the dimensional deviations due to temperature effects such as in a passive specimen.

Crown fixation and deformation analyses

The self-adhesive dual cured resin cement (Rely X U200; 3M ESPE) was selected for crown fixation. The resin cement was mixed and applied to the inner surface of the ceramic crowns, which were inserted to the tooth preparation and remained seated under finger pressure. . Excess cement was removed with a dry microbrush and resin cements were light-activated using monowave light curing unit (Radii-Cal unit; SDI,) operating at 1200 mW/cm^2 for 40 seconds on each surface: buccal, lingual and occlusal, resulting in 120 s, totalizing 144 J. The ceramic crown deformation was measured during the crown stabilization and self-curing polymerization for 5 minutes. Ceramic crown deformation data were obtained with the strain gauges through data analysis software (AqDados 7.02 and AqAnalisys; Lynx). The strain values were recorded at 4 Hz during the fixation and during the light activation and sustained for 5 minutes after the polymerization process.

Delivery of Irradiance and Emission spectrum of curing units

Before fixation, all crowns were measured. The occlusal, buccal and lingual thickness and a three block of lithium disilicate were reproduced with 1.3 mm, 1.7mm and 1.8mm respectively. Five light-curing protocols were realized to verify the mean of emission spectrum of the curing unit and mean of irradiance delivered using a MARC resin simulator (Blue Light analytics Inc.) in two situations: with 0mm sensor distance and through the ceramic block with different thickness: 1.3 mm for occlusal, 1.7mm for buccal and 1.8mm for lingual. The device presented a cosine-corrector optical fiber irradiance probe capable of capturing all emitted light, which in turn was guided into a spectral calibrated radiometer.[34] The MARC resin simulator was transferred to the computer, the data and the software analysis (version 3.0.4.0) of emission spectrum peak in nm and mean irradiance delivery in mW/cm^2.

Statistical analysis

Internal adaptation, marginal fit, irradiance emitted by the light curing unity and ceramic crown deformation data were tested for normal distribution (Shapiro-Wilk) and variance equality (Levene test). Data were analyzed by using One-way analysis followed by the Tukey post hoc test for pair-wise comparison. All analyses were performed using Sigma Plot statistical software (version 12.0; Systat Software Inc.) with significance level of $\alpha = .05$.

RESULTS

Mean and standard deviation of internal fit measured considering axiogingival, axial and occlusal walls are shown on Figure 3. One-way ANOVA demonstrated significant difference for axiogingival (*df=2 F=7.4* p = .001), axial (*df=2 F=17.3 p < .001,*) and occlusal (*df=2 F=4.9* p = .01). Tukey test demonstrated that LD160 resulted in significantly higher occlusal and axial internal fit than LD40 and LD80 (p< .001). For axiogingival fit LD80 demonstrated significantly lower values than LD40 and LD160 (p=.003, p=.006)

Mean data and standard deviation of vertical fit recorded by region and luting space are shown on Figure 4. One-way ANOVA yielded significant difference for all regions, buccal (*df=2, F=4.2,* p =.025), lingual (*df=2, F=4,* p = .029) medial (*df=2, F=6.1* p = .006) and distal (*df=2 F=7.5* p=.002). Tukey test demonstrated that LD40 resulted in significantly higher marginal fit than LD80 and LD160, irrespective of region analyzed.

Mean data and standard deviation of ceramic crown deformation measured on buccal and distal strain gauge are shown on Figure 5. One-way ANOVA demonstrated significant difference on ceramic deformation for buccal (*df=2, F=32.0,* $p < .001$) and distal (*df=2, F=56.8,* $p < .001$). Tukey test demonstrated that LD160 resulted in significantly higher deformation than LD40 and LD80, irrespective of region analyzed ($p<.001$).

