Ana Luíza Serralha de Velloso Vianna

Efeito da morfologia do preparo cavitário e técnica restauradora indireta em molares. Avaliação laboratorial e revisão sistemática da literatura

Effect of cavity design and indirect restorative technique on molars
Laboratory evaluation and systematic review

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

Uberlândia, 2019

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Orientadora: Prof. Drª. Aline Arêdes Bicalho

Banca Examinadora:
Profª. Drª. Aline Arêdes Bicalho
Prof. Dr. Carlos José Soares
Profª. Drª. Karla Zancopé
Prof. Dr. João Henrique Ferreira Lima
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Uberlândia, 2019

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ATA

Ata da defesa de TESE DE DOUTORADO junto ao Programa de Pós-graduação em Odontologia da Faculdade de Odontologia da Universidade Federal de Uberlândia.

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Projeto de Pesquisa de vinculação: Propriedades físicas e biológicas dos materiais odontológicos e das estruturas dentais

As **quatorze horas** do dia **vinte e oito 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 dezembro de 2018, assim composta: Professores Doutores: Carlos José Soares (UFU); Karla Zancopé (UFU); João Henrique Ferreira Lima (UNITRI); Rodrigo Dantas Pereira (FUNORTE); e orientador(a) do(a) candidato(a) **Aline Arêdes Bicalho.**

Iniciando os trabalhos o(a) presidente da mesa ***Dra. Aline Arêdes Bicalho*** 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 (as), 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 17 horas e 20minutos. Foi lavrada a presente ata que após lida e achada conforme foi assinada eletronicamente pela Banca Examinadora.

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Dedico este estudo à minha **família**, e em especial:

à **Deus**.

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À **Deus**,

por sempre iluminar meus passos e abençoar a minha família, que é o meu bem mais precioso.

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que são referências de amor, sabedoria, força e coragem.

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Quantos cafés!
Quantas comidas! Afinal, somo o quê? Gordinhas.
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Romanos 8:28

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RESUMO

RESUMO

As cerâmicas são usadas rotineiramente para confecções de restaurações indiretas tais como inlays, onlays e coroas totais, devido às suas várias vantagens. Existem diversas técnicas de preparo cavitários para cada uma delas, sendo que devemos priorizar menor desgaste dentário, melhor comportamento biomecânico, simplicidade de técnica, e, além disso, deve-se considerar a quantidade de estrutura remanescente e se o dente é ou não tratado endodonticamente. Esta tese de doutorado possui três objetivos específicos: 1) Avaliar o efeito da configuração do preparo cavitário e da composição cerâmica no comportamento biomecânico de restaurações indiretas em molares vitais. Quarenta molares foram divididos em quatro grupos (n=12), submetidos a teste de resistência à fratura, modo de falha, deformação, e análise por elementos finitos. 2) Analisar as bolhas internas e integridade marginal do cimento resinoso e a adaptação de restauração indireta em molares vitais com diferentes preparos cavitários e diferentes cerâmicas. Vinte molares divididos em quatro grupos (n=5), foram escaneados usando o micro-CT 3D de alta resolução para contagem do volume e porosidade do cimento resinoso. 3) Investigar em estudos “in vivo” e “in vitro” preparo para dentes tratados endodonticamente com grande perda de estrutura dentária utilizando a técnica endocrown. Na revisão sistemática, sessenta estudos tiveram seus dados extraídos e avaliados. Após a análise estatística dos dados destes estudos, as onlays cerâmicas de dissilicato de lítio tiveram significantemente maior resistência à fratura que as reforçadas por leucita, e os preparos com caixas proximais e oclusais restaurados por cerâmica de dissilicato de lítio tiveram diminuição significativa da resistência à fratura. No modo de falha, onlays de dissilicato de lítio resultaram em fraturas mais catastróficas independente da geometria do preparo cavitário. Os preparos feitos com caixas proximal e oclusal resultaram em uma deformação similar ao preparo sem as caixas. Na adaptação marginal o preparo sem caixas apresentou menor volume e porosidade do cimento resinoso do que com caixas. Na revisão sistemática, os estudos “in vitro” mostraram que as restaurações endocrown apresentaram um preparo mais conservador, com biomecânica tão boa quanto a técnica clássica com pino de fibra de vidro, preenchimento de resina composta e coroa total cerâmica. Apesar dos estudos clínicos apresentarem resultados satisfatórios de dentes restaurados com endocrown, eles são insuficientes para confirmação clínica desta técnica. De acordo com as limitações deste estudo, as cerâmicas reforçadas por leucita teve menor deformação coronal e menor modo de falha. A espessura homogênea das restaurações influenciou em menor porosidade e volume no cimento. Foram observados que preparos mais conservadores, como onlay sem caixas proximais e oclusais e os preparos endocrowns, além de tornar uma técnica mais fácil e rápida, aumentaram a resistência à fratura. No entanto, são necessários estudos clínicos longitudinais para a comprovação destas técnicas de restaurações indiretas.

Palavras-chaves: cerâmica, onlay, endocrown, resistência fratura, deformação, micro CT, análise por elementos finitos.

ABSTRACT

ABSTRACT

Ceramics are used for indirect restorations such as inlays, onlays and full crowns, due to their advantages. There are some cavity preparation designs for each of them, and we should prioritize preservation of tooth structure, better biomechanical behavior, simplicity of technique, and, in addition, we must consider the tooh structure remaining for vital tooth and for endodontically treated tooth. This doctoral thesis has three specific objectives: 1) To evaluate the effect cavity preparation design and ceramic type on biomechanical behavior of indirect restorations in vital molars. Forty molars were divided into four groups (n=12), submitted to fracture resistance, failure mode, stress distribution and finite element analysis. 2) To analyze the internal and marginal integrity of the resin cement and the adaptation of indirect restoration in vital molars for different cavity designs and different ceramics types. Twenty molars divided into four groups (n=5) were scanned using the high-resolution 3D micro-CT for calculate the porosity and volume of the cement. 3) To investigate “in vivo” and “in vitro” the endocrown technique cavity design for endodontically treated teeth with extensive loss of tooth structure. In the systematic review, sixty studies had their data extracted and evaluated. After data analysis from these studies, the lithium disilicate ceramic onlay exhibited significantly higher fracture resistance than leucite ceramic, and the presences of boxes on disilicate ceramic restorations reduced significantly the fracture resistance. The failure mode distributions showed that the lithium disilicate ceramic resulted in more severe failure mode irrespective of cavity preparation. The cavity design with boxes resulted in a coronal deformation similar to cavity designs without boxes. The marginal adaptation on the non-boxes preparation design decresed the volume and porosity in resin cement compared with boxes. In the systematic review, the “in vitro” studies showed that the endocrown restorations presented a more conservative preparation design and presents biomechanical advantages with a same performance in a classical technique design restoration with fiberglass post, composite resin core and full ceramic crown. Despite the clinical studies presents satisfactory results of teeth restored with endocrown, they are insufficient for clinical confirmation of this technique. Within the limitations of this study, the ceramics reinforced by leucite had less coronal deformation and failure mode. The homogeneous thickness of ceramic restorations influenced in less porosity and volume in the resin cement. It was observed that more conservative preparations designs, such as onlay without proximal and occlusal boxes and the endocrown preparations designs, requires less chair time because there are fewer procedures, and besides being easier and faster techniques, they also present greater resistance to fracture. However, longitudinal clinical studies are needed to prove these indirect restoration techniques.

Keywords: ceramic, onlay, endocrown, fracture resistence, deformation, micro CT, finite elements analysis.

INTRODUÇÃO E REFERENCIAL TEÓRICO

1. INTRODUÇÃO E REFERENCIAL TEÓRICO

O interesse e a valorização da Odontologia Estética têm sido marcantes na última década. A procura por restaurações que devolvam a função, fonética e a cor natural dos dentes tem aumentado. Assim, as cerâmicas podem ser consideradas uma excelente alternativa de material restaurador estético posterior (Pagani *et al.*, 2003).

Devido à sua natureza friável as restaurações cerâmicas estão susceptíveis a fratura devido a pequenas falhas ou trincas sob a aplicação de força, que ocorre com pequena ou nenhuma deformação plástica. Vários fatores estão associados à iniciação e propagação de trincas nas restaurações cerâmicas, dentre eles: forma da restauração, falta de homogeneidade micro estrutural, dimensão e distribuição das falhas de superfície, tensões residuais induzidas por polimento ou processamento térmico, meio em contato com a restauração, características da interface cerâmica-cimento, espessura e variação da espessura da restauração, módulo de elasticidade dos componentes da restauração e magnitude e orientação das forças aplicadas (Wu *et al.*, 2009; Abou-Madina *et al.*, 2012).

Entre as cerâmicas odontológicas, a cerâmica feldspática é muito utilizada devido à sua alta translucidez, que proporciona uma fiel mimetização do esmalte natural. No entanto, devido a sua baixa resistência mecânica, é indicada como recobrimento em restaurações multicamadas e restaurações cerâmicas parciais. (Øilo *&* Gjerdet, 2013). Tentando contornar esse problema, surgiram as cerâmicas reforçadas por meio da adição de leucita, dissilicato de lítio, silicato de lítio reforçado com zircônia, alumina e zircônia. No entanto, resistência mecânica e propriedades estéticas são indiretamente proporcionais, e, por isso, as indicações desses materiais acabam sendo limitadas (Silva *et al.*, 2017).

Enquanto as falhas mais comumente relacionadas com as restaurações metalocerâmicas estão associadas com fraturas ou cáries nos dentes pilares, (Walton *et al.*, 2003) a complicação clínica mais comumente relatada na falha de restaurações totalmente cerâmicas é a fratura da cerâmica de cobertura e/ou da infraestrutura (Bindl *et al.*, 2005; Fradeani *et al.*, 2005).

Existem diversas técnicas para aplicação da cerâmica de cobertura sobre a infraestrutura, entre elas, as técnicas de estratificação, injeção ou *computer aided design/computer aided machining* (CAD/CAM). Todas essas técnicas visam a otimizar a resistência dessa camada e, em alguns casos, reduzir o estresse na geração de calor residual (Corazza *et al.*, 2015)

Um fato controverso diante da reabilitação de dentes posteriores é o limite definido entre a indicação de técnica direta e o emprego de técnicas restauradoras indiretas, envolvendo fatores estéticos, biomecânicos, anatômicos e financeiros (Soares *et al.*, 2006).

Um elevado sucesso das inlays e onlays é observado quando se utiliza um protocolo correto quanto ao preparo do dente, espessura adequada de suporte e ajuste oclusal correto da peça instalada. Além disso, a qualidade e durabilidade da união entre o material e o dente também garantem o sucesso clínico das restaurações cerâmicas, sendo que a composição da cerâmica tem um significante efeito na resistência à fratura da união dentina-cerâmica (Tekçe *et al.*, 2016).

Na reabilitação de dentes com grande destruição coronária é um desafio clínico e um assunto que tem sido discutido na literatura ao longo do tempo, principalmente em dentes não-vitais. A redução na rigidez e resistência à fratura de dentes tratados endodonticamente é a perda de integridade estrutural associada a cargas oclusais, trauma e preparo cavitário extenso, e também devido à remoção da polpa e dos tecidos circunvizinhos da dentina. (Zhu *et al.*, 2015, Chang *et al.*, 2009).

Geralmente, são necessários retentores intra-radiculares combinados ou não com núcleos de preenchimento, pois a retenção coronal das restaurações fica comprometida. Os pinos intra-radiculares alcançaram sucesso clínico, porém a grande desvantagem deste sistema é afetar o comportamento biomecânico dos dentes restaurados (Roscoe *et al.*, 2013) e aumentar a remoção de tecido sadio necessário para a colocação do pino no canal radicular (Lazari *et al.*, 2013).

O termo "endocrown" foi definido pela primeira vez por Bindl e Mörmann (1999) como uma construção de cerâmica monolítica ligada à estrutura do dente por material adesivo. Com mínima invasão do canal radicular, que é um fator importante para a preservação de estrutura dentária, a endocrown, é capaz de fornecer uma adesão adequada de uma restauração de cerâmica (Sevimli *et al.*, 2015). As restaurações endocrown são ancoradas na porção interna da câmara pulpar e nas margens da cavidade, resultando assim em processos macro e micro-mecânicos retenção, proporcionada pelas paredes pulpares e cimentação adesiva, respectivamente Bindl e Mörmann (1999) e El-Damanhoury *et al.* (2015). Além da vantagem de remover menores quantidades de tecido sadio em comparação com outras técnicas, essa técnica restauradora exige menor tempo clínico pois são menos etapas. A outra vantagem é de possuir maior dissipação das tensões mastigatórias recebidas no complexo dente/restauração ao longo da estrutura dentária (Sevimli *et al.*, 2015). As endocrowns são indicadas quando há grande destruição da coroa, quando o espaço interoclusal é limitado e reabilitação tradicional com pino e coroa não é possível por causa de inadequada espessura cerâmica, Sendo assim, dentes com coroas clínicas curtas ou atrésicas, calcificadas, canais radiculares curvos também são uma indicados nesse tipo de reabilitação (Sevimli *et al.*, 2015; Rocca *et al.*,2015).

Os princípios que regem o preparo para Endocrown seguem o mesmo padrão dos princípios dos preparos para restaurações indiretas Inlay e Onlay. Segundo Clavijo et al.(2007), o preparo deve ser realizado utilizando-se pontas diamantadas de extremo arredondado no formato tronco-cônicas, que conferem expulsividade de aproximadamente 10º nas paredes axiais da câmara pulpar e resultam em ângulos internos arredondados. A oclusal precisa possuir 3mm para conferir adequada espessura a cerâmica e o término do preparo deverá ser feito com pontas cilíndricas no nível gengival.

As caixas proximais e oclusal dos preparos para onlays, inicialmente usadas para ganhar retenção ao preparo cavitário, se tornam questionáveis quando tão consolidadas as reabilitações livres de metais. As restaurações livres de metais podem ser usadas com técnicas adesivas que dispensariam retenções por meios mecânicos, salientando a discussão em torno da necessidade das caixas oclusais e proximais dos preparos para onlays e se a adequação do preparo cavitário ao material restaurador terá influência sobre a deformação e resistência à fratura do elemento dental. Da mesma forma, as restaurações endocrown, que embora vem crescendo novamente na popularidade, ainda fica dúvidas sobre o comportamento biomecânico e o prognóstico desse tipo de tratamento reabilitador comparando com o tratamento convencional com pinos intra-radiculares.

Na análise biomecânica das estruturas dentais e materiais restauradores, os ensaios mecânicos destrutivos para análise da resistência à fratura são importantes meios de análise do comportamento do dente em situações de aplicação de cargas pontuais e de alta intensidade. Porém apresentam limitações com relação à obtenção de informações do comportamento interno do complexo dente restauração. Parece apropriado para resposta mais precisa à interferências de pequenos fatores no processo restaurador que se empregue associação de metodologias não destrutivas, quer experimentais; (Krance *et al.*, 2018) ou por análises computacionais (Ausiello *et al.*, 2004; Schmitter *et al.*, 2012; Liu *et al.*, 2018) à ensaios mecânicos convencionais.

Uma importante ferramenta cada vez mais frequente na análise de comportamento mecânico de estruturas dentais e materiais restauradores é o método de elementos finitos. Vários estudos têm abordado análises comparativas de elementos finitos de forma isolada (Rodrigues *et al.*, 2009; Ausiello *et al.*, 2004; Lin *et al.*, 2008), associadas com ensaios não-destrutivo, como extensometria (Valdivia *et al.*, 2018).

Tensões são geradas a partir da aplicação de carga sobre uma estrutura que resultam em deformações estruturais, se estas se acentuam ultrapassando o regime elástico pode resultar em ruptura da estrutura. Neste processo, a associação de metodologias representa a possibilidade de analisar sequencialmente este processo contínuo e cíclico. Algumas tecnologias têm sido empregadas para análise de deformação (Palin *et al.,* 2005) e extensômetros. De acordo com Sakaguchi *et al.* (1991) e Soares *et al.* (2013) um bom método para mensuração de deformações externas é a utilização de extensômetros aderidos na face externa da estrutura dental.

A adaptação marginal de coroas protéticas é fator vital para o sucesso em longo prazo, porque o cimento é um agente fraco de ligação no processo restaurador (Lin *et al.*, 2012). Quando a dissolução do cimento ocorre, uma fenda é estabelecida entre a dentina e a coroa. A medição da fenda marginal, que é uma medição perpendicular a partir da superfície interna da coroa para a margem do dente preparado, têm sido relatada na literatura para estabelecer a comparação entre métodos de obtenção do modelo virtual (Rocca *et al.*, 2016; da Costa *et al.*, 2010). Diferentes técnicas têm sido escolhidas para avaliar a adaptação marginal de coroas. Uma nova técnica que utiliza micro-tomografia computadorizada (micro-CT) foi utilizada para investigar a desadaptação, e tem a vantagem de ser não destrutiva (Liu *et al.*, 2018, Krasanaki *et al.*, 2012). Esta técnica permite a investigação de pequenos objetos em 3D com alta resolução. A desadaptação marginal é obtida dentro do intervalo de alguns micrometros em vários locais e direções (Seo *et al.*, 2009).

A resistência à fratura de um dente está diretamente relacionada à quantidade de estrutura sadia remanescente que o mesmo possui. A remoção das cristas marginais, o aumento na largura do istmo e o aumento na profundidade do preparo no sentido ocluso-gengival são as principais razões para a diminuição dessa resistência (Mondelli *et al.,* 1980; Mondelli *et al.*, 2007) em um dos seus estudos compararam a resistência à fratura de pré-molares superiores humanos sadios com diferentes larguras de cavidade, provando que a remoção de tecido dentário afeta significativamente a resistência à fratura de dentes.

Define-se revisão sistemática como a aplicação de estratégias científicas que limitam o viés na seleção sistemática, na avaliação crítica e na síntese de todos os estudos relevantes em um tópico específico. A revisão sistemática é uma revisão planejada para responder a uma pergunta específica e que utiliza métodos explícitos e sistemáticos para identificar, selecionar e avaliar criticamente os estudos publicados na literatura científica, evitando o viés em cada uma de suas etapas. Os métodos estatísticos - como a meta-análise, utilizada na revisão sistemática para integrar os resultados dos estudos incluídos - podem ou não ser utilizados na análise e na síntese dos resultados dos trabalhos (Straus et al, 2005; Khan et al, 2001; Olkin I, 1995)

As técnicas de preparo das restaurações indiretas e o material restaurador é um assunto pertinente no cotidiano dos cirurgiões dentistas. Sendo assim estudos laboratoriais associados a estudos clínicos randomizados e uma revisão sistemática são essenciais para o profissional tomar decisões sobre o atendimento clínico de cada paciente individualmente.

OBJETIVOS

2. OBJETIVOS

Objetivo Geral

O objetivo geral do presente estudo foi avaliar as características biomecânicas e adaptação marginal de restaurações indiretas de cerâmica em dentes vitais e em dentes não-vitais.

Objetivos específicos

Objetivo específico 1

Capítulo 1 – *Effect of cavity preparation design and ceramic type on the stress distribuition, strain and fracture resistance of CAD/CAM onlay in molas.*

O objetivo deste estudo foi avaliar o comportamento biomecânico em dois de dois tipos de preparos cavitários: preparo convencional com caixas proximais e oclusal e preparo conservador sem caixas proximais e oclusais; e do tipo do material cerâmico: leucita e dissilicato de lítio. A hipótese nula é que o tipo de cerâmica e preparo cavitário não têm efeito sobre o dente remanescente na resistência à fratura, modo de falha, distribuição de tensõe e deformação de restaurações indiretas do tipo onlay.

Objetivo específico 2

Capítulo 2 – *Micro-CT analysis on different cavity preparations designs restored by CAD-CAM ceramics.*

O objetivo deste estudo foi analisar por meio do Micro CT, a adaptação marginal e integridade interna do cimento resinoso em dois de dois tipos de preparos cavitários: preparo convencional com caixas proximais e oclusal e preparo conservador sem caixas proximais e oclusais; e no tipo do material cerâmico: leucita e dissilicato de lítio. A hipótese nula é que o preparo cavitário e o tipo cerâmico não influenciaram na porosidade e no volume marginal e interno do cimento e na adaptação das onlays cerâmicas feitas CAD/CAM.

Objetivo específico 3

Capítulo 3 – *Oral rehabilitation with endocrown: a systematic review*

O objetivo deste estudo foi investigar em estudos, tanto “in vitro” quanto “in vivo” no efeito da configuração do preparo cavitário em dentes tratados endodonticamente com grande perda de estrutura dentária utilizando a técnica do tipo endocrown por meio de uma revisão sistemática da literatura.

CAPÍTULOS

3. CAPÍTULOS

3.1. CAPÍTULO 1

Artigo publicado no periódico Journal of Applied Oral Science

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Effect of cavity preparation design and ceramic type on the stress distribution, strain and fracture resistance of CAD/CAM onlays in molars

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Abstract

Objective: This study aimed to evaluate the effect of the cavity preparation and ceramic type on the stress distribution, tooth strain, fracture resistance and fracture mode of human molar teeth restored with onlays. Material and Methods: Forty-eight molars were divided into four groups (n=12) with assorted combinations of two study factors: BL- conventional onlay preparation with boxes made from leucite ceramic (IPS-Empress CAD, Ivoclar Vivadent); NBL- conservative onlay preparation without boxes made from leucite ceramic; BD- conventional onlay preparation with boxes made from lithium disilicate glass ceramic (IPS e.max CAD, Ivoclar Vivadent); NBL- conservative onlay preparation with boxes made from lithium disilicate glass ceramic cuspal deformation (µS) was measured at 100 N and at maximum fracture load using strain gauge. Fracture resistance (N) was measured using a compression test, and the fracture mode was recorded. Finite element analysis was used to evaluate the stress distribution by modified von Mises stress criteria. The tooth strain and fracture resistance data were analyzed using the Tukey test and two-way ANOVA, and the fracture mode was analyzed by the chi-square test (α=0.05). Results: The leucite ceramic resulted in higher tooth deformation at 100 N and lower tooth deformation at the maximum fracture load than the lithium disilicate ceramic ($P<0.001$). The lithium disilicate ceramic exhibited higher fracture resistance than the leucite ceramic ($P<0.001$). The conservative onlay resulted in higher fracture strength for lithium disilicate ceramic. Finite element analysis results showed the conventional cavity preparation resulted in higher stress concentration in the ceramic restoration and remaining tooth than the conservative onlay preparation. The conservative onlays exhibited increased fracture resistance, reduced stress concentration and more favorable fracture modes. Conclusion: Molars restored with lithium disilicate CAD-CAM ceramic onlays exhibited higher fracture resistance than molars restored with leucite CAD-CAM ceramic onlays.

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Introduction

Ceramic restorations are improved because of their increased translucency and light transmission.[1] Another advantage includes minimal tooth reduction compared with metal ceramics; minimal thermal conductivity; mimic natural dentition because they have desirable properties, including their physical and mechanical properties; excellent biocompatibility to periodontal tissues; reduced plaque accumulation compared with composite resin; and less susceptibility to metal allergies.[2,3] When an indirect restoration is selected as the treatment option for posterior teeth, the clinician must determine the configuration of the cavity preparation.[4,5] Several designs have been proposed for preparing all-ceramic resin-bonded posterior restorations,[6,7] as guided by the particular mechanical and structural characteristics of ceramic restorative materials.[8]

The primary causes of failure of ceramic inlay or onlay restorations are cohesive bulk fractures and marginal deficiencies,[9] which manifest clinically as marginal discoloration and secondary caries.[10] Tooth preparation designs for posterior ceramic restorations have been based on traditional cast metal restoration designs, but with more occlusal tooth reduction and with a slightly increased taper.[4] These preparations may involve the removal of considerable tooth structure.[11] As more structure is removed, higher tooth strain and lower fracture resistance may occur.[5] The increased tooth structure loss may increase cuspal flexure, thereby reducing the tooth fracture resistance, or open the restoration-tooth interface.[12] However, it has been demonstrated that cusp recovery results in fewer failures, likely increasing the longevity of posterior ceramic restorations.[6] Recently, minimally invasive cavity preparations for posterior indirect restorations were demonstrated to present the benefit of conservation of tooth structure, as well as improved stress distribution.[13] However, the performance of posterior restoration is also material dependent.[14,15] Due to the continuous advancements in dental ceramics and innovative manufacturing techniques, the following question arises: could traditional preparation guidelines for ceramic onlays be modified in terms of minimally invasive therapy? Several all-ceramic systems, such as leucite and lithium disilicate CAD-CAM systems, have two major recent developments: dentine bonding and stronger all-ceramic crown systems.[16] Ceramic inlays and onlays can be manufactured in a laboratory or milled chairside from ceramic blocks using CAD/CAM technology.[17] The restorations prepared with indirect technique with CAD/CAM system in case of more extensive loss of dental structure can be preferred because of their better fracture resistance, esthetic looks, implementation in a single visit, and shorter intraoral working time.[18] This system shows good clinical performance; however, it depends on the material and its indication in fixed prostheses of one or more elements.[15] However, the use of these materials is extremely technique sensitive. CAD/CAM ceramic materials are manufactured under optimized conditions, which can minimize voids and volume defects.[17,19,20] The fracture rate for CAD/CAM posterior ceramic restorations is suggested to be related to design aspects of the restoration and to the composition of the ceramic.[15]

Fracture resistance tests have been used to predict the failure of ceramic restorations under influence of the preparation design.[21] Nondestructive experimental methodologies, such as the strain gauge test,[22] and finite element analysis[23,24] should be combined with conventional mechanical tests to better explain the failure of the ceramic restorations.[22,25] The stresses generated by bite loading cause structural strain; if such stresses become excessive and exceed the elastic limit, structural failure may result.[26] To the best of the authors' knowledge, to date, no study has integrally analyzed the failure of minimal cavity preparations for posterior teeth with different ceramic compositions in comparison with conventional cavity preparation designs. Therefore, this study aimed to analyze the biomechanical performance of onlays made from leucite and lithium disilicate-reinforced ceramics in CAD/CAM restorations associated with both conventional cavity preparations and minimal preparations without occlusal and proximal boxes. The null hypothesis was that the ceramic type and cavity preparation design have no effect on the remaining tooth strain, stress distribution, fracture resistance and fracture mode of molars restored with onlays.

Material and methods

Teeth selection and cavity preparation

In this *in vitro* study, forty-eight freshly extracted mandibular molars were selected with the approval of the Ethics Committee in Human Research (protocol #307.608). The teeth were selected to have an intercuspal width that fell within a maximum deviation of no more than 10% of the determined mean. The measured intercuspal width varied between 5.2 mm and 6.1 mm. The teeth were embedded in a polystyrene resin (Cristal, Piracicaba, SP, Brazil) up to 2.0 mm below the cervical line to simulate alveolar bone support, and for simulating the periodontal ligament was used a 0.3 mm layer of a polyether impression material (Impregum; 3M ESPE, St Paul, MN, USA).[27] The tooth was placed down into a hole in a wooden board, leaving the root in a vertical position perpendicular to the supporting radiographic film, placed over the root and fixed in position with wax. A polystyrene resin was manipulated according to manufacturer and poured into a plastic cylinder. The teeth were removed from the cylinder after resin polymerization, and the wax was removed from the root surface and resin cylinder, simulating the alveolus. The polyether material was placed inside the resin cylinders.[27] The teeth were cleaned using a rubber cup and fine pumice water slurry and distributed into four groups (n=12) (Figure 1): BL, onlay cavity preparation with proximal and occlusal boxes made from leucite ceramic (IPS Empress CAD, Ivoclar Vivadent AG, Schaan, Liechtenstein); NBL, onlay cavity preparation without proximal and occlusal boxes made from leucite ceramic; BD, onlay cavity preparation with proximal and occlusal boxes made from lithium disilicate glass ceramic (IPS Empress CAD, Ivoclar Vivadent AG, Schaan, Liechtenstein); NBD, onlay cavity preparation without proximal and occlusal boxes made with lithium disilicate glass ceramic.

Before the cavity preparation, x-rays (Timex 70 E, Gnatus, Ribeirão Preto, SP, Brazil) of all the teeth in the buccal and mesial directions were taken. Two different cavity preparation designs with internal rounded angles were defined. For the conventional onlay preparation, the occlusal reduction was 1.5 mm, maintaining the inclination of the cusps using a diamond bur (#2143, KG Sorensen, Barueri, SP, Brazil). The occlusal box was extended by 1.0 mm in depth according to the anatomical characteristics of each tooth, and an overall preparation angle of 6° toward the occlusal aspect was created with a conical flat-end diamond bur (#3131, KG Sorensen, Barueri, SP, Brazil) to produce converging walls to the occlusal. For the preparation of proximal boxes, the same diamond bur was used within 0.5 mm from the gingival margin with an isthmus measuring one third of the buccolingual width. The conservative onlay preparation included only the occlusal reduction, excluding the occlusal and proximal boxes (Figure 1). All the restorations used the minimum thickness of material specified by the manufacturer. All the teeth were prepared using a high-speed handpiece with copious air-water spray, using a cavity preparation machine[28]. This machine consisted of a high-speed handpiece (EXTRA torque 605 C; KaVo do Brasil, Joinville, SC, Brazil) coupled to a mobile base. The mobile base could move vertically and horizontally with three precision micrometric heads (152-389; Mitutoyo Sul Americana Ltda, Suzano, SP, Brazil), attaining a 0.002 mm level of accuracy.

Ceramic preparation and cementation

An optical impression was made using intraoral

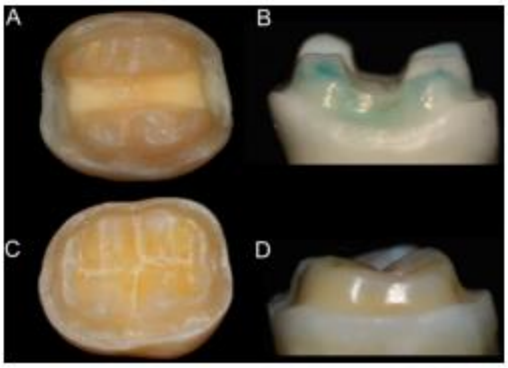

Figure 1- Cavity preparation with occlusal and proximal boxes. (A, B) Cavity with boxes; (C, D) Cavity without boxes

digitization (Cerec Blue Cam & MCXL, Dentsply Sirona, Bensheim, Germany) to generate a 3D virtual model. Using CAD, the design of the restoration was created, maintaining the same occlusal anatomy for all the restorations. This image was sent to the CAM, and the biogeneric copy technique was used to obtain the indirect restoration by milling a ceramic block. All CAD/CAM restorations were produced using the CEREC System (CEREC System, Sirona, Germany), and CAD/CAM onlays were fabricated using leucite ceramic (IPS Empress CAD) and lithium disilicate ceramic (IPS E-max CAD). All the restorations were produced and cemented according to the manufacturer's instructions. The accuracy of each restoration fit was assessed, and adjustments were made when necessary. Leucite-reinforced ceramic onlays were etched with 10% hydrofluoric acid (Condicionador de Porcelanas; Dentsply, São Paulo, SP, Brazil) for 60 s, and lithium disilicate-reinforced ceramic onlays were etched with 10% hydrofluoric acid for 20 s,[29] followed by silanization using a pre-hydrolyzed silane agent (Angelus, Londrina, PR, Brazil) applied for 60 s and then dried with air spray.[29] The self-adhesive resin cement (RelyX U200, 3M-Espe, St Paul, MN, USA) was manipulated as recommended by the manufacturer and inserted into the intaglio surface of the ceramic restorations, which were seated in place using digital pressure. Excess luting agent was removed, and after 5 minutes,[30,31] the resin cement was activated using a halogen curing unit (XL 3000; 3M ESPE, St Paul, MN, USA) with 800 mw/cm^2 checked by using Resin Calibrator (BlueLight, Halifax, NS, Canada), activating in the buccal, lingual, and occlusal directions for 40 s, totaling 120 s for each tooth.

Strain measurement and fracture resistance tests

Coronal deformation was measured with strain gauges (PA-06-060CC-350L, Excel Sensores, SP, Brazil), which had an internal electrical resistance of 350 X, a gauge factor of 2.1, and a grid size of 21.0 mm^2. The gauge factor is a proportional constant between electrical resistance variation and strain. The strain gauges were bonded to the lingual surfaces of the ceramic restorations with cyanoacrylate adhesive (Super Bonder; Loctite, São Paulo, SP, Brazil), and the wires were connected to a data acquisition device (ADS0500IP; Lynx Tecnologia Eletrônica, São Paulo, SP, Brazil). The strain gauges were placed in the region in which a finite element model indicated the presence of the highest polymerization stresses. The specimens were subjected to nondestructive axial compressive loading using a metal sphere 6mm in diameter at this orientation and a crosshead speed of 0.5 mm/min[32] in a mechanical testing machine (DL2000; EMIC) until reaching 100 N, when the first strain value was recorded. Then, the load was applied until failure, and the second strain value was recorded (n=7). The maximum load to cause failure of the sample was recorded (N) for all the samples (n=12). Strain data were transferred to a computer by using specific acquisition signal transformation and data analysis software (AQDADOS 7.02 and AQANALISYS; Lynx, São Paulo, SP, Brazil).

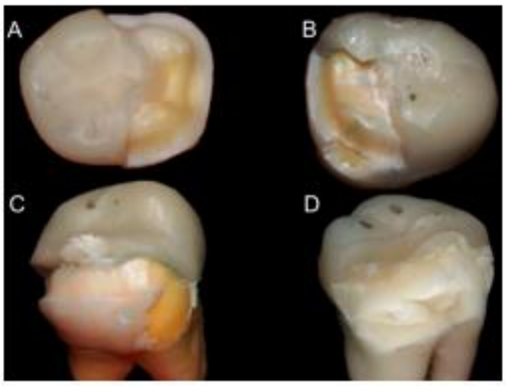

Figure 2- Types of fracture. (A) Type 1, Fractures involving a small portion of the coronal tooth structure; (B) Type 2, fractures involving a small portion of the coronal tooth structure and cohesive failure of the restoration; (C) Type 3, fractures involving the tooth structure, cohesive and/or adhesive failure of the restoration, and root involvement that can be restored in association with periodontal surgery; and (D) Type 4, severe root and crown fracture, necessitating extraction of the tooth

The mode of fracture for each specimen was analyzed under a stereomicroscope (Mitutoyo, Tokyo, Japan) to determine modes of fracture and then assigned to 1 of the 4 categories[33], as shown in Figure 2.

Statistical analysis

The data of deformation at 100 N, deformation at maximum fracture load and fracture resistance were tested for normal distribution (Shapiro-Wilk) and the equality of variances (Levene's test). Two-way analysis of variance (ANOVA) for 2 study factors, ceramic restorations (2 levels: lithium disilicate or leucite ceramic) and cavity preparation (2 levels: conventional or minimally invasive preparations), was performed followed by the Tukey test. The fracture mode data were subjected to the chi-square test. All the tests used a 0.05 level of statistical significance and all statistical analyses were carried out with Sigma Plot version 13.1 (Systat Software Inc., San Jose, CA, USA).

Finite element analysis – FEA

Buccolingual bidimensional models were created from a longitudinal cut of a sound mandibular molar, simulating the dimensions of each dental structure and of the indirect restoration made by the CAD-CAM system. The stress analysis was performed using MSC. Mentat (preprocessor and postprocessor) and MSC. Marc (solver) software (MSC Software Corporation, Santa Ana, CA, USA). The external outline of the tooth specimen positioned in the polystyrene resin base and simulated periodontal ligament were included in the model. The same experimental conditions used for fracture resistance and strain gauge tests were simulated in FEA. Coordinates were obtained using ImageJ software (public domain, Java-based image processing and analysis software developed at The National Institutes of Health, Bethesda, MD, USA). The mesh was manually created using a four-node isoparametric arbitrary quadrilateral element written for plane strain applications using reduced integration (one integration point - element type 115). The frictional contact was inserted between the metallic sphere and the restored tooth sample. All other interfaces were considered bonded. A dynamic structural analysis was performed. All the materials were assumed to be linear, elastic, isotropic and homogeneous. The mechanical properties were represented by Young's modulus of elasticity and Poisson's ratio extracted from the literature (Table 1).[24,30,31,34] Boundary conditions were defined by the restriction of the movements applied at the external lateral outline and cylindrical specimen support base. Stress distribution analysis was performed by the quantitative association of the main maximum stresses by the modified von Mises criteria.

Results

Coronal Deformation (CD)

The tooth deformation values (strain) for the two ceramic restorations and the two cavity preparations at 100 N are shown in Table 2. Two-way ANOVA showed ceramic type factor (P=0.005) had significant effects on tooth deformation; however, the cavity preparation factor (P=0.426) interaction between the two study factors had no significant effect (P=0.258). The Tukey test showed leucite ceramic restorations had a significantly higher deformation than lithium disilicate ceramic restorations, irrespective of the cavity preparation design (P<0.001). Both cavity preparations had similar deformation, irrespective of the type of ceramic restoration (P=0.942).

Table 1- Mechanical properties of isotropic structures

Structure	Elastic Modulus (MPa)	Poisson Ratio	References
Enamel	84.100	0.20	37, 40
Dentin	18.600	0.31	37, 40
Pulp	2.0	0.45	37, 38
Periodontal ligament	50.0	0.45	37, 38
Polystyrene resin	13.500	0.31	42
Lithium disilicate ceramic	96.000	0.25	36
Leucite ceramic	65.000	0.23	36
Resin cement	8.600	0.30	36, 40

Table 2- Coronal deformation (µS) measured by strain gauges (n=7 teeth)

Ceramic Type	Coronal deformation (µS)			
	100 N		Maximum fracture load	
	Cavity preparation without box	Cavity preparation with box	Cavity preparation without box	Cavity preparation with box
Lithium disilicate ceramic	31.7±5.6^{Aa}	34.2±10.8^{Aa}	1141.0±155.4^{Ba}	1151.9±134.9^{Ba}
Leucite ceramic	58.1±17.5^{Ba}	48.8±7.9^{Ba}	695.4±137.6^{Aa}	749.5±68.1^{Aa}

Different uppercase letters in columns indicate the ceramic type for each cavity preparation design and load condition; lowercase letters in rows indicate the cavity preparation design for each ceramic and load condition (P<0.05)

Table 3- Fracture resistance (N) measured by the axial compression test (n=12 teeth)

Ceramic Type	Fracture Resistance – N	
	Cavity preparation without box	Cavity preparation with box
Lithium disilicate ceramic	3099.1±757.3^{Aa}	2108.6±476.9^{Ab}
Leucite ceramic	1794.9±516.3^{Ba}	1591.3±414.6^{Ba}

Different uppercase letters in columns indicate the ceramic type for each cavity preparation design; lowercase letters in rows indicate the cavity preparation design for each ceramic (p<0.05)

Ceramic Type	Cavity preparation without box				Cavity preparation with box			
	I	II	III	IV	I	II	III	IV
Lithium disilicate ceramic	6	1	3	2	7	2	1	2
Leucite ceramic	9	1	1	1	12	0	0	0

Fracture modes: I, fractures involving a small portion of the coronal tooth structure; II, fractures involving a small portion of the coronal tooth structure and cohesive failure of the restoration; III, fractures involving the tooth structure, cohesive and/or adhesive failure of the restoration, and root involvement that can be restored in association with periodontal surgery; and IV, severe root and crown fracture, necessitating extraction of the tooth

Figure 3- Fracture mode distribution (n=12 teeth)

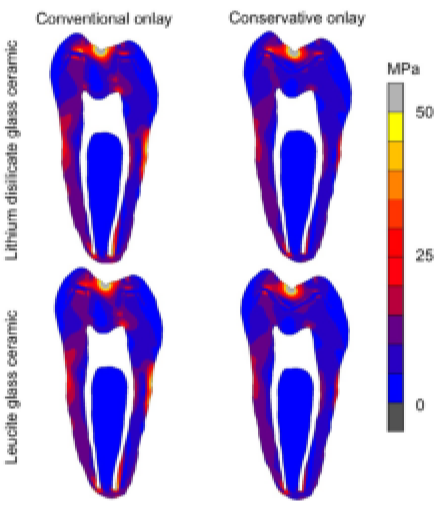

Figure 4- Modified von Mises stress distributions for all groups at 100 N. (A) Conventional onlay/ lithium disilicate glass ceramic; (B) Conventional onlay/leucite glass ceramic; (C) Conservative onlay/lithium disilicate glass ceramic; (D) Conservative onlay/ leucite glass ceramic

The coronal deformation values (strain) for the two ceramic restorations and the two cavity preparations at the maximum fracture load are shown in Table 2. Two-way ANOVA showed the ceramic type (P=0.020) had a significant effect on fracture resistance; however, the cavity preparation (P=0.426) and the interaction between the two study factors had no significant effect (P=0.258). The Tukey test showed the lithium disilicate ceramic restorations exhibited significantly higher deformation than leucite restorations (P=0.029). Both cavity preparations had similar deformation, irrespective of the type of ceramic restoration (P=0.258).