The light irradiance spectrum emissions are shown on Figure 6 and Figure 7, in two situations with 0 mm of sensor and through the ceramic block to the sensor. The irradiance delivery of the curing unit reduced significantly with the interposition of the ceramic block to the sensor (*df=3, F= 133331.805,* $p < .001$). The light spectrum presented a wavelength between 360nm and 540nm, and a statistically similar spectrum peak for all tested groups (*df=3, F=.591,* $p < .630$).

DISCUSSION

The null hypothesis of this study was rejected. The luting space settings influenced the internal fit, marginal fit and ceramic deformation as a result of polymerization shrinkage of the resin cement used for cementing CAD/CAM lithium disilicate all- ceramic crowns. Ceramic thickness promoted the attenuation of light irradiation delivery and presented light spectrum similar.

The measured points were critically selected to express the internal fit in different sites of the crowns. Reduced internal space of crowns optimizes the cement properties.[3,4,5] However, it is clear that when the smallest luting space was selected, internal contacts can occur within the axial walls of the preparation, preventing the total evacuation of cement excess and consequently influencing the crown seating and the final marginal fit.[3,6] Intermediary values of luting space settings (80 µm) presented the best results for internal fit on axiogingival measurement. LD40 and LD80 groups had similar internal fit for both axial and occlusal measurements. However, the crowns fabricated with 160 μm settings resulted in significantly higher values for axial and occlusal internal fit. Considering the occlusal luting space settings, all groups presented values over 100 μm. This situation could generate critical stress and possible failures.[4,5] Moreover, the present study demonstrated that there is no precise manufacturing reproduction of luting space settings selected on tested software and the measured internal fit of the crowns.

Regarding marginal fit, reduced luting space settings promotes higher misfit values. Previous studies demonstrated similar results.[1,3] Inner contact between crowns and preparation could contribute to the marginal fit, because the crowns do not seat completely, injuring soft tissue and (favoring the resin cement exposing second caries) enabling the resin cement to expose second caries.[1,3,6,7,14] In the present study, the crowns milled with luting space settings of 80 μm or 160 μm, presented better results than 40 μm. It may be due to the fact that in situations of higher inner space there is no internal contact allowing for better seating. In this situation, mean values presented less than 75 μm, which seems to be clinically acceptable.[2,13]

On the other hand, if the luting space is larger than 80 μm, the polymerization process could be influenced.[3,6] This fact could be observed when the luting space was set at 160 μm. Crown deformation was analyzed in two sites (buccal and distal) by strain gauge analyses, confirming the finite element results of other studies.[4,5,9] Crowns produced with160 μm luting space presented higher deformation when compared to other groups. This condition could increase stress on cement line, generating ceramics microcracks and bonding failure of the crown, which may compromise the longevity of all-ceramic restorations. Shrinkage stress is a serious concern, as has been demonstrated clinically by a high incidence of loss of marginal integrity. It can be observed in this study that the major cement margin causes high deformation on the surface of the ceramic crown.[4,5,9] Finite element analyses have shown little effect of tensile stresses when occlusal cement thickness of ceramic crows is thinner.[4,5] On the other hand, when the cement layer reaches thickness higher than 100 μm on the occlusal region of the internal surface of the crown, the critical stress on the axial-occlusal line was recorded.[4,5]

The shrinkage process is dependent on the resin cement polymerization, which may be influenced by irradiance emitted by the light-curing unit.[18, 21, 22, 24] Thus, the current study characterized the light irradiance delivered by the curing unit used in the experiment and also the effect of different ceramic thickness in occlusal, buccal and lingual regions.[25] The polymerization process could be different at different sites and the shrinkage process was determined by the standard time of polymerization. As observed in this study, the higher the ceramic thickness, the lower irradiance reached the resin cement lays. This aspect clearly shows that the light activation time defined for resin cement should be considered not only as to the characteristic of the irradiance described by light curing unit. Radii-cal used in this study showed high irradiance when measured directly on the sensor, however when the ceramics were placed over the sensor the irradiance reduced significantly. It is important to understand that another curing unit could present different irradiance and spectrum affecting the amount of polymerization shrinkage.

The results of the present study suggest that selected settings of 80 μm of luting space favored the marginal and internal fit promoting clinically acceptable seating and also presented low crown deformation as a result of shrinkage stress of the resin cement layer. However, other studies employing lower than 80 μm and higher than 40 μm could be performed in the future to ascertain the best luting space value and, after that, the crowns could be submitted to cyclic loading or fracture and adhesive strength tests considering the different luting spaces. Other curing units could be evaluated and polymerization time could be evaluated as to different ceramic thickness to determine the influence on crowns deformation.

CONCLUSION

Within the limitations of this in vitro study, the following conclusions can be drawn:

- The lower luting space settings could promote internal contact to axial walls preventing all-ceramic crowns seating.
- The higher luting space setting resulted in higher resin cement shrinkage stress that generated higher ceramic crown deformation.
- Ceramic thickness in different sites affected the irradiance delivered by the curing unit and influenced the crown deformation.
- The intermediary luting space settings of 80 μm could be selected on Cerec software 4.2.5 to fabricate lithium disilicate CAD-CAM crowns with reduced internal fit, lower marginal fit and lower influence of shrinkage stress of the resin cement layer and ceramic deformation.

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TABLE

Table I. Literature review of marginal adaptation and internal fit of different CAD/CAM ceramic crowns produced with different luting cement settings

Authors	Camera, Software	Luting cement settings	Ceramic Material	Marginal adaptation	Internal fit
Nakamura et al, 2003	Cerec 3D, CCD	10 µm	Feldspathic	95-108 µm	119-136 µm
Nakamura et al, 2003	Cerec 3D, CCD	30 µm	Feldspathic	53-66 µm	116-141 µm

Nakamura et al, 2003	Cerec 3D, CCD	50 μm	Feldspathic	55-61 μm	135-162 μm
Luthardt et al, 2004	Cerec 3 Camera	0 μm	Feldspathic	380 μm	
Luthardt et al, 2004	Cerec 3 Camera	0 μm	Leucite	342 μm	
Lee et al, 2008	Cerec 3D, CCD	30 μm	Feldspathic	94.4±11.6μm	109.5±4.7μm
Neves et al, 2014	Bluecam/ 4.0	70 μm	Lithium disilicate	39.2±13.8 μm	
Neves et al, 2014	Bluecam/ 4.0	70 μm	Feldspathic	62.6±65.2 μm	
Baig et al, 2015	Bluecam/ 3.8	10 μm	Feldspathic	148±57 μm	
Baig et al, 2015	Bluecam/ 3.8	20 μm	Feldspathic	164±48 μm	