Fracture resistance and fracture mode

The fracture resistances in N for the two ceramic restorations and the two cavity preparations are shown in Table 3. Two-way ANOVA revealed that the ceramic restoration (P<0.001), the cavity preparation (P<0.001) and the interaction between the two study factors (P=0.018) had significant effects on fracture resistance. The Tukey test showed the presence of a box had no significant effect for leucite ceramic restorations (P=0.375); however, the presence of a box in lithium disilicate ceramic restorations significantly reduced the fracture resistance (P<0.001). The lithium disilicate ceramic restorations had significantly higher fracture resistance than leucite ceramic restorations (P<0.001), irrespective of the cavity preparation.

The fracture mode distributions are shown in Figure 3. The chi-square test showed the lithium disilicate ceramic resulted in a more severe fracture mode, irrespective of the type of cavity preparation.

Finite element analysis

Modified von Mises stress distributions for all the groups at 100 N are shown in Figure 4. The type of cavity preparation influenced the stress distribution and intensity more than the type of ceramic. The cavity preparation with an occlusal box resulted in higher stresses at the ceramic restoration and higher remaining tooth structure than cavity preparations without occlusal box. The lithium disilicate ceramic restorations resulted in a slightly higher stress concentration in the ceramic than leucite ceramic restorations.

Discussion

This study investigated the influence of ceramic type and cavity preparation design on the tooth remaining deformation, stress distribution, fracture resistance and fracture mode of molar restored with ceramic onlays. The results showed that the lithium disilicate ceramic had better performance than leucite ceramic onlay and that conservative cavity preparation without occlusal and proximal boxes is the best choice for improving biomechanical performance of posterior ceramic onlays. Therefore, the null hypothesis was rejected.

To minimize the discrepancy between experimental assessments and clinical failures, different methods have been used, such as the association of tooth remaining deformation, fracture resistance tests, fracture mode analysis and finite element analysis.[22,25,35,36] *In vitro* tests are the primary methods used to investigate the fracture strength of restorations; however, the different methodologies used in different studies, such as the mode and direction of load application, crosshead speed, fracture mode, and root embedding, may result in different outcomes, making any comparison difficult.[21] Tooth fracture is defined by the moment when stress intensity exceeds a critical value prompting rupture.[32] The periodontal ligament plays an important role in this failure process, because it can deform and accommodate the tooth in the alveolus, which alleviates stress in the cervical region of the tooth. In this experiment, a polyether impression material was used with polystyrene resin to simulate more realistic fractures observed clinically.[27] Other important aspect is the speed employed on the fracture resistance test, structures with ductile characteristics tend to be brittle when submitted to higher crosshead speed load applications.[32] To simulate the tooth fracture with compressive loading, crosshead speeds of 0.5 were used in this study, which allows a better stress distribution inside the restored tooth.[32] In the biomechanical analysis of tooth structures and restorative materials, destructive mechanical tests used to determine fracture resistance are important means of analyzing tooth behavior in situations of high intensity load application. However, these tests do show limitations with regard to obtaining information about the internal behavior of the tooth-restoration complex. For a more precise response, the combination of experimental nondestructive methodologies, such as strain-gauge test,[22,25] and finite element analysis, with conventional mechanical tests, seems appropriate.[1,22,25,36-38] The association of experimental tests and computational analysis, characterizing the fracture of a restorative material or tooth structure and the strain/stress behavior, provides important data to facilitate the improvement of restorative procedures.[39] In this study, a non-linear finite element analysis using modified von Mises stress was performed for comparing different models. Modified von Mises equivalent stress expressed the stress conditions, using compressive-tensile strength. Stresses in three dimensions were integrated into one scalar value by using a modified von Mises criterion to represent the overall stress condition that could be used to show areas with most critical stress concentrations.[25]

Many variables can affect the fatigue and fracture behavior of all-ceramic restorations, including the dimensions of core and veneer materials, inherent or processing flaws within the materials, and preparation design.[11,21] In this study, in order to control the thickness of the ceramic restorations, the CAD/CAM method was used. Ceramic thickness and geometry of cavity preparations are key factors that influence the clinical longevity of all-ceramic restorations.[4] Enamel is a natural brittle structure that covers the crown of the tooth, it is under layered by dentin, which has ductile behavior. The enamel and dentin are integrated by uniform transition without sharped angle. The conservative cavity preparation confirmed that the uniform thickness of the brittle material is important for stress/strain transferring between structures with different elastic moduli.[37,38] The finite element analysis showed the cavity preparation influenced the stress concentration more than the type of ceramic. Conventional onlay models, with occlusal and proximal boxes, showed higher concentrations of stress in the ceramic restoration and in the remaining tooth structure than the conservative onlay. This may be explained by the larger amount of tooth structure removed from the occlusal surface, which creates more sharp angles that may concentrate stress. Additionally, the ceramic thickness increasing impacted on the stress concentration level inside of the material.

The leucite ceramic resulted in greater tooth deformation than that of lithium disilicate ceramic at 100 N, irrespective of the type of cavity preparation. A load applied to an object causes the stress concentration and structural strain. The direct and linear relationship between stress and strain is primarily promoted by the elastic modulus, an important mechanical property that is fundamental to understand the biomechanical behavior of materials and their relationships.[40] The elastic modulus of the restorative lithium disilicate is greater than that of the leucite ceramic. The stiff material tends to concentrate stress inside the material, reducing the stress transfer to the remaining tooth structure. A recent study accessed the database of an industry-scale machining center in Germany and obtained information on 34,911 CAD/CAM all-ceramic posterior restorations, showed the fractures rates over a period of 3.5 y, reported that the lithium disilicate showed significantly better performance than the leucite-based Empress CAD for onlays and inlays, highlighting the role of the microstructure in the fracture process.[15]

When the load is within the elastic limit of the restored tooth, the structural integrity is not affected. When the tooth structure is removed, more cusp strain is observed, requesting more of the interfaces, and then may reduce the fracture resistance.[12] In the presence of the higher levels of the stress concentration factors and high load applied on the occlusal surface, the concentrated stress may result in crack formation and propagation, causing fracture and structural failure. Although the IPS e-max CAD has greater elastic modulus and stiffness than IPS empress CAD,[17] at a maximum fracture load, the samples restored with lithium disilicate exhibited greater tooth structure deformation than the samples restored with leucite. This may be because the load exceeded the elastic limit of the resistance of the remaining tooth structure. The maximum load, which can reach values higher than 4500 N, exceeds the upper limits of a normal occlusion. Additionally, the stress generated was most concentrated within the ceramic material and could initiate crack formation and propagation, resulting in the cohesive fracture of the ceramic material. This may explain why most of the samples exhibited fractures of ceramic restorations before failure of the remaining tooth structure.

In this study, the lithium disilicate ceramic groups had significantly higher fracture resistance than the leucite ceramic restoration groups, irrespective of the type of cavity preparation. This may be due to the higher elastic modulus and fracture strength.[17] The disilicate ceramic can support higher load, absorbing greater amounts of energy inside the ceramic material before fracture. This aspect is very important in the new paradigm that determines conservative occlusal reduction. Therefore, for occlusal reconstruction in patients with bruxism, lithium disilicate may be preferable. Analyzing the fracture modes in addition to fracture resistance is important. The findings of this study may be explained by the higher stiffness of lithium disilicate, which reaches the yield strength and leads to the fracture of the remaining tooth structure. The lesser deformation of lithium disilicate is caused by the higher elastic modulus and, therefore, leads to support greater deformation of the remaining tooth structure, resulting in a higher percentage of complex fracture. The maximum preservation of healthy tooth structure and the use of restorative materials with mechanical properties similar to dental structure may promote a greater longevity of the tooth-restoration complex.

Conclusions

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

1. Ceramic onlays with conservative preparation without occlusal and proximal boxes demonstrated better biomechanical performance than conventionally prepared ceramic onlay restorations;

2. The thickness of ceramic restorations influenced the stress concentration, in which a more homogeneous thickness promoted a better stress distribution;

3. Conservative preparations resulted in higher fracture resistance in molars restored with lithium disilicate CAD-CAM ceramic onlays;

4. Molars restored with lithium disilicate CAD-CAM ceramic onlays exhibited higher fracture resistance than molars restored with leucite CAD-CAM ceramic onlays;

5. The association of the strain-gauge test with fracture resistance, fracture mode and finite element analysis provides a better explanation of the failure process of posterior ceramic restorations.

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References

1- Raigrodski AJ, Chiche GJ. The safety and efficacy of anterior ceramic fixed partial dentures: a review of the literature. J Prosthet Dent. 2001;86(5):520-5.

2- Esquivel-Upshaw J, Rose W, Oliveira E, Yang M, Clark AE, Anusavice K. Randomized, controlled clinical trial of bilayer ceramic and metal-ceramic crown performance. J Prosthodont. 2013;22(3):166-73.

3- D'Arcangelo C, De Angelis F, Vadini M, D'Amario M. Clinical evaluation on porcelain laminate veneers bonded with light-cured composite: results up to 7 years. Clin Oral Inv. 2012;16(4):1071-9.

4- Molin MK, Karlsson SL. A randomized 5-year clinical evaluation of 3 ceramic inlay systems International. J Prosthodont. 2000;13(3):194-200.

5- Morin D, DeLong R, Douglas WH. Cusp reinforcement by the acid-etch technique. J Dent Res. 1984;639(8):1075-8.

6- Momoi Y, Hayashi M, Fujitani M, Fukushima M, Imazato S, Kubo S, et al. Clinical guidelines for treating caries in adults following a minimal intervention policy – evidence and consensus based report. J Dent. 2012;40(2):95-105.

7- Broderson SP. Complete-crown and partial-coverage tooth preparation designs for bonded cast ceramic restorations. Quintessence Int. 1994;25(8):535-9.

8- Bremer BD, Geurtsen W. Molar fracture resistance after adhesive restoration with ceramic inlays or resin-based composites. Am J Dent. 2001;14(4):216-20.

9- Pihlaja J, Näpänkangas R, Raustia A. Early complications and short-term failures of zirconia single crowns and partial fixed dental prostheses. J Prosthet Dent. 2014;112(4):778-83.

10- Araujo NS, Moda MD, Silva EA, Zavanelli AC, Mazaro JV, Pellizzer EP. Survival of all-ceramic restorations after a minimum follow-up of five years: a systematic review. Quintessence Int. 2016;47(5):395-405.

11- Jiang W, Bo H, Yongchun G, LongXing N. Stress distribution in molars restored with inlays or onlays with or without endodontic treatment: a three-dimensional finite element analysis. J Prosthet Dent. 2010;103(1):6-12.

12- Pereira JR, McDonald A, Petrie A, Knowles JC. Effect of cavity design on tooth surface strain. J Prosthet Dent. 2013;110(5):369-75.

13- Bakeman EM, Rego N, Chaiyabutr Y, Kois JC. Influence of ceramic thickness and ceramic materials on fracture resistance of posterior partial coverage restorations. Oper Dent. 2015;40(2):211-7.

14- Simsek H, Derelioglu S. *In vitro* comparative analysis of fracture resistance in inlay restoration prepared with CAD-CAM and different systems in the primary teeth. Biomed Res Int. 2016;2016:4292761.

15- Belli R, Petschelt A, Hofner B, Hajtó J, Scherrer SS, Lohbauer U. Fracture rates and lifetime estimations of CAD/CAM all-ceramic restorations. J Dent Res. 2016;95(1):67-73.

16- Pamato S, Valle AL, Andrade GH, Vidotti HA, Só MV, Pereira JR. Does hybridized dentin affect bond strength of self-adhesive resin cement? J Clin Exp Dent. 2016;8(4):e409-14

17- Holand W, Schweiger M, Frank M, Rheinberger V. A comparison of the microstructure and properties of the IPS Empress 2 and the IPS Empress glass-ceramics. J Biomed Mat Res. 2000;53(4):297-303.

18- Vadachkoria D, Vadachkoria O. Clinical protocols: preparation, impression and bonding of all-ceramic glass-based disilicate lithium crowns: review and case report. Georgian Med News. 2017;4(265):94-8.

19- Fasbinder DJ. Materials for chairside CAD/CAM restorations. Compend Cont Educ Dent. 2010;31(9):702-9.

20- Sadowsky SJ. An overview of treatment considerations for esthetic restorations: a review of the literature. J Prosthet Dent. 2006;96(6):433-42.

21- Soares CJ, Martins LR, Fonseca RB, Correr-Sobrinho L, Fernandes Neto AJ. Influence of cavity preparation design on fracture resistance of posterior leucite-reinforced ceramic restorations. J Prosthet Dent. 2006;95(6):421-9.

22- Bicalho AA, Pereira RD, Zanatta RF, Franco SD, Tantbirojn D, Versluis A, et al. Incremental filling technique and composite material-part I: cuspal deformation, bond strength, and physical properties. Oper Dent. 2014;39(2):E71-82.

23- Rodrigues FP, Li J, Silikas N, Ballester RY, Watts DC. Sequential software processing of micro-XCT dental-images for 3D-FE analysis. Dent Mater. 2009;25(6):e47-55.

24- Lin CL, Chang YH, Liu PR. Multi-factorial analysis of a cusp-replacing adhesive premolar restoration: a finite element study. J Dent. 2008;36(3):194-203.

25- Bicalho AA, Valdivia AD, Barreto BC, Tantbirojn D, Versluis, Soares CJ. Incremental filling technique and composite material-part II: shrinkage and shrinkage stresses. Oper Dent. 2014;39(2):E83-92.

26- May LG, Kelly JR, Bottino MA, Hill T. Effects of cement thickness and bonding on the failure loads of CAD/CAM ceramic crowns: multi-physics FEA modeling and monotonic testing. Dent Mater. 2012;28(8):e99-109.

27- Soares CJ, Pizi EC, Fonseca RB, Martins LR. Influence of root embedment material and periodontal ligament simulation on fracture resistance tests. Braz Oral Res. 2005;19(1):11-6.

28- Soares CJ, Fonseca RB, Gomide HA, Correr-Sobrinho L. Cavity preparation machine for the standardization of *in vitro* preparations. Braz Oral Res. 2008;22(3):281-7.

29- Soares CJ, Soares PV, Pereira JC, Fonseca RB. Surface treatment protocols in the cementation process of ceramic and laboratory-processed composite restorations: a literature review. J Esthet Rest Dent. 2005;17(4): 224-35.

30- 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.

31- Pereira RD, Valdivia A, Bicalho AA, Franco SD, Tantbirojn D, Versluis A, et al. Effect of photoactivation timing on the mechanical properties of resin cements and bond strength of fiberglass post to root dentin. Oper Dent. 2015;40(5):E206-21.

32- Naves LZ, Silva GR, Correr-Sobrinho L, Costa AR, Valdivia AD, Soares CJ. Influence of crosshead speed on failure load and failure mode of restored maxillary premolars. Braz Oral Res. 2016;30(3):1-6.

33- Burke FJ, Wilson NH, Watts DC. Fracture resistance of teeth restored with indirect composite resins: the effect of alternative luting procedures. Quintessence Int. 1994;25(4):269-75.

34- Silva NR, Aguiar GC, Rodrigues MP, Bicalho AA, Soares PB, Verissimo C, et al. Effect of resin cement porosity on retention of glass-fiber posts to root dentin: an experimental and finite element analysis. Braz Dent J. 2015;26(6):630-6.

35- Soares CJ, Martins LR, Pfeifer JM, Giannini M. Fracture resistance of teeth restored with indirect-composite and ceramic inlay systems. Quintessence Int. 2004;35(4):281-6.

36- Campos RE, Soares PV, Versluis A, Oliveira Júnior OB, Ambrosano GM, Nunes IF. Crown fracture: Failure load, stress distribution, and fractographic analysis. J Prosthet Dent. 2015;114(3):447-55.

37- Ausiello P, Rengo S, Davidson CL, Watts DC. Stress distributions in adhesively cemented ceramic and resin-composite Class II inlay restorations: a 3D-FEA study. Dent Mater. 2004;20(9):862-72.

38- Magne P, Belser UC. Porcelain versus composite inlays/onlays: effects of mechanical loads on stress distribution, adhesion, and crown flexure. Int J Periodont Rest Dent. 2003;23(6):543-55.

39- 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.

40- Soares CJ, Raposo LH, Soares PV, Santos-Filho PC, Menezes MS, Soares PB, et al. Effect of different cements on the biomechanical behavior of teeth restored with cast dowel-and-cores-in vitro and FEA analysis. J Prosthodont. 2010;19(2):130-7.

3.2. CAPÍTULO 2

Vianna ALSV, Prado CJD, Reis DCS, Agostinho LB, Soares CJ, Bicalho AA. Micro-CT analysis on different cavity preparations designs restored by CAD-CAM ceramics. Braz Oral Res.

Title: Micro-CT analysis on different cavity preparations designs restored by CAD-CAM ceramics.

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Short title: Adaptation of CAD/CAM ceramic restorations

Keywords: Micro-CT, CAD/CAM ceramic, cavity preparation, adaptation, resin cement.

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Title: Micro-CT analysis on different cavity preparations designs restored by CAD-CAM ceramics.

ABSTRACT

Objective: This study aimed to evaluate the marginal and internal integrity of resinous cement of different CAD/CAM ceramic restorations cemented on conventional and conservative preparation design.

Material and Methods: Twenty human mandibular teeth were divided into four groups onlay cavity preparation with proximal and occlusal boxes made with leucite ceramic (BL group); onlay cavity preparation without proximal and occlusal boxes made with leucite ceramic (NBL group); onlay cavity preparation with proximal and occlusal boxes made with lithium disilicate glass ceramic (BD group); onlay cavity preparation without proximal and occlusal boxes made with lithium disilicate glass ceramic (NBD group). The samples were scanned by using high-resolution 3D micro-CT scanner and the images were reconstructed. The 3D software analysis tool was used to calculate the volume of bubbles and porosity of the cement for visualization and qualitative and quantitative evaluation of the specimens. The marginal and internal analysis data were tested for a normal distribution (Shapiro-Wilk) and equality of variances (Levene's test). The values were submitted to a two-way ANOVA followed by Duncan's tests.