FIGURE LEGENDS

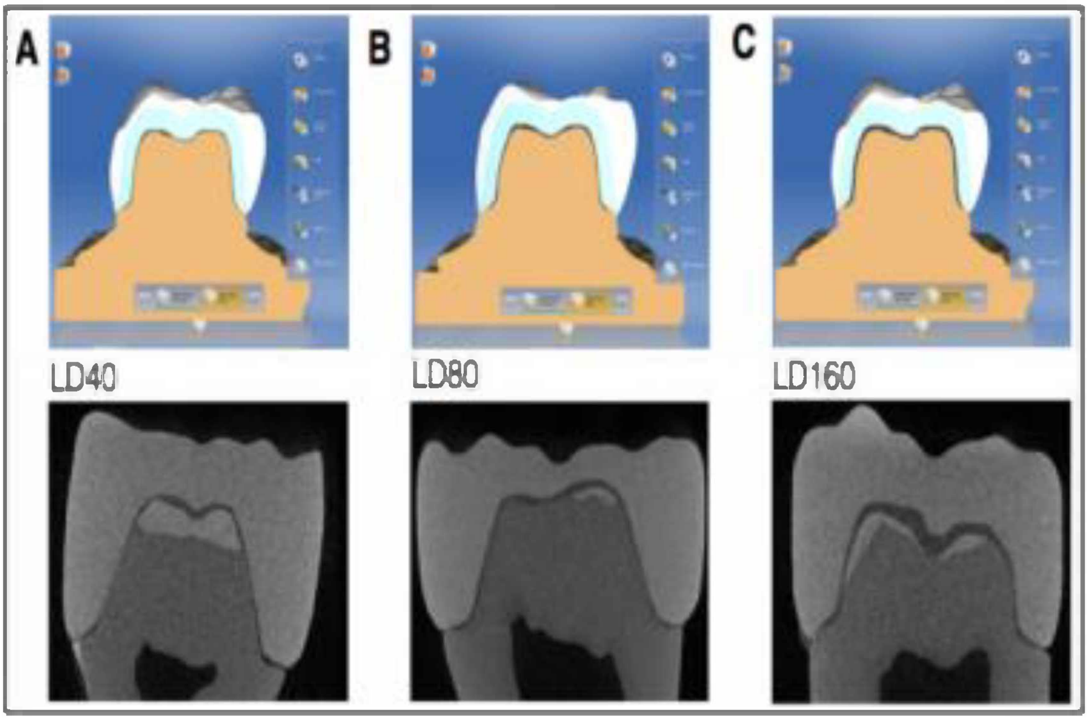

Fig. 1. Different luting space settings on CAD/CAM crown design software and micro-computed tomography images: LD40 (A), LD80 (B), LD160 (C).

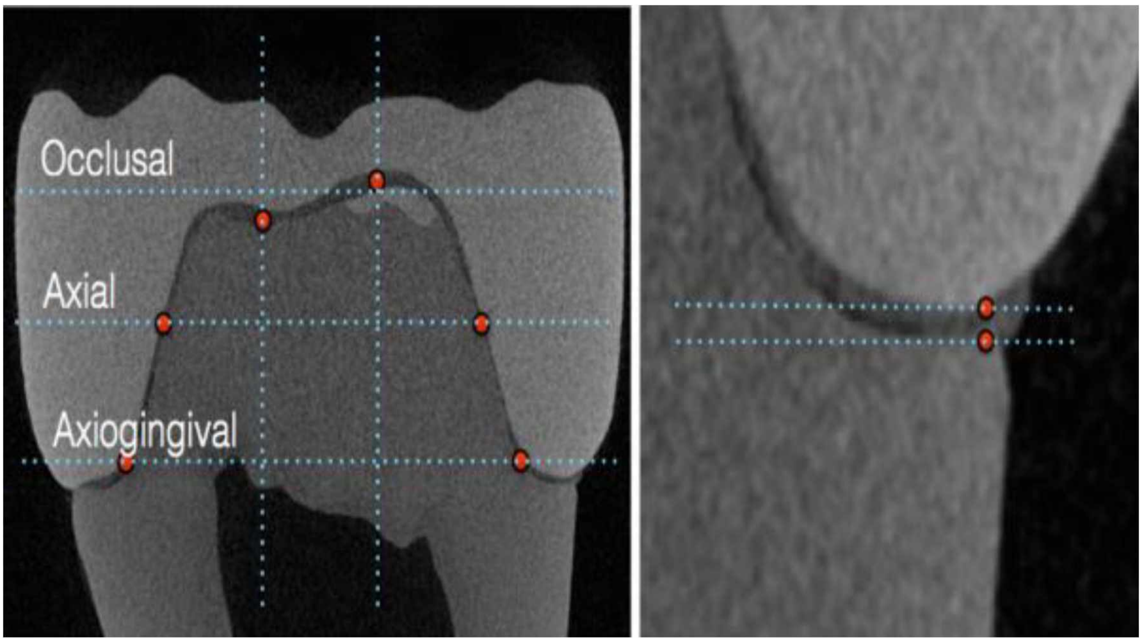

Fig. 2. A, Schematic showing Internal fit measurements on occlusal, axial, and axiogingival walls. B, Schematic showing marginal fit measurements.