Results: The cavity design ($p < 00.5$), ceramic type ($p < 00.5$) and the interaction between the two factors ($p < 00.5$) were all significant on the porosity and volume respectively. The group with box demonstrated significative difference for ceramics. The lithum disilicate ceramic have higher percentage of porosity and higher volume of bubles.

Conclusion: With the limitations of this study, using 3D micro-CT, the preparation design without boxes presented a smaller volume and porosity in the cement than cavities with boxes. The homogeneous thickness of ceramic restorations and leucite reinforced ceramic influenced in less porosity and volume, which could be considered clinically acceptable.

INTRODUCTION

All-ceramic indirect restorations present excellent aesthetics and predictable fracture resistance[1].The clinical success of ceramic restorations depends on the margin and internal adaptation to the cavity preparation[12]. Tooth preparation designs for posterior ceramic restorations have been based on traditional cast metal restoration designs, with the presence of proximal and occlusal boxes but with more expulsive designs[9]. These preparations can involve the removal of considerable tooth structure[11], which may lead to lower fracture resistance [10].

The primary causes of failure of ceramic inlay or onlay restorations are cohesive bulk fractures and marginal deficiencies[13], which manifest clinically as marginal discoloration and secondary caries[14]. Ceramic restorations can be manufactured in the laboratory or milled chairside from ceramic blocks using Computer Aided Design/Computer Aided Manufacture (CAD/CAM) technology[15]. Several all-ceramic systems, such as leucite and lithium disilicate CAD/CAM systems, have been introduced to reduce these drawbacks[16]. CAD/CAM ceramic materials are manufactured under optimized conditions, which can minimize voids and volume defects[16,17]. The sharp angles would induce stress concentration and crack initiation and propagation[18]. The machining system of the prosthetic part, especially the shape of the drill bit and its thickness, cannot reproduce angles of this type. The sharp angles would induce stress concentration and crack initiation and propagation.

The cementation process can influence the adaptation and biomechanical performance of a ceramic restoration. Resinous cements consist of a matrix of polydimethacrylate and inorganic fillers that are polymerized by rapid reactions of free radicals when mixed and submitted to light[24]. Volume reduction during the polymerization process of the resinous cement, which result in shrinkage stress, is recognized as important factor that affects the integrity between the restoration and the structure of the tooth, and the formation of porosity or gaps[25]. Porosity can also greatly affect the longevity and success of a restoration[53] and with less than 10% of porosity can reduce the overall strength by 50%[26]. As a consequence of cement application voids and bubbles are observed within the resin cement caused air entrapment[18,43]. The bubbles and voids may reduce the resin cement contact area with the crown surface and ultimately to retention the ceramic with the tooth preparation. In cases where the fitting surface of a prepared tooth has complexed geometry, the discrepancy in the internal gaps between the preparation designs can be attributed to the three-dimensional (3D) optical impression and the milling processes[36,37].

A large variability of the studies have been related the method used for analysis for restoration cementation[54]. Different methods are predominantly applied o marginal fit[48], for in vitro studies: radiodensity[51], stereomicroscopy[49,54], scanning electron microscopy[50], optical microscopy[27]and micro-computed tomography (μ-CT)[47]. However, no consistent data is presented in the literature regarding the internal structure of dental cement after the cementation process. The Micro-CT is a non-destructive 3D method very suitable to investigate the details of dental structure relating to restoration[28,29.] Data about the void formation from conventional methods has been provided based on destructive such as SEM, and two-dimensional methods, such as X-ray, high pressure mercury intrusion porosimetry[45.] For the destructive techniques, sectioned specimens are used to characterize the structure, and the structure is damaged. Furthermore, these methods cannot precisely define the void formation at the volumetric scale[45,46]. Micro-CT has is a non-destructive, rapid, and powerful tool to evaluate the different materials. This method allows for examination of the internal structure and void detection. Micro-CT has been recently used in the dentistry to analyze several factors linked to restorative procedures [44,48,52]. However, few studies have used this method to analyze the effect different cavity preparations designs on the adaptation of CAD-CAM ceramics restorations.

Therefore, the aim of this study was to evaluate the marginal and internal integrity of resinous cement of different CAD/CAM ceramic restorations cemented on conventional and conservative preparation design. The null hypothesis tested was that that cavity preparation and ceramic type would not influence the porosity, marginal and internal volume of the cement of the CAD/CAM ceramic onlays.

MATERIALS AND METHODS

Twenty human mandibular first molar were selected (Ethics Committee in Human Research#307.608) and prepared by an experienced operator with a high-speed handpiece and copious air-water spray, using a cavity preparation machine[2]. The standardization of the selected teeth should have an intercuspal width that fell within a maximum deviation of no more than 10% of the determined mean. The measured intercuspal width varied between 5.17mm and 6.13mm.

The four experimental groups (n=5) were based on different prepared methods and different ceramics and were designated as follows: onlay cavity preparation with proximal and occlusal boxes made with leucite ceramic (BL group); onlay cavity preparation without proximal and occlusal boxes made with leucite ceramic (NBL group); onlay cavity preparation with proximal and occlusal boxes made with lithium disilicate glass ceramic (BD group); onlay cavity preparation without proximal and occlusal boxes made with lithium disilicate glass ceramic (NBD group). All groups used IPS Empress CAD (Ivoclar Vivadent AG, Liechtenstein). A standard set of diamond rotary instruments #2143 and #3131 (KG Sorensen, Barueri, SP, Brazil) suitable for ceramic onlay preparation was used. Two different cavity preparation designs were defined with internal rounded angles. The occlusal reduction was 1.5mm, maintaining the inclination of the cusps using a diamond bur, the occlusal box was extended by 1.0mm in depth according to the anatomical characteristics of each tooth. An overall preparation angle of 6◦ toward the occlusal aspect was created with a conical flat-end diamond bur to produce converging walls to the occlusal. The preparation of proximal boxes, the same diamond bur was used within 0.5mm from the gingival margin with an isthmus measuring one-third of the bucco-lingual width. For the conservative NBL and NBD groups, the preparation design included only the occlusal reduction, excluding the occlusal and proximal boxes. All cavity preparation designs with internal rounded angles were defined. (FIG1)

A CAD/CAM system (CEREC System, Sirona, Germany) were used to produce the ceramic restoration. An optical impression was made using an intraoral digitization (Cerec Blue Cam & MCXL, Sirona, Germany) to generate a 3D virtual model. Using CAD, the design of the restoration was created, maintaining the same occlusal anatomy for all restorations. For milling parameters, 40 μm for the spacer and 20 μm for the cement gap were established[3]. The file was sent to the CAM system, and the biogeneric copy technique was used to obtain the indirect restoration by milling a ceramic block. Onlay restorations were adhesively cemented by the self-adhesive resin cement (RelyX U200, 3M-Espe, St Paul, MN) and their surface were previously treated. For Leucite-reinforced ceramic onlays were etched with 10% hydrofluoric acid (Condicionador de Porcelanas;

Dentsply, Sao Paulo, Brazil) for 60 seconds, and lithium disilicate-reinforced ceramic onlays were etched with 10% hydrofluoric acid (Condicionador de Porcelanas; Dentsply, Sao Paulo, Brazil) for 20 seconds, followed by silanization using a pre-hydrolyzed silane agent (Angelus, Londrina, Brazil) applied for 60 seconds and then dried with air spray[4]. The excess of the cement was removed using a microbrush (KG Sorensen, Sao Paulo, Brazil) and after 5 minutes the resin cement was ligth activated from the buccal, lingual and occlusal aspects for 40 s using a halogen light curing unit with 800 mw/cm2 (XL 3000; 3M ESPE)[5].

The samples were scanned by using a high-resolution 3D micro-CT scanner (SkyScan 1272; Bruker Micro-CT, Kontich, Belgium). The equipment was operated at 100 kV and 100 μA using a 0.5 mm Al+Cu filter at a resolution of 1632/1092 pixels - 10μm. Each specimen was scanned for a total of 60 minutes at 180° rotation around the vertical axis with a rotation step of 0.40, average frame of 3, and random movement of 20 mm. The images were reconstructed by a system reconstruction software (NRecon v.1.6.3, SkyScan; Bruker) at axial cross-sections of the resulting 2D images (8-bit TIFF) with a beam hardening correction of 55%, smoothing of 5, and an attenuation coefficient range of 0 to 0.062991. Thereafter, the 3D software analysis tool (CTAn, Bruker Micro-CT) was used to calculate the volume of bubbles and porosity of the cement and CT Vol v.2.2.1, SkyScan; Bruker-micro-CT) was used for 3D reconstruction (volume, surface area and structure model index) for visualization and qualitative evaluation of the specimens.

STATISTICAL ANALYSIS

The marginal and internal adaptation data were tested for a normal distribution (Shapiro-Wilk) and equality of variances (Levene's test), followed by parametric statistical tests. Marginal and internal adaptation values were submitted to a two-way ANOVA followed by Duncan's tests. All tests used an $\alpha = 0.05$ significance level and all analyses were carried out using Sigma Plot version 13.1 (Systat Software Inc., San Jose, CA, USA).

RESULTS

The means and standard deviation of volume and porosity are shown on table I. Two-way ANOVA showed that cavity design ($p < 00.5$), ceramic type ($p < 00.5$) and the interaction between the two factors ($p < 00.5$) were all significant on the porosity an volume respectively. The qualitative analysis are shown on figure 1.

Given the significant parameters, both porosity and volume the group without box demonstrate no significance irrespective of ceramics. The group with box demonstrated significative difference for ceramics. The lithum disilicate ceramic have higher percentage of porosity and higher volume of bubles (Table 1).

DISCUSSION

Micro-CT analyzed the internal porosity and the integrity of resin cement used for cementation of indirect restorations and the porosity and volume cement were influenced by the interaction between the cavity preparation and ceramic type; thus, the null hypothesis had to be rejected. In addition to being a non-destructive method, another advantage of using these systems, is the samples remain available after scanning for additional bonding testing and the images can be examined several times[30,31.] It possible to obtain comprehensive imaging of the spatial organization of the specimen structures by using the micro-CT combined with 3D reconstructions and it is also possible to estimate the volume of voids between the adhesive interfaces, as was done in the present study, which the cementation line between dental and ceramic structure was analyzed. The porosity and volume cement were influenced by the interaction between the cavity preparation and ceramic type; thus, the null hypothesis had to be rejected. The box design increased the presence of bubbles in the cement, which may interfere in the bond integrity facilitating the dissolution of the cement. The solubility of the resin cement can provide the marginal gap formation between tooth and preparation facilitating bacterial growth, gingival inflammation, caries recurrence and pulpal inflammation[49,53]. The preparation design with boxes presented a significantly larger overall porosity and volume of bubbles that of the non-boxes preparation design.

The design of the cavity preparations and the ceramic thickness can influence the clinical longevity of all-ceramic restorations[18,34]. The enamel and dentin are integrated by a uniform transition without sharp angle and to mimic the natural tooth, the conservative preparation was done to maintain a uniform thickness of the ceramic, resulting in less angles with the exclusion of the proximal and occlusal boxes of this cavity preparation design. The reduction of the boxes and internal angles can explain the lower volume of bubbles and the better internal and marginal adaptation. It can be occurred a phenomenon called ‘overshooters’ that simulates virtual peaks near the edges during the optical impression process[35,36]. The software transformed the point clouds obtained by the optical impression into a smooth and continuous surface[37]. The 3D optical impression used to capture the prepared tooth and the milling accuracy of Cerec may not always be reliable when the internal design has complex geometry.

The porosity into the resin cement in the cavity designs with boxes was higher irrespective of the ceramic restorations. This may be explained during the cementation process, that air bubbles can be introduced into the material due to the method of mixing the self-adhesive cement used[40]. The preparations with boxes resulted in larger contact surface, they may have trapped more bubbles into the resin cement layer. Thus, it can be related that the smaller number of angles the smaller the imprisonment of bubbles inside the cement[38,39].

The limitation of this study was to test only the hand mixed resin cement. In future studies, the use of automix resin cements should be considered[6,41]. The automixing resulted in lower porosity and better bond integrity[56]. Another aspect that may be included in the future studies is the vibration by using ultrasound devices to increasy the flowability of the resin cement, reducing the porosity[55]. The preparation design that requires to remove larger amount intact tooth structure must be rejected for a number of reasons: exposure of dentin near the pulp with a high proportion of dentin tubules, increased secretion of dentinal fluid, adverse influence on the ratio of residual dentin to cavities (pulp cavity, dentin tubules), increased risk of postoperative sensitivity. Therefore, the use of ceramic materials in the cavity preparation design without boxes seems to be easier, safer and produce better internal and marginal integrity compared to traditional ones.

CONCLUSIONS

With the limitations of this study, using 3D micro-CT, the preparation design without boxes presented a smaller volume and porosity in the cement than cavities with boxes. The homogeneous thickness of ceramic restorations and leucite reinforced ceramic influenced in less porosity and volume, which could be considered clinically acceptable.

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The authors of this study attest that there is not conflict of interest.

REFERENCES

1. Boening KW, Wolf BH, Schmidt AE, Kästner K, Walter MH. Clinical fit of Procera AllCeram crowns. J Prosthet Dent 2000;84:419-24.
2. Soares CJ, Fonseca RB, Gomide HA & Correr-Sobrinho L. Cavity preparation machine for the standardization of in vitro preparations Braz Oral Res 2008; 22(3) 281-287.
3. Reich S, Gozdowski S, Trentzsch L, et al: Marginal fit of heat-pressed vs. CAD/CAM processed all-ceramic onlays using a milling unit prototype. Oper Dent 2008;33:644-650.
4. Soares CJ, Soares PV, Pereira JC & Fonseca RB. Surface treatment protocols in the cementation process of ceramic and laboratory-processed composite restorations: a literature review J Esthet Restor Dent 2005;17(4) 224-235.
5. 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 Sep-Oct;41(5):491-500.
6. Da Silva NR, Aguiar GC, Rodrigues Mde P, Bicalho AA, Soares PB, Veríssimo C, Soares CJ. Effect of Resin Cement Porosity on Retention of Glass-Fiber Posts to Root Dentin: An Experimental and Finite Element Analysis. Braz Dent J. 2015.
7. Brito-Júnior M, Leoni GB, Pereira RD, Faria-e-Silva AL, Gomes EA, et al.. Novel dentin push-out bond strength model that uses micro–computed tomography. J Endod 2015; 41:2058-2063
8. Kim JH, Cho BH, Lee JH, Kwon SJ, Yi YA, Shin Y, Roh BD, Seo DG. Influence of preparation design on fit and ceramic thickness of CEREC 3 partial ceramic crowns after cementation. Acta Odontol Scand. 2015 Feb;73(2):107-13.
9. Etemadi S, Smales RJ, Drummond PW & Goodhart JR. Assessment of tooth preparation designs for posterior resin-bonded porcelain restorations Journal of Oral Rehabilitation 1999; 26(9):691-7.

10. Scotti N, Coero Borga FA, Alovisi M, Rota R, Pasqualini D & Berutti, Is fracture resistance of endodontically treated mandibular molars restored with indirect onlay composite restorations influenced by fibre post insertion? Journal of Dentistry 2012; 40(10):814-20.
11. Jiang W, Bo H, Yongchun G & LongXing N (2010) Stress distribution in molars restored with inlays or onlays with or without endodontic treatment: a three-dimensional finite element analysis The Journal of Prosthetic Dentistry 103(1):6-12
12. D'Arcangelo C, Zarow M, De Angelis F, Vadini M, Paolantonio M, Giannoni M, D'Amario M. Five-year retrospective clinical study of indirect composite restorations luted with a light-cured composite in posterior teeth. Clin Oral Investig. 2014;18(2):615-24.
13. Pihlaja J, Napankangas R & Raustia A. Early complications and short-term failures of zirconia single crowns and partial fixed dental prostheses J Prosthet Dent 2014; 112(4) 778-783.
14. Araujo NS, Moda MD, Silva EA, Zavanelli AC, Mazaro JV & Pellizzer EP. Survival of all-ceramic restorations after a minimum follow-up of five years: A systematic review Quintessence Int 2016; 47(5) 395-405.
15. Li RW, Chow TW, Matinlinna JP. Ceramic dental biomaterials and CAD/CAM technology: state of the art. J Prosthodont Res. 2014 Oct;58(4):208-16. doi: 10.1016/j.jpor.2014.07.003. Epub 2014 Sep 22. Review. PubMed PMID: 25172234.
16. Guess PC, Selz CF, Steinhart YN, Stampf S, Strub JR. Prospective clinical split-mouth study of pressed and CAD/CAM all-ceramic partial-coverage restorations: 7-year results. Int J Prosthodont. 2013 Jan-Feb;26(1):21-5.
17. Holand W, Schweiger M, Frank M & Rheinberger V. A comparison of the microstructure and properties of the IPS Empress 2 and the IPS Empress glass-ceramics J Biomed Mater Res 2000; 53(4) 297-303.
18. Rosentritt M, Preis V, Behr M, Hahnel S. Influence of preparation, fitting, and cementation on the vitro performance and fracture resistance of CAD/CAM crowns. J Dent. 2017 Oct;65:70-75.

19. Belli R, Wendler M, de Ligny D, Cicconi MR, Petschelt A, Peterlik H, Lohbauer U. Chairside CAD/CAM materials. Part 1: Measurement of elastic constants and microstructural characterization. Dent Mater. 2017 Jan;33(1):84-98.
20. Wendler M, Belli R, Petschelt A, Mevec D, Harrer W, Lube T, Danzer R, Lohbauer U. Chairside CAD/CAM materials. Part 2: Flexural strength testing. Dent Mater. 2017 Jan;33(1):99-109.
21. Badawy R, El-Mowafy O, Tam LE. Fracture toughness of chairside CAD/CAM materials - Alternative loading approach for compact tension test. Dent Mater. 2016 Jul;32(7):847-52.
22. Chavali R, Nejat AH, Lawson NC. Machinability of CAD-CAM materials. J Prosthet Dent. 2017 Aug;118(2):194-199.
23. Curran P, Cattani-Lorente M, Anselm Wiskott HW, Durual S, Scherrer SS. Grinding damage assessment for CAD-CAM restorative materials. Dent Mater. 2017 Mar;33(3):294-308.
24. Sideridou I, Tserki V, Papanastasiou G: Effect of chemical structure on degree of conversion in light-cured dimethacrylate-based dental resins. Biomaterials 2002; 23:1819-1829
25. Condon JR, Ferracane JL: Reduced polymerization stress through non-bonded nanofillerparticles. Biomaterials 2002; 23:3807-3831
26. Barralet JE, Gaunt T, Wright AJ, et al: Effect of porosity reduction by compaction on compressive strength and microstructure of calcium phosphate cement. Biomed Mater Res 2002; 63:1-9
27. Van den Breemer CR, Gresnigt MM, Cune MS. Cementation of Glass-Ceramic Posterior Restorations: A Systematic Review. Biomed Res Int. 2015; 2015:148954. doi: 10.1155/2015/148954. Epub 2015 Oct 18. Review. PubMed PMID: 26557651; PubMed Central PMCID: PMC4628770.
28. Borba M, Cesar PF, Griggs JA, et al: Adaptation of all-ceramic fixed partial dentures. Dent Mater 2011; 27:1119-1126
29. Stock S: Micro CT in practice. In Stock SR (ed): Micro Computed Tomography: Methodology and Applications, Vol 5 (ed 1). Boca Raton, FL, Taylor & Francis, 2009, pp. 85-108

30. Clementino-Luedemann TN, Kunzelmann KH. Mineral concentration of natural human teeth by a commercial micro-CT. Dent Mater J 2006 ;25:113-119
31. Swain MV, Xue J. State of the art of Micro-CT applications in dental research. Int J Oral Sci 2009; 1:177-188
32. Michelson C, Ghuman T, Cakir D, et al. Shear bond strength of four cements on four substrates. J Dent Res 2009;88(SpecIss A). Abstr. #1841
33. Zorzin J, Belli R, Wagner A, Petschelt A, Lohbauer U. Self-adhesive resin cements: adhesive performance to indirect restorative ceramics. J Adhes Dent. 2014 Dec;16(6):541-6.
34. Barão VA, Gennari-Filho H, Goiato MC, dos Santos DM, Pesqueira AA. Factors to achieve aesthetics in all-ceramic restorations. J Craniofac Surg. 2010 Nov;21(6):2007-12.
35. Mou SH, Chai T, Wang JS, Shiau YY. Influence of different convergence angles and tooth preparation heights on the internal adaptation of Cerec crowns. J Prosthet Dent 2002; 87:248–55.
36. Pfeiffer J. Dental CAD/CAMtechnologies: the optical impression (II). Int J Comput Dent 1999; 2:65–72.
37. Luthardt R, Weber A, Rudolph H, Schone C, Quaas S, Walter M. Design and production of dental prosthetic restorations: basic research on dental CAD/CAM technology. Int J Comput Dent 2002; 5:165–76.
38. Mou SH, Chai T, Wang JS, Shiau YY. Influence of different convergence angles and tooth preparation heights on the internal adaptation of Cerec crowns. The Journal of Prosthetic Dentistry 2002; 87:248–55.
39. Hickel R, Dasch W, Mehl A, Kremers L. CAD/CAM-fillings of the future? International Dental Journal 1997; 47:247–58.
40. Malkoç MA, Sevimay M, Tatar İ, Çelik HH. Micro-CT Detection and Characterization of Porosity in Luting Cements. J Prosthodont. 2015 Jan 5.
41. Milutinović-Nikolić AD, Medić VB, Vuković ZM. Porosity of different dental (luting cements. Dent Mater. 2007 Jun;23(6):674-8.
42. Pishevar L, Ghavam M, Pishevar A. Stress analysis of two methods of ceramic inlay preparation by finite element. Indian J Dent Res. 2014 May-Jun;25(3):364-9.