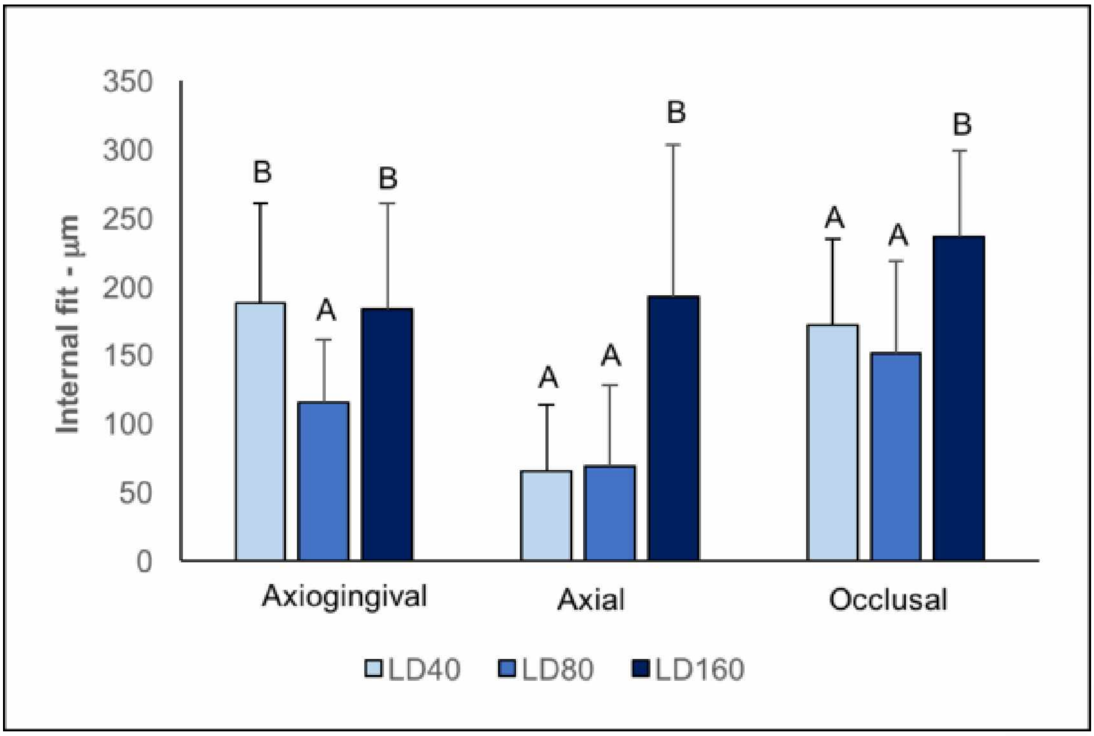

Fig. 3. Internal fit of lithium disilicate crowns with different luting space settings in µm.