43. Lorenzoni FC, Bonfante EA, Bonfante G, Martins LM, Witek L, Silva NR. Micro-CT analysis of a retrieved root restored with a bonded fiber-reinforced composite dowel: a pilot study. J Prosthodont 2013; 22:478-483.
44. Grandini S, Goracci C, Monticelli F, Borracchini A, Ferrari M. SEM evaluation of the cement layer thickness after luting two different posts. J Adhes Dent 2005; 7:235-240.
45. Kainose K, Nakajima M, Foxton R, Wakabayashi N, Tagami J. Stress distribution in root filled teeth restored with various post and core techniques: effect of post length and crown 3D micro-CT analysis of void formations and push-out bonding strength of resin cements used for fiber post cementation height. Int Endod J 2015; 48:1023–1032.
46. Uzun İH, Malkoç MA, Keleş A, Öğreten AT. 3D micro-CT analysis of void formations and push-out bonding strength of resin cements used for fiber post cementation. J Adv Prosthodont. 2016 Apr;8(2):101-9.
47. Neves FD, Prado CJ, Prudente MS, Carneiro TA, Zancopé K, Davi LR, Mendonça G, Cooper LF, Soares CJ. Micro-computed tomography evaluation of marginal fit of lithium disilicate crowns fabricated by using chairside CAD/CAM systems or the heat-pressing technique. J Prosthet Dent. 2014 Nov;112(5):1134-40.
48. Contrepois M, Soenen A, Bartala M,Laviole O. Marginal adaptation of ceramic crowns: a systematic review. J Prosthet Dent 2013; 110:447-54.
49. Grenade C, Mainjot A, Vanheusden A. Fit of single tooth zirconia copings: comparison between various manufacturing processes. J Prosthet Dent 2011; 105:249-55.
50. da Costa JB, Pelogia F, Hagedorn B,Ferracane JL. Evaluation of different methods of optical impression making on the marginal gap of onlays created with CEREC 3D. Oper Dent 2010; 35:324-9
51. Soares CJ, Martins LR, Fernandes Neto AJ, Giannini M. Marginal adaptation of indirect composites and ceramic inlay systems. Oper Dent. 2003 Nov-Dec;28(6):689-94.
52. Riccitiello F, Amato M, Leone R, Spagnuolo G, Sorrentino R. In vitro Evaluation of the Marginal Fit and Internal Adaptation of Zirconia and Lithium Disilicate

Single Crowns: Micro-CT Comparison Between Different Manufacturing Procedures. Open Dent J. 2018 Feb 22;12: 160-172.

53. Goldin EB, Boydi NW, Goldstein GR, Hittelman EL, Thompson VP. Marginal fit of leucite-glass pressable ceramic restoration and ceramic- pressed-to-metal restorations. J Prosthet Dent. 2005; 93(2): 143-147.
54. Masood TM, Abbassy MA, Bakry AS, Matar NY, Hassan AH. Fourier-transform infrared spectroscopy/attenuated total reflectance analysis for the degree of conversion and shear bond strength of Transbond XT adhesive system. Clin Cosmet Investig Dent. 2018 Dec 7;10:275-280.
55. Cantoro A, Goracci C, Coniglio I, Magni E, Polimeni A, Ferrari M. Influence of ultrasound application on inlays luting with self-adhesive resin cements. Clin Oral Investig. 2011 Oct;15(5):617-23.
56. Johnson GH, Lepe X, Patterson A, Schäfer O. Simplified cementation of lithium disilicate crowns: Retention with various adhesive resin cement combinations. J Prosthet Dent. 2018 May;119(5):826-832.

FIGURES

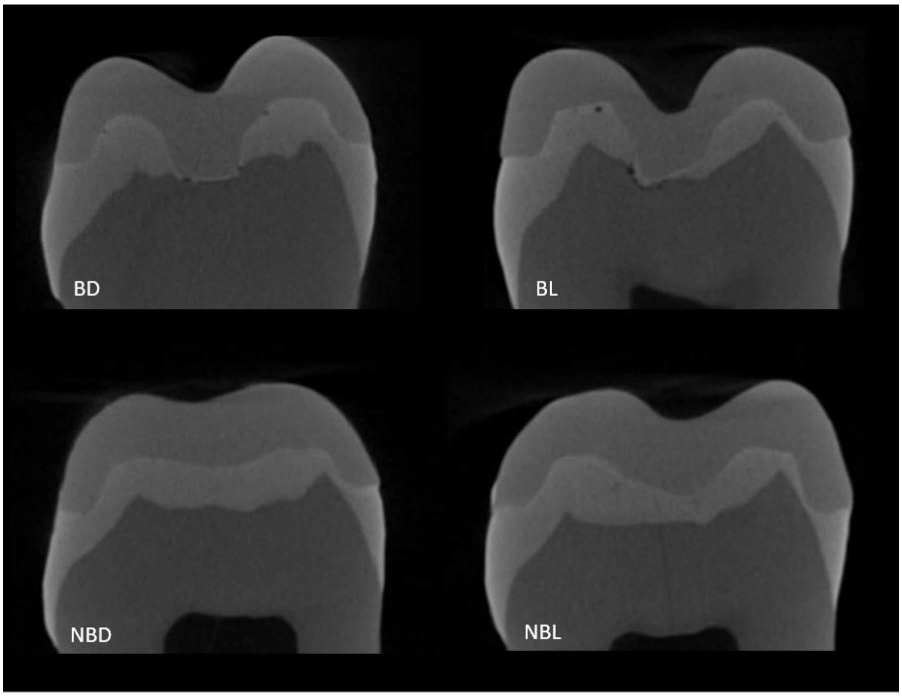

Fig 1. - Micro-CT images of a greater amount of porosity in the cement of the onlays restorations from axial view.

Table I. - Means and standard deviation of volume and porosity

Ceramic Type	Volume (mm^3)		Porosity (%)	
	Cavity preparation without box	Cavity preparation with box	Cavity preparation without box	Cavity preparation with box
Lithium disilicate ceramic	0,152692+0,047667^{Aa}	3,421588±0,300786^{Ba}	0,002464±0,001136^{Aa}	0,035545±0,003896^{Ba}
Leucite ceramic	0,096750+0,029229^{Aa}	1,271632±0,020602^{Bb}	0,001196±0,000276^{Aa}	0,012949±0,000735^{Bb}

Different uppercase letters in columns indicate the ceramic type for each cavity preparation design; lowercase letters in rows indicate the cavity preparation design for each ceramic ($p<0.05$)

3.3 CAPÍTULO 3

Vianna ALSV, Zancopé K, Reis DCS, Soares CJ, Bicalho AA.
Oral rehabilitation with endocrown: a systematic review. J Oral Rehabi.

Title: Oral rehabilitation with endocrown: a systematic review

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Short title:

Keywords: endocrown, endontically treated teeth; intraradicular posts.

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Title: Oral rehabilitation with endocrown: a systematic review

ABSTRACT

Objective: A systematic review was conducted to evaluate "in vitro" and "in vivo" studies of endocrown restorations compared to conventional treatments (intraradicular posts, direct composite resin, inlay/onlay).
Data: This report followed the PRISMA Statement. A total of 59 studies were included in this review.
Sources: Two reviewers performed a search at electronic databases (Pubmed and Scopus) up to July 2018. A total of 59 studies were included in this review.
Study selection: Only "in vitro" and "in vivo" studies that evaluated endocrown rehabilitation were included. Studies in language other than English, studies that do not evaluated endocrown rehabilitation, reviews, duplicated and studies with insufficient data in the title and abstract to make a clear decision were excluded from this systematic review. After the title and abstract examination, 53 studies were selected (total of 39 "in vitro" studies and 14 "in vivo"). The laboratory studies, 54% of them "in vitro" were fracture resistance tests, 15 studies with finite elements analysis, 4 studies analyzed marginal adaptation, 1 study analyzed microhardness of resin cement used in endocrown restoration, 20 studies compare endocrowns to conventional treatments, 8 studies compare endocrown made with different materials, 7 studies analyzed different extention of pulp chamber, and 2 studies analyzed different endocrown cavities design. A total of clinical studies were 5 of retrospective study and 9 case reports were demonstrated.
Conclusion: The literature suggests that endocrowns have been used as an alternative to conventional post-core and fixed partial dentures in restoration of ETT with extensive coronal tissue loss.
Clinical significance: Although further studies are still necessary to confirm the present findings, the advantages of endocrowns are better aesthetics and mechanical performance, low cost and short clinical time compared to traditional methods

INTRODUCTION

The rehabilitation of teeth with a large coronal destruction is a clinical challenge and a subject that has been controversially discussed in the literature to date, especially in non-vital teeth. Reduction in stiffness and fracture resistance of endodonticallty treated teeth is the loss of structural integrity associated with caries, trauma and extensive cavity preparation, and also due dehydration or physical changes in dentin after the removal of the pulp and the surrounding tissues of the dentin [1,2]

Intra-radicular posts combined or not with core materials may be required because coronal retention of the restoration is usually compromised. This system, despite all clinical success achieved, presents the disadvantage of revealed to affect the overall biomechanical behavior of the restored teeth[3] and the additional removal of sound tissue needed for fitting the post into the root canal[4] . The term ‘endocrown’ was first defined by Bindl and Mörmann[5] as a monolithic ceramic bonded construction fixed to the tooth structure by adhesive material. The root canal with minimal invasion, which is an important factor for the preservation of tooth structure, the endocrown is able to provide adequate adhesion of a ceramic restoration[6]. The endocrown restorations are anchores to the internal portion of the pulp chamber and on the cavity margins, thereby resulting in both macro- and micro-mechanical retention, provided by the pulpal walls and adhesive cementation, respectively[5,7]. In addition to the advantage of removing smaller amounts of sound tissue compared to other techniques, this restorative technique requires less chair time because there are fewer procedures. The other advantage is to have greater dissipation of the masticatory tensions received in the tooth /restoration along the dental structure[2]. The endocrowns are indicated when there is excessive destruction of the crown, when the interocclusal space is limited and traditional rehabilitation with post and crown is not possible because of inadequate ceramic thickness. Thus, teeth with short clinical crowns or atresic, calcified, curved root canals are also indicated in this type of rehabilitation [6,10]

The performance of endocrown restorations can be influenced depending on the type of material. There are several resin and ceramic composites, such as feldspathic ceramics, leucite reinforced ceramics, lithium disilicate reinforced ceramics, zirconia, hybrid composite resins and the CAD/CAM ceramic and resin composite blocks[8,9]

Despite dentists are returning to restore endodontically treated teeth using the endocrown technique, doubts remain about the biomechanical behavior and prognosis of this oral rehabilitation treatment compared to conventional treatment intraradicular post. Thereby a review of literature taking into account this subject is needed. Therefore, the aim of this study was to systematically review the literature to consider this subject for investigation of in vitro and in vivo studies to date.

MATERIALS AND METHODS

Search strategy

This systematic review was conducted by following the guidelines of Transparent Reporting of Systematic Reviews and Meta-analyses (PRISMA statement)[77]. The review question was formulated by the following PICO[78] framework (Patient Population, Intervention, Comparison, and Outcome). The following keywords were used: "endocrown" OR "endo-crown".

Eligibility criteria

Literature published from 2008 to July 2018, in English language, was selected. All in vitro and in vivo studies that evaluated endocrown rehabilitation were included. The inclusion criteria were: in vitro and/or in vivo studies that used endocrown to rehabilitate. The exclusion criteria were: studies in language other than English, studies that do not evaluated endocrown rehabilitation, reviews, and studies with insufficient data in the title and abstract to make a clear decision. Duplicated and published studies that did not meet the inclusion/exclusion criteria were excluded from this systematic review.

Screening and selection

An electronic search was performed through PubMed (MEDLINE) and Scopus databases up to July 2018. A hand searching process was also applied. Two prosthodontists reviewers (A.L.S.V.V. and K.Z.) independently ran the described search for eligibility and compared the list.

Data extraction and risk of bias

A specific data extraction form was developed and used by the authors to all desired information (title, year of publication, journal, authors, impact factor, aim of study, number of samples, groups analyzed, material, cementation, methodology of analysis of samples, statistical results and conclusion). To assess methodological quality of the studies, the JADAD scale[79] was used to report any potential risk for bias. Authors elected to exclude all papers on the topic with a JADAD score of 3 or less.

RESULTS

Based on the aim of this systematic review and on the heterogeneity of the selected studies, it was not possible to perform meta-analysis of the data. Therefore, a descriptive presentation of the data was adopted.

An initial electronic search identified 1099 studies (Figure 1), and the hand searching process identified 53 studies (total of 39 "in vitro" [41,42,9,43,44,13,46,47,11,33,53,12,50,52,54,56,57,58,59,14,61,10,7,63,28,18,67,68,69,71,31,29,73,74,17,62,34,31,32] and 14 "in vivo" studies[45,35,48,51,76,55,60,64,65,66,72,5,75,70]. The initial screening of the titles and abstracts resulted in 53 full-text papers that were read in full. The characteristics of all 53 studies that were included are summarized in Table 1. Six studies that did not meet the inclusion criteria (Figure 1) were excluded [35,39,77,78,79,80].

Description of studies

This systematic review included studies that analyzed in vitro and in vivo if endocrown is a reliable choice to rehabilitate. The most articles used was "in vitro" studies, that represents 74% the articles and 26% was "in vivo" studies.

The laboratorial studies of these articles, most of them were tests of fracture resistance, that corresponding to more than half of the articles selected, that is 54%. Fifteen studies with finite elements analysis [18,28,29,31-34,41,46,53,62,68,69,71,73], that three of them associate Weibull analysis and four studies use Micro CT analysis. Only 4 studies analyzed marginal adaptation [10,13,42,67], and only one study analyzed microhardness of resin cement used in endocrown restoration [63]. 20 studies compare endocrowns to conventional treatments [10-13,17,18,28,29,31,33,46,50,52,54,61,67,68-69,71,74]; 8 studies compare endocrown made with different materials[7,9,14,42,56,59,63,73]; 7 studies analyzed different extention of pulp chamber[41,43,47,52,53,57,58] and 2 studies analyzed different endocrown cavities design[13,44]. A total of 14 clinical studies were selected, 5 of them were retrospective study with 10[35], 7[45],3[65] and 2 years[5,72] follow-up; and 9 case reports[48,51,55,60,64,66,72,75,76] were demonstrated.

The restorative material most used in both laboratory and clinical studies was lithium disilicate ceramic fabricated by CAD/CAM blocks and/or press technique. The resin cement used for majority cases was self-adhesive and dual-cure cement.

DISCUSSION

The aim of this systematic review was to perform a bibliographic research about the performance of endocrown restorations in the last ten years. Although some “in vitro” studies have demonstrated that endocrown restorations appeared to be better choice to rehabilitate endodontically treated teeth than restorative with post, resin core and crown, there are a few longitudinal clinical studies to prove it. The results of this study indicated that most of “in vitro” studies were fracture resistance tests.

The fracture resistance of endocrown comparing with conventional crown with fiber posts showed no difference in percentages of fracture resistance[11,12,54,61]. When considering only the material type factor, no evidence was found that the choice either for lithium disilicate glass-ceramic or non-ceramic would result in higher load-to-failure[14]. The other studies analyze fracture resistance in endocrowns according different materials[9,14,56,73] Recent study demonstrates that restoration made by zirconia displayed the highest fracture strength, while composite resin had the lowest fracture strength out of the materials used for the endocrowns[9]. The use of metal ceramics as endocrown material may lower the risk of failure during clinical use. A reduced endocrown material strength was observed on endocrown restorations with press lithium disilicate ceramics and composite resin endocrowns. The fracture of the restorations with metal ceramics endocrowns revealed some specific features that are almost equal the fracture of ductile materials. The loss of the base strength (tooth fracture) was easily compensated by the elasticity of the metal cap. It could be explained because the metal base of the metal ceramic endocrown obviously increased the fracture plasticity due to its elastic characteristics[15,16]. Recent study demonstrates that, under axial loading, molars restored with endocrowns performed similar with both lithium disilicate ceramic and multiphase resin composite but the latter was less durable under lateral loading[9]. Based on the results of this study, since material type did not show significant difference in terms of fracture strength under axial forces but under lateral forces, on the other hand, since lateral forces decreased the fracture strength for all groups significantly compared to axial forces. Therefore, the fracture strength should be analyzed not only by the type of material, but also by the direction in which the forces were applied.

Another analysis in this systematic review was to evaluate the fracture resistance in relation to the extensions of endocrowns inside the pulp chamber. The clinical significance of these studies [41,43,47,49] refers to the decision-making about which depth of the teeth chamber are most suitable for restoration with an endocrown. The fractures resistances were influenced by different extensions inside the pulp chamber. The fracture strength showed that the lower depth of intracoronal extension of endocrowns negatively influenced the fracture resistance of endodontically treated posterior teeth because the lower the extension of the endocrowns, the lower the fracture resistance and the greater the possibility of rotating the piece when in function[41]. This may have occurred because of the decreased contact area between different extensions of endocrowns inside the pulp chamber relative to the remaining molar teeth, which leads to the assumption that increased space available inside the pulp chamber allows for increased stability and retention of the endocrown[65] So, according to these results, this technique could not be really considered minimally invasive or a conservative alternative once the greater depth inside the pulp chamber generated better results, and it is related to greater dentin preparation. There are various studies in the literature on the effect of post length on fracture strength, but no data is available on the effect of preparation depths of endocrowns for central teeth. Ramírez-Sebastià reported that post application and post lengths had no effect on the fracture strength of restorations because no statistically significant differences were obtained among the endocrowns and the crowns with long glass fiber post and short glass fiber post. In other works, cavity depths were investigated in terms of marginal and internal adaptations for molars, and it revealed that the discrepancy was increased with the deepening of the cavity. In contrast, the effect of central teeth preparation depths on the fracture strength of endocrowns, it was aimed to provide relevant data for clinical applications that the discrepancy was increased with the deepening of the cavity, in addition, it could be noticed that zirconia and lithium disilicate ceramic groups could be used reliably in clinical applications of endocrown restorations with long and short preparation depths[43]. Kannat, observed that feldspathic ceramic, resin-ceramic and polymer infiltrated ceramic groups did not exceed the limits of bite forces[19-21] while making a decision on which ceramic material would be a better choice for clinical applications.