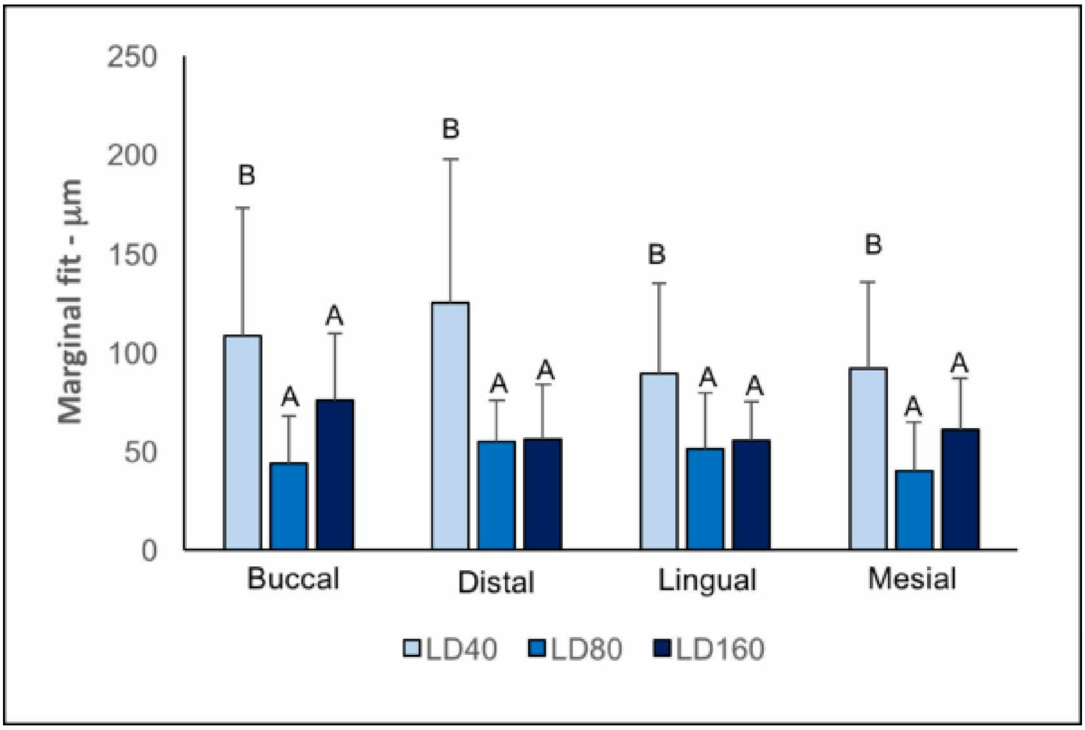

Fig. 4. Marginal fit of lithium disilicate crowns with different cement thickness in µm.