The fracture types of the materials should also be considered. In addition, the catastrophic failures occur more frequently when the zirconia material was chosen, with regards to lithium disilicate glass ceramic[43]. The failure mode according chamber extension depth, the groups with 3 and 4mm demonstrated catastrophic tooth fracture, whereas 2-mm chamber depth extension group demonstrated non-restorable fractures[49]. Although visual examination some specimens that were initially thought repairable, after evaluated through the microCT, irreparable root fractures were found, which depending on location, may or may not be visible on a standard periapical film. Therefore, the analysis in micro CT, is a valuable tool in failure mode assessment[49].

With the recent advances in the adhesive dentistry, more conservative configuration/design and thickness in endocrown restorations have been introduced for restoring endodontically treated teeth. The first endocrown design, the preparation is similar to those of conventional crowns and can be described as a ‘bracing mechanism’ of the restoration around the cervical tooth structure[22], but may cause the loss of sound enamel and dentin tissues that would be important for proper bonding of the restoration[24]. A macroretentive design is no longer a prerequisite if there are sufficient tooth surfaces for bonding[23], so the conservative preparation design is usually prepared without ferrule[41-43,49]. However, further investigations, especially the fatigue behavior, is needed to ensure the increase of fracture resistance with different cavity designs. According to Taha, showed that classical endocrown design with axial reduction and a shoulder finish line had higher mean fracture resistance values than conservative endocrowns with butt margin design and the mean difference was statistically significant. It could be justified, because butt joint designs provide a stable surface that resists the compressive stresses because it is prepared parallel to the occlusal plane, and the forces are distributed over the cervical butt joint (compression) or axial walls (shear force). Neutralization of shear stresses occurs through axial walls and better distribution of load across the margin, thus moderating the load on the pulp floor[23] There is a reduction of the thermal and polymerization shrinkage and the stress applied to the ceramic because axial reduction may have decreased the amount of the resin cement thickness in relation to the bulk of ceramic material compared to the butt margin design[26].

This review showed 38% of non-destructive "in vitro" test with finite elements analysis. Six FEA studies compare endocrown technique versus fiber post with resin core and crown, three of which are in pre-molar teeth[29,31], one in molars[28] and two in central incisors[32,33]. Three FEA studies was associated with Weibul analysis[29,31,34]. Weibull analysis frequently has been used to calculate the probability of fracture in brittle materials. It also has provided a method for predicting cumulative failure probability at selected levels of stress.

Equivalent stress levels in the dentin of molars restored with posts and cores and ceramic crowns were higher than stress levels in the tooth with the endocrown, as well as stress levels in the intact tooth. The highest modified von Mises (mvM) stresses in dentin and crown occurred in molar restored with FRC posts[28]. Equivalent stress levels in the dentin of molars restored with posts and cores and ceramic crowns were higher than stress levels in the tooth with the endocrown, as well as stress levels in the intact tooth. The highest mvM stresses in dentin and crown occurred in molar restored with FRC posts. Composite posts and cores do not reinforce the structure of endodontically treated teeth, but only ensure retention for the supragingival part[27]. On the contrary, in anterior teeth, the mvM stress in endocrown restoration was significantly higher compared to the teeth with metal post and cores, except for resin composite endocrown. From a clinical point of view, endocrown for anterior teeth have different mechanical behavior compared to posterior teeth. So, endocrown restorations present the advantage of reducing the interface of the restorative system.

Moreover, composite resins seem to be the most reliable materials to build-up endocrown restoration, as they generate low amounts of stress concentration[32]. The numeric investigation in studies with premolars by FEA and Weibull analysis[29,31,34] suggests that endocrown and conventional crown restorations for endodontically treated premolars present similar longevity. According with Lin, all cumulative failure probability simulations were under the assumption of a perfectly bonded interface between the ceramic and tooth tissue. The adhesive interfacial debonding mechanism and the influences of different resin cement thicknesses were not simulated because of the complicated nature and were not the investigated objective in this study. The resin cement was used to simulate the adhesive in ceramic/tooth tissue, and uniform cement thickness of 100 mm was assumed in all FE simulations. The load condition of the resulting axial force crossing the central position (200 N) force assumed in this study was not realistic and only approximated the complex balance between the masticatory forces and their reactions. Complicated actual occlusal forces usually cannot fully be presented in numeric simulations and need to be simplified as typical axial/lateral loads to apply in the model. Therefore, the lateral load effect was not considered in this study as a result of reducing the complicated data interpolations. Linear elastic (homogeneous and isotropic) properties were adopted for all materials as a result of numeric-convergence considerations. Therefore, further in vitro/in vivo studies are needed to examine the correlation between the numeric analysis and clinical outcome.

Something important to consider is that the majority of the included studies were performed on posterior teeth, with molars summing approximately 51% of the total teeth samples analyzed here, 28% was premolar teeth and 28% and anterior teeth was approximately 17%. There is one retrospective study comparing the performance of anterior and posterior endocrowns in the same standardized study[35]. This study evaluated documented cases of ceramic and composite endocrowns and correlate failures with clinical parameters such as tooth preparation characteristics and occlusal parameters in the last ten years. The results analysis parameter in this study is the type of preparation regarding the presence of an extension in the pulp chamber (92.0% of cases) and a ferrule effect (54.5% of cases). Yet, due to the reduced amount of failures, no statistical correlation could be established with neither those factors, nor with occlusal risk. Indeed, the restorations demonstrated an excellent survival rate, which was shown to be 99.0% after a mean observation period of 44.7 ± 34.6 months while the 10-year Kaplan-Meier estimated survival rate was 98.8%. These positive findings confirm results of previous studies about endocrowns, but related to smaller sample size and/or observation time[5,37,38].

The “in vivo” studies of this systematic review, revealed that endocrown restorations seemed to perform better results when compared to conventional restorations. Unfortunately, there were no randomized controlled trials, only five retrospective study with 7, 10 and 2 years follow-up[5,35,45,65,72]. The others 9 “in vivo” studies were case reports[48,51,55,60,64,66,72,75,76], most of them were clinical cases of endocrown restorations in molars[5,35,45,48,51,60,64-66,72] (85%), except for one clinical case[55] (deciduous molar). Endocrowns have more fails in anterior teeth compared to posterior teeth. Incisors and /or canines receive higher non-axial forces when compared to the more axially directed forces that posterior teeth face during oral function[40]; so, greater non-axial forces when compared to the more axially directed forces that the posterior teeth face during the oral function[20,21]; consequently, the anterior teeth receive more stresses than the posterior ones, increasing the chance of restoration failure. This fact may explain the lack of clinical and in vitro studies in anterior teeth, reinforcing the need for well-designed studies on the subject.

The endocrown restoration bring potential application for oral rehabilitation purposes when compared to other treatment modalities, and considering that endocrowns may be more cost effective, thus faster/simpler to prepare and cheaper.

CONCLUSIONS

The available literature found suggests that endocrowns have been used as an alternative to conventional post-core and fixed partial dentures in restoration of endodontically treated teeth with extensive coronal tissue loss. Compared to traditional methods, better aesthetics and mechanical performance, low cost and short clinical time are the advantages of endocrowns. However, Further studies investigations into the biomechanical behaviors among these restorative configurations are necessary to ensure the clinical survival rate could be achieved.

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The authors of this study attest that there is not conflict of interest.

REFERENCES

1. Zhu Z, Dong XY, He S, Pan X, Tang L. Effect of Post Placement on the Restoration of Endodontically Treated Teeth: A Systematic Review. The International Journal of Prosthodontics 2015;**28**(5):475-83.
2. Chang CY KJ, Lin YS, Chang YH. Fractureresistance and failure modes of CEREC endocrowns and conventional post and core-supported CEREC crowns. J Dent Sci 2009;4(3):110-117.
3. Roscoe MG, Noritomi PY, Novais VR, Soares CJ. Influence of alveolar bone loss, post type, and ferrule presence on the biomechanical behavior of endodontically treated maxillary canines: strain measurement and stress distribution. The Journal of Prosthetic Dentistry 2013;**110**(2):116-26.
4. Lazari PC, Oliveira RC, Anchieta RB, Almeida EO, Freitas Junior AC, Kina S, et al. Stress distribution on dentin-cement-post interface varying root canal and glass fiber post diameters. A three-dimensional finite elemento analysis based on micro-CT data. Journal of Applied Oral Science 2013;21(6):511-7.
5. Bindl A, Mörmann WH. Clinical evaluation of adhesively placed Cerec endo-crowns after 2 years — preliminar results. JAdhesDent1999;1(3):255–65.
6. Sevimli G, Cengiz S, Oruc S. Endocrowns: review. J Istanbul Univ Fac Dent 2015;49(2):57–63.
7. El-Damanhoury HM, Haj-Ali RN, Platt JA. Fracture resistance and microleakage of endocrowns utilizing three CAD-CAM blocks. Operative Dentistry 2015;**40**(2):201-10.
8. Chen B, Ma Y, Wu K, Chen H, Li L, Liang L, et al. Influence of various materials on biomechanical behavior of endocrown-restored, endodontically treated mandibular first molar: a 3D-finite element analysis. J Wuhan Univ Technol Mater Sci Ed 2015;30(3):643–8.

9. Skalskyi V, Makeev V, Stankevych O, Pavlychko R. Features of fracture of prosthetic tooth-endocrown constructions by means of acoustic emission analysis. Dent Mater. 2018 Mar;34(3):e46-e55.
10. Rocca GT, Saratti CM, Poncet A, Feilzer AJ, Krejci I. The influence of FRCs reinforcement on marginal adaptation of CAD/CAM composite resin endocrowns after simulated fatigue loading. *Odontology* 2015.
11. Atash R, Arab M, Duterme H, Cetik S. Comparison of resistance to fracture between three types of permanent restorations subjected to shear force: An in vitro study. J Indian Prosthodont Soc. 2017 Jul-Sep;17(3):239-249.
12. Pedrollo Lise D, Van Ende A, De Munck J, Umeda Suzuki TY, Cardoso Vieira LC,Van Meerbeek B. Biomechanical behavior of endodontically treated premolars using different preparation designs and CAD/CAM materials. J Dent. 2017 Apr;59:54-61.
13. Rocca GT, Daher R, Saratti CM, Sedlacek R, Suchy T, Feilzer AJ, Krejci I. Restoration of severely damaged endodontically treated premolars: The influence of the endo-core length on marginal integrity and fatigue resistance of lithium disilicate CAD-CAM ceramic endocrowns. J Dent. 2018 Jan;68:41-50.
14. Gresnigt MM, Özcan M, van den Houten ML, Schipper L, Cune MS. Fracture strength, failure type and Weibull characteristics of lithium disilicate and multiphase resin composite endocrowns under axial and lateral forces. Dent Mater. 2016 May;32(5):607-14.
15. Vianna ALSV, Prado CJD, Bicalho AA, Pereira RADS, Neves FDD, Soares CJ. Effect of cavity preparation design and ceramic type on the stress distribution, strain and fracture resistance of CAD/CAM onlays in molars. J Appl Oral Sci. 2018;26:e20180004.
16. Tribst JPM, Dal Piva AMO, Madruga CFL, Valera MC, Borges ALS, Bresciani E, de Melo RM. Endocrown restorations: Influence of dental remnant and restorative material on stress distribution. Dent Mater. 2018 Oct;34(10):1466-1473.
17. Biacchi GR, Basting RT. Comparison of fracture strength of endocrowns and glass fiber post-retained conventional crowns. Oper Dent 2012;37:130–6.

18. Ramírez-Sebastià A, Bortolotto T, Cattani-Lorente M, Giner L, Roig M, Krejci I. Adhesive restoration of anterior endodontically treated teeth: influence of post length on fracture strength. Clin Oral Investig. 2014;18(2):545-54.
19. Fontijn-Tekamp FA, Slagter AP, Van Der Bilt A, Van ,T Hof MA, Witter DJ, Kalk W, Jansen JA. Biting and chewing in overdentures, full dentures, and natural dentitions. J Dent Res 2000; 79: 1519-1524.
20. Helkimo E, Carlsson GE, Helkimo M. Bite force and state of dentition. Acta Odontol Scand 1977; 35: 297-303.
21. Röhrle O, Saini H, Lee PVS, Ackland DC. A novel computational method to determine subject-specific bite force and occlusal loading during mastication. Comput Methods Biomech Biomed Engin. 2018 May;21(6):453-460.
22. Jotkowitz A, Samet N. Rethinking ferrule--a new approach to an old dilemma. British Dental Journal 2010;**209**(1):25-33.
23. Goodacre CJ, Campagni WV, Aquilino SA. Tooth preparations for complete crowns: an art form based on scientific principles. J Prosthet Dent 2001;85:363–76.
24. Soares CJ, Soares PV, de Freitas Santos-Filho PC, Castro CG, Magalhaes D, Versluis A. The influence of cavity design and glass fiber posts on biomechanical behavior of endodontically treated premolars. J Endod. 2008 Aug;34(8):1015-9.
25. Fages M, Bennasar B. The endocrown: a different type of all-ceramic reconstruction formolars. JCanDentAssoc 2013;79:d140.
26. Magne P, Versluis A, Douglas WH. Effect of luting composite shrinkage and Termal loads on the stress distribution in porcelain laminate veneers. J Prosthet Dent1999;81:335–44.
27. Morgano SM. Restoration of pulp less teeth: application of traditional principles in present and future contexts. J Prosthet Dent 1996;75:375–80.
28. Dejak B, Młotkowski A. 3D-Finite element analysis of molars restored with endocrowns and posts during masticatory simulation. Dent Mater. 2013 Dec;29(12):e309-17.

29. Lin CL, Chang YH, Pa CA. Estimation of the risk of failure for an endodontically treated maxillary premolar with MODP preparation and CAD/CAM ceramic restorations. J Endod. 2009 Oct;35(10):1391-5.
30. Lin CL, Chang YH, Pai CA. Evaluation of failure risks in ceramic restorations for endodontically treated premolar with MOD preparation. Dent Mater. 2011 May;27(5):431-8. doi: 10.1016/j.dental.2010.10.026.
31. Lin CL, Chang YH, Chang CY, Pai CA, Huang SF. Finite element and Weibull analyses to estimate failure risks in the ceramic endocrown and classical crown for endodontically treated maxillary premolar. Eur J Oral Sci. 2010 Feb;118(1):87-93.
32. Zarone F, Sorrentino R, Apicella D, Valentino B, Ferrari M, Aversa R, Apicella A. Evaluation of the biomechanical behavior of maxillary central incisors restored by means of endocrowns compared to a natural tooth: a 3D static linear finite elements analysis. Dent Mater. 2006 Nov;22(11):1035-44.
33. Dejak B, Młotkowski A. Strength comparison of anterior teeth restored with ceramic endocrowns vs custom-made post and cores. J Prosthodont Res. 2018 Apr;62(2):171-176.
34. Gulec L, Ulusoy N. Effect of Endocrown Restorations with Different CAD/CAM Materials: 3D Finite Element and Weibull Analyses. Biomed Res Int. 2017;2017:5638683.
35. Belleflamme MM, Geerts SO, Louwette MM, Grenade CF, Vanheusden AJ, Mainjot AK. No post-no core approach to restore severely damaged posterior teeth: An up to 10-year retrospective study of documented endocrown cases. J Dent. 2017 Aug;63:1-7.
36. J. Bernhart, A. Brauning, M.J. Altenburger, K.T. Wrbas, Cerec3D endocrowns--two-yearclinical examination of CAD/CAM crowns for restoring endodontically treated molars,International journal of computerized dentistry 13(2) (2010) 141-54.
37. Bindl A, Richter B, Mörmann WH. Survival of ceramic computer-aided design/manufacturing crowns bonded to preparations with reduced macroretention geometry. Int J Prosthodont. 2005 May-Jun;18(3):219-24.

38. Otto T. Computer-aided direct all-ceramic crowns: preliminary 1-year results of a prospective clinical study. Int J Periodontics Restorative Dent. 2004 Oct;24(5):446-55.
39. Otto T, Mörmann WH. Clinical performance of chairside CAD/CAM feldspathic ceramic posterior shoulder crowns and endocrowns up to 12 years. Int J Comput Dent. 2015;18(2):147-61.
40. Silva GR, Santos-Filho PC, Simamoto-Junior PC, Martins LR, Mota AS, Soares CJ. Effect of post type and restorative techniques on the strain and fracture resistance of flared incisor roots. Brazilian Dental Journal 2011;**22**(3):230-7.
41. Dartora NR, de Conto Ferreira MB, Moris ICM, Brazão EH, Spazin AO, Sousa-Neto MD, Silva-Sousa YT, Gomes EA. Effect of Intracoronal Depth of Teeth Restored with Endocrowns on Fracture Resistance: In Vitro and 3-dimensional Finite Element Analysis. J Endod. 2018 Jul;44(7):1179-1185.
42. Zimmermann M, Valcanaia A, Neiva G, Mehl A, Fasbinder D. Three-Dimensional Digital Evaluation of the Fit of Endocrowns Fabricated from Different CAD/CAM Materials. J Prosthodont. 2018 Mar 6.
43. Kanat-Ertürk B, Saridağ S, Köseler E, Helvacioğlu-Yiğit D, Avcu E, Yildiran-Avcu Y. Fracture strengths of endocrown restorations fabricated with different preparation depths and CAD/CAM materials. Dent Mater J. 2018 Mar 30;37(2):256-265.
44. Taha D, Spintzyk S, Schille C, Sabet A, Wahsh M, Salah T, Geis-Gerstorfer J. Fracture resistance and failure modes of polymer infiltrated ceramic endocrown restorations with variations in margin design and occlusal thickness. J Prosthodont Res. 2018 Jul;62(3):293-297.
45. Fages M, Raynal J, Tramini P, Cuisinier FJ, Durand JC. Chairside Computer-Aided Design/Computer-Aided Manufacture All-Ceramic Crown and Endocrown Restorations: A 7-Year Survival Rate Study. Int J Prosthodont. 2017 November/December;30(6):556–560.
46. Helal MA, Wang Z. Biomechanical Assessment of Restored Mandibular Molar by Endocrown in Comparison to a Glass Fiber Post-Retained Conventional Crown: 3D Finite Element Analysis. J Prosthodont. 2017 Oct 25.