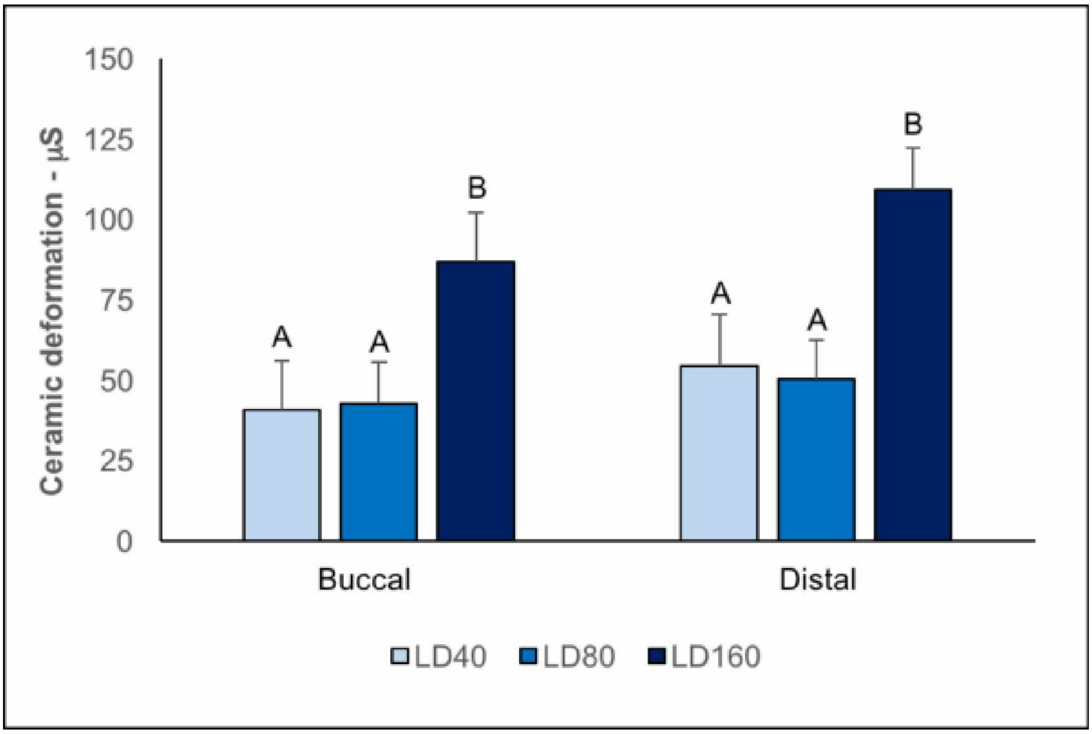

Fig. 5. Buccal and Distal of lithium disilicate ceramic crown deformation in microstrain (µS) cementation shrinkage polymerization in Microstrain (µS).

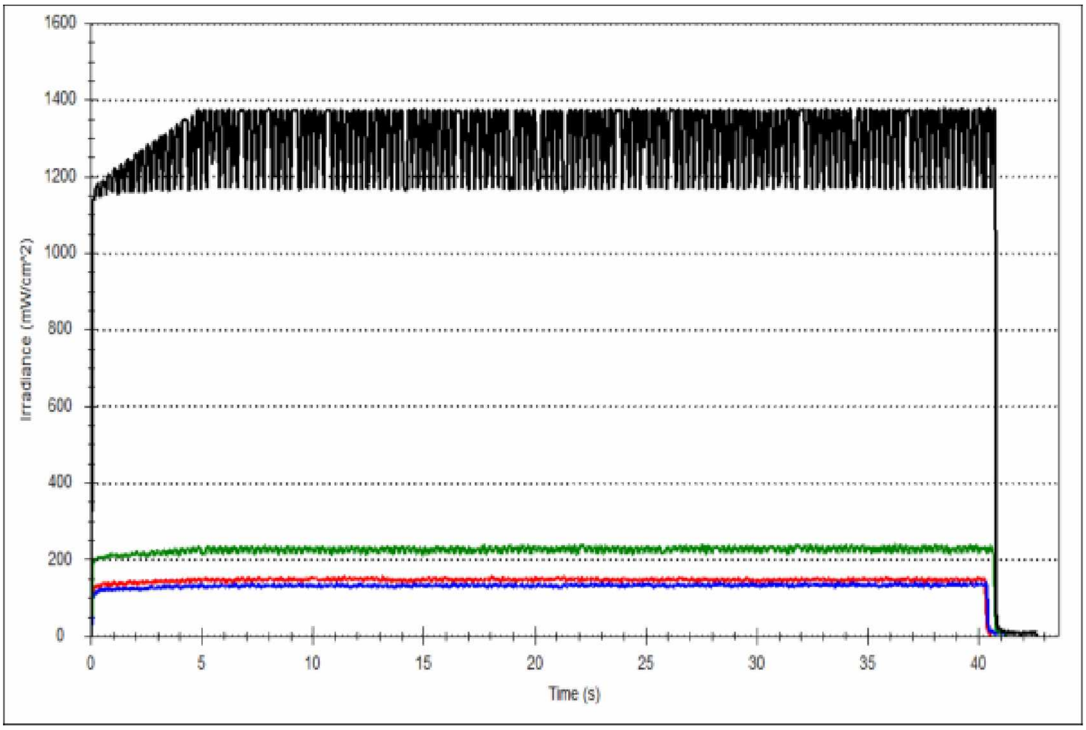

Fig. 6. Irradiance emitted by curing unit (Radii Cal) through different ceramic thickness in nm: Black line (without ceramic), Green line (1.3 mm of occlusal ceramic thickness),

Red line (1.7 mm of buccal ceramic thickness), Blue line (1.8 mm of lingual ceramic thickness).