47. Einhorn M, DuVall N, Wajdowicz M, Brewster J, Roberts H. Preparation Ferrule Design Effect on Endocrown Failure Resistance. J Prosthodont. 2019 Jan;28(1):e237-e242.
48. Dablanca-Blanco AB, Blanco-Carrión J, Martín-Biedma B, Varela-Patiño P, Bello-Castro A, Castelo-Baz P. Management of large class II lesions in molars: how to restore and when to perform surgical crown lengthening? Restor Dent Endod. 2017 Aug;42(3):240-252.
49. Hayes A, Duvall N, Wajdowicz M, Roberts H. Effect of Endocrown Pulp Chamber Extension Depth on Molar Fracture Resistance. Oper Dent. 2017 May/Jun;42(3):327-334.
50. Bankoğlu Güngör M, Turhan Bal B, Yilmaz H, Aydin C, Karakoca Nemli S. Fracture strength of CAD/CAM fabricated lithium disilicate and resin nano ceramic restorations used for endodontically treated teeth. Dent Mater J. 2017 Mar 31;36(2):135-141.
51. da Cunha LF, Gonzaga CC, Pissaia JF, Correr GM. Lithium silicate endocrown fabricated with a CAD-CAM system: A functional and esthetic protocol. J Prosthet Dent. 2017 Aug;118(2):131-134.
52. Guo J, Wang Z, Li X, Sun C, Gao E, Li H. A comparison of the fracture resistances of endodontically treated mandibular premolars restored with endocrowns and glass fiber post-core retained conventional crowns. J Adv Prosthodont. 2016 Dec;8(6):489-493.
53. Zhu J, Rong Q, Wang X, Gao X. Influence of remaining tooth structure and restorative material type on stress distribution in endodontically treated maxillary premolars: A finite element analysis. J Prosthet Dent. 2017 May;117(5):646-655.
54. Rocca GT, Sedlakova P, Saratti CM, Sedlacek R, Gregor L, Rizcalla N, Feilzer AJ, Krejci I. Fatigue behavior of resin-modified monolithic CAD-CAM RNC crowns and endocrowns. Dent Mater. 2016 Dec;32(12):e338-e350.
55. Bilgin MS, Erdem A, Tanrıver M. CAD/CAM Endocrown Fabrication from a Polymer-Infiltrated Ceramic Network Block for Primary Molar: A Case Report. J Clin Pediatr Dent. 2016;40(4):264-8.

56. Aktas G, Yerlikaya H, Akca K. Mechanical Failure of Endocrowns Manufactured with Different Ceramic Materials: An In Vitro Biomechanical Study. J Prosthodont. 2018 Apr;27(4):340-346.
57. Shin Y, Park S, Park JW, Kim KM, Park YB, Roh BD. Evaluation of the marginal and internal discrepancies of CAD-CAM endocrowns with different cavity depths: An in vitro study. J Prosthet Dent. 2017 Jan;117(1):109-115.
58. Gaintantzopoulou MD, El-Damanhoury HM. Effect of Preparation Depth on the Marginal and Internal Adaptation of Computer-aided Design/Computer-assisted Manufacture Endocrowns. Oper Dent. 2016 Nov/Dec;41(6):607-616.
59. El-Damanhoury HM, Gaintantzopoulou M. The effect of immediate dentin sealing and optical powder removal method on the fracture resistance of CAD/CAM-fabricated endocrowns. Int J Comput Dent. 2016;19(2):135-51.
60. da Cunha LF, Mondelli J, Auersvald CM, Gonzaga CC, Mondelli RF, Correr GM, Furuse AY. Endocrown with Leucite-Reinforced Ceramic: Case of Restoration of Endodontically Treated Teeth. Case Rep Dent. 2015;2015:750313.
61. Carvalho AO, Bruzi G, Anderson RE, Maia HP, Giannini M, Magne P. Influence of Adhesive Core Buildup Designs on the Resistance of Endodontically Treated Molars Restored With Lithium Disilicate CAD/CAM Crowns. Oper Dent. 2016 Jan-Feb;41(1):76-82.
62. Schmidlin PR, Stawarczyk B, DeAbreu D, Bindl A, Ender A, Ichim IP. Fracture resistance of endodontically treated teeth without ferrule using a novel H-shaped short post. Quintessence Int. 2015 Feb;46(2):97-108.
63. Gregor L, Bouillaguet S, Onisor I, Ardu S, Krejci I, Rocca GT. Microhardness of light- and dual-polymerizable luting resins polymerized through 7.5-mm-thick endocrowns. J Prosthet Dent. 2014 Oct;112(4):942-8.
64. Carlos RB, Thomas Nainan M, Pradhan S, Roshni Sharma, Benjamin S, Rose R. Restoration of endodontically treated molars using all ceramic endocrowns. Case Rep Dent. 2013;2013:210763.
65. Biacchi GR, Mello B, Basting RT. The endocrown: an alternative approach for restoring extensively damaged molars. J Esthet Restor Dent. 2013 Dec;25(6):383-90.

66. Rocca GT, Krejci I. Crown and post-free adhesive restorations for endodontically treated posterior teeth: from direct composite to endocrowns. Eur J Esthet Dent. 2013 Summer;8(2):156-79.
67. Ramírez-Sebastià A, Bortolotto T, Roig M, Krejci I. Composite vs ceramic computer-aided design/computer-assisted manufacturing crowns in endodontically treated teeth: analysis of marginal adaptation. Oper Dent. 2013 Nov-Dec;38(6):663-73.
68. Lin CL, Chang YH, Hsieh SK, Chang WJ. Estimation of the failure risk of a maxillary premolar with different crack depths with endodontic treatment by computer-aided design/computer-aided manufacturing ceramic restorations. J Endod. 2013 Mar;39(3):375-9.
69. Hasan I, Frentzen M, Utz KH, Hoyer D, Langenbach A, Bourauel C. Finite element analysis of adhesive endo-crowns of molars at different height levels of buccally applied load. J Dent Biomech. 2012;3:1758736012455421.
70. Rocca GT, Rizcalla N, Krejci I. Fiber-reinforced resin coating for endocrown preparations: a technical report. Oper Dent. 2013 May-Jun;38(3):242-8.
71. Lin CL, Chang YH, Pai CA. Evaluation of failure risks in ceramic restorations for endodontically treated premolar with MOD preparation. Dent Mater. 2011 May;27(5):431-8.
72. Bernhart J, Bräuning A, Altenburger MJ, Wrbas KT. Cerec3D endocrowns--two-year clinical examination of CAD/CAM crowns for restoring endodontically treated molars. Int J Comput Dent. 2010;13(2):141-54.
73. Aversa R, Apicella D, Perillo L, Sorrentino R, Zarone F, Ferrari M, Apicella A. Non-linear elastic three-dimensional finite element analysis on the effect of endocrown material rigidity on alveolar bone remodeling process. Dent Mater. 2009 May;25(5):678-90.
74. Forberger N, Göhring TN. Influence of the type of post and core on in vitro marginal continuity, fracture resistance, and fracture mode of lithia disilicate-based all-ceramic crowns. J Prosthet Dent. 2008 Oct;100(4):264-73.
75. Lander E, Dietschi D. Endocrowns: a clinical report. Quintessence Int. 2008 Feb;39(2):99-106.

76. Zoidis P, Bakiri E, Polyzois G. Using modified polyetheretherketone (PEEK) asan alternative material for endocrown restorations: A short-term clinical report. J Prosthet Dent. 2017 Mar;117(3):335-339.
77. Sedrez-Porto JA, Rosa WL, da Silva AF, Münchow EA, Pereira-Cenci T. Endocrown restorations: A systematic review and meta-analysis. J Dent. 2016 Sep;52:8-14.
78. Sevimli G, Cengiz S, Oruc MS. Endocrowns: review. J Istanb Univ Fac Dent. 2015 Apr 29;49(2):57-63.
79. Leonard DL. Commentary: the endocrown: an alternative approach for restoring extensively damaged molars. J Esthet Restor Dent. 2013 Dec;25(6):391.
80. Decerle N, Bessadet M, Munoz-Sanchez ML, Eschevins C, Veyrune J, Nicolas E. Evaluation of Cerec endocrowns: a preliminary cohort study. Eur J Prosthodont Restor Dent. 2014 Jun;22(2):89-95.

FIGURES

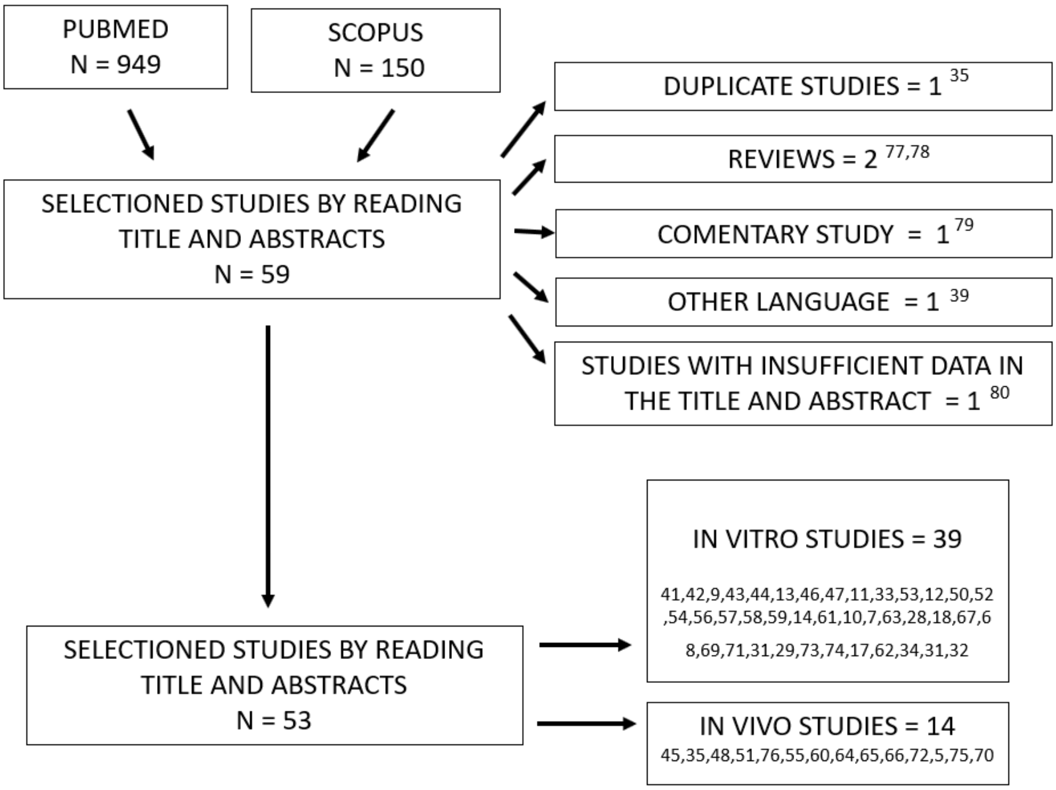

Fig. 1. Flowchart of the article eligibility process.

Table 1 – “in vitro” studies

n.i - not informed

Title	Effect of Intracoronal Depth of Teeth Restored with Endocrowns on Fracture Resistance: In Vitro and 3-dimensional Finite Element Analysis.	Three-Dimensional Digital Evaluation of the Fit of Endocrowns Fabricated from Different CAD/CAM Materials.	Features of fracture of prosthetic tooth-endocrown constructions by means of acoustic emission analysis.	Fracture strengths of endocrown restorations fabricated with different preparation depths and CAD/CAM materials.	Fracture resistance and failure modes of polymer infiltrated ceramic endocrown restorations with variations in margin design and occlusal thickness.	Effect of Endocrown Restorations with Different CAD/CAM Materials: 3D Finite Element and Weibull Analyses.	Restoration of severely damaged endodontically treated premolars: The influence of the endo-core length on marginal integrity and fatigue resistance of lithiumdisilicate CAD-CAM ceramic endocrowns.	Biomechanical Assessment of Restored Mandibular Molar by Endocrown In Comparison to a Glass Fiber Post-Retained Conventional Crown: 3D Finite Element Analysis.	Preparation Ferrule Design Effect on Endocrown Failure Resistance.	Comparison of resistance to fracture between three types of permanent restorations subjected to shear force: An in vitro study.
Year	2018	2018	2018	2018	2017	2017	2018	2017	2017	2017
Journal	Journal of Endodontics	Journal of Prosthodontics	Dental Materials	Dental Materials Journal	Journal of Prosthodontics research	BioMed research international	Journal of Prosthodontics by the American College of Prosthodontists	Journal of prosthodontics: official journal of the American College of Prosthodontists	Journal of prosthodontics: official journal of the American College of Prosthodontists	Journal of Indian Prosthodontic Society
Authors	Dartora NR, et al.,	Zimmermann M, et al.,	Skalskyi V, et al.,	Kanat-Ertürk et al	Taha D, et al.,	Gulec L and Ulusoy N	Rocca GT, et al.,	Abu Helal M,S, Wang Z	Einhorn M, et al.,	Atash R, et al.,
Aim of study	To analyze and compare the biomechanical behavior of endodontically treated teeth restored using different extensions of endocrowns inside the pulp chamber in vitro and using 3-dimensional finite element analysis (FEA).	To investigate the infliuence of different CAD/CAM materials for fitting accuracy with a new 3D method. The null hypothesis was that there are no significant differences for the fitting accuracy if different CAD/CAM materials are used.	To use acoustic emission method to compare the fracture resistance of different restorative materials used in dental endocrown constructions and respective endocrown restorations under quasi-static compressive loading. The initial and final fracture loads were evaluated.	The null the various CAD/ CAM materials would not affect the fracture strength of endocrown restorations, 2) the preparation depth has no influence on the fracture strength of central endocrown restorations, 3) the failure type would not be affected from the CAD/CAM materials and preparation depths.	The purpose of this in vitro study was to assess the effect of two margin designs and two occlusal thicknesses on the fracture resistance and mode of failures of endodontically treated teeth restored with polymer infiltrated ceramic endocrown restorations.	To evaluate the effects of two endocrown designs and computer aided design/manufacturing (CAD/CAM) materials on stress distribution and failure probability of restorations applied to severely damaged endodontically treated maxillary first premolar tooth (MFP).	To test the influence of the endo-core length on the marginal adaptation, fatigue resistance and fracture mode of ceramic endocrowns to restore severely destroyed upper premolars.	To compare equivalent and contact stresses in mandibular molar restored by all-ceramic crowns through two methods: ceramic endocrowns and ceramic crowns supported by fiber-reinforced composite (FRC) posts and core, by using 3D finite element analysis during normal masticatory load.	To determine the effect on endocrown restoration failure strength by the incorporation of ferrule features to the endocrown preparation.	To attempt to compare the fracture resistance of premolars that were extracted, endodontically treated, and restored using three different prosthetic methods when they were subjected to a load-simulating shear forces.
Number of samples	30 human molars	30 restorations	5 Discs 25 human molars	100 maxillary central first incisors	32 human molars	6 models of 3-D FE	48 human premolars	3 models of 3-D FE	48 human molars	30 human premolars
Groups analysed	Endocrown extensions inside the pulp chamber: Group 1: 5mm Group 2: 3mm Group 3: 1mm	Endocrown was performed on a maxillary right first molar on a typodont: Group 1: zirconia-reinforced lithium silicate ceramic Group 2: leucite-reinforced silicate ceramic Group 3: resin nanoceramic	Discs: Group B: zirconium dioxide Group C: ceramics Group D: metal ceramic Group E: composite resin Group F: luting cement Molars endocrowns: Group A: control – no restoration Group BE: restored by zirconium dioxide Group CE: restored by ceramic Group DE: restored by metal ceramic Group EE:restored by composite resin	Preparation depth of teeth endocrown: Group S: short: 3-mm Group L:long: 6-mm Subgroups of CAD/CAM blocks: Feldspathic ceramic, Lithium disilicate glass-ceramic, Resin-ceramic, Polymer infiltrated ceramic, Monoblock zirconia.	Group B2: endocrown with a butt joint with 2 mm occlusal thickness. Group B3.5: endocrown with a butt joint with 3.5 mm occlusal thickness Group S2: endocrown with with 1 mm shoulder finish line, with 2 mm occlusal thickness. Group S3.5: endocrown with with 1 mm shoulder finish line, with 3.5 mm occlusal thickness. .	Group (E): Endocrown with macromechanical retention was provided by the internal portion of the pulp chamber for the endocrown design. Group (ME): Modified Endocrown in addition to the pulp chamber, 3.0mm intraradicular extensions were generated to both canals for macromechanical retention. Three different CAD/CAM materials were used for each type of restoration design; Group (1): Feldspathic Ceramic. Group (2): Polymer-Infiltrated Hybrid Ceramic. Group (3): Nanoceramic Resin Lava Ultimate	Group A (negative control): flat CAD-CAM overlays with no endo-core. Group B: CAD-CAM endocrowns with a 2-mm high endo-core. Group C: CAD-CAM endocrowns with a 4-mm high endo-core. Group D (positive control): conventional CAD-CAM crowns.	Group A: intact molar with no restoration; Group B: ceramic endocrown-restored molar Group C: ceramic crown supported by FRC posts and core restored molar	Group 0: endocrown with no ferule; Group 1: endocrown with 1mm ferule; Group 2: endocrown with 2mm ferule.	Group 1: (all ceramic endocrown), Group 2: (glass fiber post + composite resin core + ceramic crown), Group 3: (cast post and core + ceramic crown).