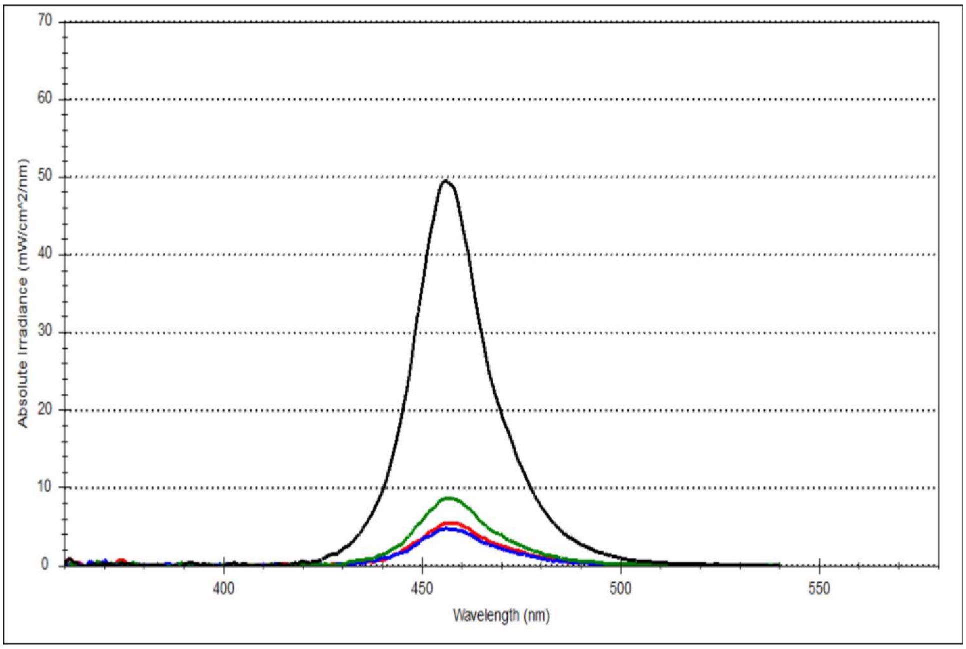

Fig. 7. Light spectrum emission delivery by curing unit through different ceramic thickness in mW/cm^2. Black line (without ceramic), Green line (1.3 mm of occlusal ceramic thickness),

Red line (1.7 mm of buccal ceramic thickness), Blue line (1.8mm of lingual ceramic thickness).

4- CONCLUSÕES

De acordo com os resultados obtidos nos estudos laboratoriais pode-se concluir que:

1- A seleção do material cerâmico pode influênciar na adaptação das coroas quando o Cerec AC com a camera Bluecam e fresadora MCXL para consultório for utilizado. Dissilicato de lítio e leucita exibiram menor adaptação vertical do que as coroas feldspáticas.

2- Coroas produzidas pelo Cerec 3D Bluecam apresentaram melhor adaptação vertical, horizontal e interna volumétrica do que as coroas obtidas pelo sistema de captura por vídeo, Omnicam. Os ajustes internos melhoraram a adaptação vertical das coroas produzidas pela Omnicam. Entretanto, a aplicação de pó previamente ao escaneamento com a Omnicam melhorou a adaptação vertical e adaptação volumétrica interna das coroas.

3- A menor discrepância marginal foi encontrada nas faces mesial, lingual e distal e interna das coroas produzidas pelo Sistema Cerec Omnicam e software 4.2.5, quando o espaço de cimentação selecionado no software foi de 80 e 160 micrometros. Entretanto maior deformação das coroas foi encontrada quando o parâmetro do espaço de cimentação foi de 160 micrometros. Diante disso sugere-se utilizar espaço de cimentação de 80 micrometros considerando à adaptação e deformação das coroas dentre os grupos avaliados. É possível concluir também que à atenuação da irradiância ocorre de acordo com a passagem da luz por diferentes espessuras cerâmicas localizadas nas faces oclusal, vesibular e lingual. Este padrão distinto de luz incodente no cimento pode causar deformação distinta das faces livres e proximais.

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