Material	IPS e.max CAD blocks	Zirconia-reinforced lithium silicate ceramic (Celtra Duo; CD); Leucite-reinforced silicate ceramic (Empress CAD; EM); Resin nanoceramic (Lava Ultimate; LU).	Zirconium dioxide (Prettauzirconia) Ceramic); Lithium dissilicate (IPS e.max Press) Metalceramic (GCInitial MC+NicralliumN2BCS) Composite resin (Nano Q)	Monoblock zircônia – inCoris TZI (Sirona Dental Systems, Bensheim,) Lithium-disilicate glass-ceramic - IPS e.max CAD (Ivoclar Vivadent, Polymer infiltrated ceramic – Vita Enamic (VITA Zahnfabrik, Bad Sä); Feldspathic-ceramic - Vita Mark II (VITA Zahnfabrik); Resin-ceramic – Lava Ultimate (3M ESPE, Seefeld, Germany)	Polymer infiltrated ceramic endocrowns (ENAMIC blocks).	Feldspathic Ceramic - Vitablocks Mark II (Vita Zahnfabrik, Bad Sackingen, Germany) Polymer-Infiltrated Hybrid Ceramic – VitaEnamic (Vita Zahnfabrik, Bad Sackingen, Germany) -Nanoceramic Resin - Lava Ultimate (3MESPE, Bad Seefeld, Germany).	CAD–CAM lithium disilicate reinforced ceramic restorations (IPS e.max CAD, Ivoclar-Vivadent)	Leucite-reinforced ceramic.	Lithium disilicate glass ceramic restoration (IPS e.max CAD, Ivoclar-Vivadent).	Lithium disilicate glass ceramic restoration (IPS e.max CAD, Ivoclar-Vivadent).
Methodolog y of analysis of samples	Fracture resistance, Fractography, 3-Dimensional FEA	Special 3D subtractive analysis technique using software OraCheck.	Fracture resistance Using acoustic emission (AE)	Fracture resistance (45°)	Fracture resistance Failure mode	3-dimensional FEA Weibull Analysis	Fracture resistance Failure Mode Fractografy	3-dimensional FEA	Fracture resistance (45°) Micro CT analysis	Fracture resistance (45°)
Stastically results	After dynamic loading, a survival rate of 100% was observed in all groups. For static loading, statistically significant differences among the groups were observed (P < .05) (G-5 mm = 2008.61 N, G-3 mm= 1795.41 N, and G-1 mm=1268.12 N). Fractography showed a higher frequency of compression curls for G-5mmandG-3mm than forG 1mm.FEAexplained the results of fracture strength testing and fractography.	Results varied from best 88.9 ±7.7 µmfor marginal fit of resin nanoceramic restorations (LUMA) to worst 182.3 ±24.0 µmfor occlusal fit of zirconia-reinforced lithium silicate restorations (CD OC). Statistically significant differences were found both within and among the test groups. Group CD performed statistically significantly different from group LU for marginal fit (MA) and axial fit (AX) (*p* < 0.05). For occlusal fit (OC), no statistically significant differences were found	A lower threshold of 220µV was selected to exclude spurious background signals.For the initial fracture load of Type 1 samples, Group F (0.029 kN) < Group E (0.039 kN) < Group D (0.056 kN) < Group C (0.253 kN) < Group B (intact). The same trend was found for the final Fracture load, i.e., Group F (1.289 kN) < Group E (1.735 kN) < Group D (3.362 kN) < Group C (6.449 kN) < Group B (intact). For the initial and final fracture load, fracture load of Type 2	The data were statistically analyzed (Kruskal-Wallis, Mann Whitney U), failure modes were evaluated with stereomicroscopy. Zirconia group provided the statistically highest fracture strength, but also exhibited non-repairable failures.	Group S3.5 showed the highest mean fracture load value (1.27 _ 0.31 kN). Endocrowns with shoulder finish line had significantly higher mean fracture resistance values than endocrowns with butt margin (p < 0.05). However, the results were not statistically significant regarding the restoration thickness. Evaluation of the fracture modes revealed no statistically significant difference between themodes of failure of tested groups.	Regarding the stresses that occurred in enamel, for each group of material, ME restoration design transmitted less stress than endocrown. During normal occlusal function, the overall failure probability was minimum for ME with VMII. ME restoration design with VE was the best restorative option for premolar teeth with extensive loss of coronal structure under high occlusal loads. Therefore, ME design could be a favorable treatment	All the specimens survived the TCML test except four specimens of Group A (early restorations' debonding). No difference in percentages of closed margins was found between endocrowns (Groups B, C) and crowns (Group D). After the stepwise test, differences in survival within the groups were not statistically significant. Most of restorations experienced non-reparable fracture.	The highest mvM stress levels in the enamel and dentin for the tooth restored by ceramic endocrown were lower in the crown ceramic than in tooth restored with FRC posts and all-ceramic crowns; however, in the resin adhesive cement interface it was lower for ceramic crown supported by FRC posts than the in ceramic endocrown restoration. The maximum contact shear and tensile stress values along the restoration/tooth	Calculated failure stress found no difference in failure resistance among the three groups; however, failure load results identified that the endocrown preparations without ferrule had significantly lower fracture load resistance. Failure mode analysis identified that all preparations demonstrated a high number of catastrophic failures.	No significant difference was observed in resistance to fracture between glass fiber post and metal post. No relationship between the displacement of prosthetic dental system and type of material used was uncovered and by comparing the type of fracture with the restoration material used. However, a greater number of favorable fractures were observed in the glass fiber group
Conclusion	Greater extension of the endocrown inside the pulp chamber provides better mechanical performance, taking into account the resistance and fracture mode as well as stress distribution patterns.	The choice of CAD/CAM material may influence the fitting accuracy of CAD/CAM fabricated restorations. Specific material class-dependent milling strategies may improve the fitting accuracy of CAD/CAM-fabricated restorations.	Dental restorations should be made of high-strength materials. Zirconia displayed the highest fracture strength, while composite resin had the lowest fracture strength out of the materials used for the endocrowns. For teeth restored with endocrowns, the use of metal. Ceramics as endocrown material may ower the risk of failure during clinical use.	Zirconia and feldspathic ceramic materials show the highest and the lowest fracture resistance values, for short and long preparation depths, respectively. The preparation depth has a significant effect on the fracture strength of endocrowns for feldspathic ceramic. Catastrophic fractures can occur when zirconia materials with high elasticity moduli are used, whereas only repairable fractures occur when lithium disilicate, polymer infiltrated ceramic, resin-ceramic and feldspathic ceramics are used.	Adding a short axial wall and shoulder finish line to the preparation design of ETT restored with endocrown can increase the fracture resistance of these teeth. However, further investigations, especially the fatigue behavior, is needed to ensure the increase of fracture resistance with small increases of restoration thickness. The violation of conservative preparation principles to increase the occlusal thickness of the restoration more than the standard thickness seems to be impractical. The use of polymer infiltrated ceramic material can provide acceptable values	Regarding the restoration design, the modified endocrown design with intraradicular extensions protected the remaining tooth structures better than endocrown design. On the effect of restorative materials tested, VMII was only successful in protecting tooth structures under normal occlusal function and it showed failure under high occlusal loads. ME restoration design with VE was the best restorative option for premolar teeth with extensive loss ofcoronal structure under highocclusal loads	Within the limits of this in-vitro study, fatigued endocrowns with both 2-mm and 4-mm long endo-cores displayed outcomes in t marginal integrity and fatigue resistance equivalent to classical crowns. Results of this test discourage the use of flat overlays with only adhesive retention to restore extremely destroyed premolars. Almost the totality of the fractured specimens broke in a catastrophic way, under the CEJ. Further in-vitro studies and clinical trials are needed to confirm these results.erms of	Ceramic endocrown restoration presented a lower mvM stress level in dentin than the conventional ceramic crown supported by FRC posts and core. Ceramic endocrown restorations in molars are less susceptible to damage than those with conventional ceramic crowns retained by FRC posts. A ceramic endocrown that is properly cemented in molars might not be fractured or loosened under the masticatory load levels presented in this investigation.	Ferrule-containing endocrown preparations Demonstrated significantly greater failure loads than standard endocrown restorations; however, calculated failure stress based on available surface area for adhesive bonding found no difference between the groups. Lower instances of catastrophic failure were observed with the endocrown preparations containing 1 mm of preparation ferrule design; however, regardless of the presence of ferrule, this study found that all endocrown restorations suffered a high proportion	Endocrown displays better resistance to fracture compared to conventional post and core restorations. In addition, endocrown did not show more displacement or cause more unfavorable fractures than the conventional restorations. This restoration may represent a reliable alternative for restoring a damaged, endodontically treated tooth.

Title	Strength comparison of anterior teeth restored with ceramic endocrowns vs custom-made post and cores.	Effect of Endocrown Pulp Chamber Extension Depth on Molar Fracture Resistance.	Biomechanical behavior of endodontically treated premolars using different preparation designs and CAD/CAM materials.	Fracture strength of CAD/CAM fabricated lithium disilicate and resin nano ceramic restorations used for endodontically treated teeth.	A comparison of the fracture resistances of endodontically treated mandibular premolars restored with endocrowns and glass fiber post-core retained conventional crowns.	Influence of remaining tooth structure and restorative material type on stress distribution in endodontically treated maxillary premolars: A finite element analysis.	Fatigue behavior of resin-modified monolithic CAD-CAM RNC crowns and endocrowns.	Mechanical Failure of Endocrowns Manufactured with Different Ceramic Materials: An In Vitro Biomechanical Study.	Evaluation of the marginal and internal discrepancies of CAD-CAM endocrowns with different cavity depths: An in vitro study.	Effect of Preparation Depth on the Marginal and Internal Adaptation of Computer-aided Design/Computer-assisted Manufacture Endocrowns.
Year	2017	2017	2017	2017	2017	2016	2016	2016	2017	2016
Journal	Journal of prosthodontics research	Operative Dentistry	Journal of dentistry	Dental Materials Journal	The Journal of Advanced Prosthodontics	Journal of Prosthetic Dentistry	Dental Materials: oficial publication of the Academy of Dental Materials	Journal of prosthodontics: oficial jornal of the American College of Prosthodontists	The Journal of Prosthetic Dentistry	Operative Dentistry
Authors	Dejak B, Młotkowski A	A Hayes, et al.,	Lise D, et al.,	Güngör M, et al.,	Guo J, et al,.	Zhu J, et al,.	Rocca G, et al,.	Aktas G, et al,.	Shin Y, et al,.	Gaintantzopoulou M, et al,.
Aim of study	To compare the strength of incisor teeth restored with ceramic endocrowns versus custom-made post and prostheticcrowns.	To evaluate the effect of CAD/CAM endocrown restorations with pulp chamber extension depths of 2, 3, and 4 mm on molar fracture resistance. The null hypothesis was that there would be no difference in fracture resistance among the three groups.	To evaluate the effect of the restoration design ('2.5-mm deep endocrown', '5-mm deep endocrown' or '5-mm deep post&crown') and the CAD/CAM material type (composite or lithium disilicate glass-ceramic) on the load-to-failure of restored ETPM.	was to evaluate and compare the fracture strength and failure modes of endocrowns, zirconia post, and fiber post supported restorations and predict the clinical outcomes of six different prostheses used for endodontically treated teeth.	To assess the fracture resistance and failure patterns of endodontically treated mandibular premolars restored with ceramic endocrowns and conventional post-core supported ceramic crowns, using intact teeth as a control.	To evaluate the influence of clinical and anatomic factors on stress distribution in maxillary premolars using FE analysis.	To test in vitro the fatigue behavior and the fracture mode of veneered CAD–CAM RNC crowns and endocrowns for upper premolars. Buccal and occlusal modifications of the restorations after cutting-back were tested.	To explore the effect of the stiffness difference in two newly introduced novel silicate-based ceramics on the fracture behavior of endocrown adhesive restorations.	To evaluate the marginal and internal discrepancies of CAD/CAM endocrowns with different cavity depths by comparing mCT images.	To evaluate the effect of cavity preparation depth and intraradicular extension on the marginal and internal fit and of resin-ceramic CAD/CAM endocrown restorations.
Number of samples	6 models of 3-D FEA	36 human molar	48 human molar	60 maxillary central first incisors	30 human premolars	5 FE models	60 humans premolars	36 humans molars	48 humans molars	n.i
Grupos analisados	Model A: Incisor Restored with post and core and prosthetic crown. Model B—Incisor restored with leucite ceramic endocrown. Model C—Incisor restored with lithium disilicate ceramic endocrown.	Group 2: endocrown with 2mm chamber extension depth. Group 3: endocrown with 2mm chamber extension depth. Group 4: endocrown with 2mm chamber extension depth.	Group lithium dissilicate endocrown with 2,5mm deep. Group composite endocrown with 2,5mm deep. Group lithium dissilicate endocrown with 5,0mm deep. Group composite endocrown with 5,0mm deep. Group lithium dissilicate crown and 5,0mm deep post. Group composite crown and 5,0mm deep post.	Group ZrRNC: rconia post and resin nano ceramic crown. Group ZrLDS: fiber post and lithium disilicate ceramic crown. Group FbRNC: fiber post and resin nano ceramic crown Group FbLDS: fiber post and lithium disilicate ceramic crowns. Group EndoRNC: resin nano ceramic endocrown. Group EndoLDS: lithium disilicate ceramic endocrown.	Group (GI): intact teeth group Group (GE): endocrown group Group (GC): conventional post-core supported crown group	Model (S): intact maxillary premolar (negative control) Model (R): endondontic treated premolar restored with composite resin (positive control) Model (E1): endocrowns (1,0mm thicknesses) Model (E2): endocrowns (2,0mm thicknesses) Model (E3): endocrowns (3,0mm thicknesses.	Group A: full anatomic endocrown (control group). Group B: buccal veneered endocrowns. Group C: buccal veneered endocrowns with an occlusal central groove. Group D: full anatomic crown (control group). Group E: buccal veneered crowns Group F: buccal veneered crowns with an occlusal central groove.	Group control: endocrown restorations from alumina silicate ceramic. Group Zr-R endocrown restorations from Zirconia reinforced glass ceramic Group P-I: endocrown restoration from polymer-infiltrated hybrid ceramic.	Group CEREC AC 2: endocrown restoration with 2mm made by CEREC AC, v4.2; Sirona Dental Systems Group CEREC AC 4: endocrown restoration with 4mm made by CEREC AC, v4.2; Sirona Dental Systems Group E4D 2: endocrown restoration with 2mm depth made by E4D Sky, v 2.0; Planmeca/E4D Technologies; Group E4D 4: endocrown restoration with 2mm depth made by E4D Sky, v 2.0; Planmeca/E4D Technologies;	Group H2: endocrown with 2mm deepth Group H3: endocrown with 3mm deepth Group H4: endocrown with 4mm deepth

Material	n.i	n.i	Composite (Cerasmart, GC) Lithium disilicate glass-ceramic (IPS e.max CAD, Ivoclar Vivadent).	Lithium disilicate (IPS e.max CAD, Ivoclar Vivadent, Schaan, Liechtenstein) and resin nano ceramic (Lava Ultimate, 3MEspe, Seefeld, Germany).	Lithium disilicate (IPS e.max CAD, Ivoclar Vivadent, Schaan, Liechtenstein).	Lithium disilicate (IPS e.max CAD, Ivoclar Vivadent, Schaan, Liechtenstein). Composite resin (Paradigm MZ100; 3M ESPE), High-leucite content ceramic (IPS Empress; Ivoclar Vivadent AG), Zirconia ceramic (In-Ceram Zirconia; Vita Zahnfabrik)	Nanoceramic Resin - Lava Ultimate (3MESPE,Bad Seefeld, Germany). Resin composite (Filtek Supreme XTE Universal Restorative, 3M ESPE, Seefeld Germany)	Alumina silicate ceramic (Vitablocs Mark II; Vita Zahnfabrik) Zzirconia-reinforced glass ceramic (Suprinity) Ppolymer-infiltrated hybrid ceramic (Enamic)	Lithium disilicate (IPS e.max CAD, Ivoclar Vivadent, Schaan, Liechtenstein).	Polymerinfiltrated ceramic network material (Vita Enamic, Vita Zahnfabrik, Bad Sackingen, Germany)
Methodology of analysis of samples	3-dimensional FEA	Fractrue Resistance Failure Mode Micro Ct analysis	Fracture resistance (45°)	Fracture resistance (45°) Failure Mode	Fracture resistance (45°) Failure Mode	3-dimensional FEA (vertical and horizontal load)	Fracture resistance (45°) Failure Mode Fractography	Fracture resistance (45°) Failure Mode	Marginal adaptation with Micro CT	Marginal adaptation with Micro CT
Stastically results	The lowest stresses occurred in the anterior tooth restored with custom post and core (model A). The mvM stress of 47.5 MPa concentrated in leucite ceramic endocrown (model B) and its value was close to the tensile strength of this material. The maximal mvM stresses in the lithium disilicate ceramic endocrown (model C) were 4 times lower than tensile strength of this material. In all cases contact stresses in the adhesive interface under restorations did not exceed the resin cement bond strength to dentin.	The 2- and 4-mm chamber extension groups demonstrated the highest fracture resistance stress, with the 3-mm group similar to the 2-mm group. The 3- and 4-mm chamber extension group specimens demonstrated nearly universal catastrophic tooth fracture, whereas half the 2-mm chamber extension group displayed nonrestorable root fractures.	A significant interaction between restoration design and CAD/CAM material was found using two-way ANOVA. In the '2.5-mm deep endocrown' groups, the composite achieved a significantly higher load-to-failure than the lithium disilicate glass-ceramic, while no differences between materials were found in the '5-mm deep endocrown' and '5-mm deep post&crown' groups. More unfavorable failures (root fractures) were observed for higher load-to failure values.	Fracture loads and modes were determined. The EndoLDS group had the highest fracture strength, followed by ZrRNC and EndoRNC group. However the results were not significantly different among groups (*p*>0.05). The failure modes of the restorations changed according to the restorative materials	The fracture resistances of GE and GC were significantly lower than that of GI (*P*<.01), while no significant difference was found between GE and GC (*P*=.702). As of the failure mode, most of the specimens in GE and GC were unfavorable while a higher occurrence of favorable failure mode was presented in GI.	As the quantity of preserved dental tissues increased, the von Mises stress in dentin decreased, and the peak von Mises strain value of the cement layer increased. When the elastic modulus of the endocrown material increased, the von Mises stress in endocrown and dentin increased, and the peak von Mises strain value of the cement layer decreased.	The differences in survival between groups were not statistically significant, except between groups D and F (p = 0.039). Endocrowns fractured predominantly with a mesio-distal wedge-opening fracture (82%). Partial cusp fractures were observed above all in crowns (70%). Analysis of the fractured specimens revealed that the origin of the fracture was mainly at the occlusal contact points of the step wise loading.	Load-to-fracture failure did not differ significantly, and the calculated meanvalues were 1035.08 N, 1058.33 N, and 1025.00 N for control, Zr-R, and P-I groups, respectively; however, the stiffness of the restoration-tooth complex was significantlyhigher than that in both test groups. No statistically significant correlation was established in paired comparisons of the failure strength, restorative stiffness, and fractured tooth distance parameters. The failure mode for teeth restored with zirconia-reinforcedglass ceramics was identified as non-restorable. The resin interface in the control and P-I groups presented similar adhesive failure behavior.	An endocrown with a 4-mm cavity showed a larger marginal and internal volume than one with a 2-mm cavity. Cementation did not show significant differences in total discrepancy thickness. Discrepancies on the pulpal floor were largest in other sites. Both chairside CAD/CAM systems showed similar discrepancy in the endocrowns.	Significant differences were found in MG, MD, and internal gap width values between the groups, with H2 showing the lowest values from all groups. S/V calculations presented significant differences between H2 and the other two groups (H3 and H4) tested, with H2 again showing the lowest values. Increasing the intraradicular extension of endocrow restorations increased the marginal and internal gap of endocrown restorations.
Conclusion	Leucite ceramic endocrowns in incisors may fracture during physiological loading. Endocrowns made of lithium disilicate ceramic are resistant to failure. Posts and prosthetic crowns are still recommended for anterior teeth restorations.	The endocrown with 2- and 4-mm displayed greater tooth fracture resistance. All groups demonstrated a high number of catastrophic fractures, but these results may not be clinically significant because the fracture force results are higher than normal reported values of masticatory function.	Only following a '2.5-mm deep endocrown' design, composite appeared more favorable than lithium disilicate glass-ceramic as crown material; this may be explained by their difference in elastic modulus.	Endodontically treated anterior teeth might be restored with endocrowns as well as other post-cor restorations, however tooth fracture failures should be considered that affect reliability of endocrowns.	For the restoration of mandibula rpremolar ,endocrown shows no advantage in fracture resistance compared with the conventional method. Both two methods cannot rehabilitate endodontically treated teeth with the same fracture resistances as that of intact mandibular premolars.	Conservative preparation of teeth for endocrowns is likely to protect the residual tooth structure may cause future cohesive bonding failure. The elastic modulus of thematerial may benefit the durability of bonding between the endocrown and the abutment; butr, it may cause fracture of the residual tooth structure.	CAD–CAM RNC restorations has no influence on their fatigue resistance except when monolithic crowns. The mode of fracture for endocrown restorations was a split vertical failure.This behavior seems to be more related to the restoration design than to the type of surface resin modification.	Mechanical failure of endocrown restorations does not significantly differ for silica-based ceramics modified either with zirconia or polymer.	Based on the present study, marginal and internal discrepancies increased depending on cavity depth. Cementation did not increase the dimension of the discrepancy between the restoration and the cavity wall. The discrepancy on the pulpal floor appeared to affect these results.	Extension of the endocrown preparation negatively affected both the marginal adaptation and the internal fit of the restoration. Marginal fit of the three groups tested proved to be significantly better than internal fit evaluated by analyzing the internal gap width in various measuring positions.

Title	The effect of immediate dentin sealing and optical powder removal method on the fracture resistance of CAD/CAM-fabricated endocrowns.	Fracture strength, failure type and Weibull characteristics of lithium disilicate and multiphase resin composite endocrowns under axial and lateral forces.	Influence of Adhesive Core Buildup Designs on the Resistance of Endodontically Treated Molars Restored With Lithium Disilicate CAD/CAM Crowns	The influence of FRCs reinforcement on marginal adaptation of CAD/CAM composite resin endocrowns after simulated fatigue loading.	Fracture resistance and microleakage of endocrowns utilizing three CAD-CAM	Fracture resistance of endodontically treated teeth without ferrule using a novel H-shaped short post.	Microhardness of light- and dual-polymerizable luting resins polymerized through 7.5-mm-thick endocrowns	3D-Finite element analysis of molars restored with endocrowns and posts during masticatory simulation.	Adhesive restoration of anterior endodontically treated teeth: influence of post length on fracture strength.	Composite vs ceramic computer-aided design/computer-assisted manufacturing crowns in endodontically treated teeth: analysis of marginal adaptation.
Year	2016	2016	2015	2016	2015	2015	2014	2013	2014	2013
Journal	International Journal of computerized dentistry	Dental Materials: oficial publication of the Academy of Dental Materials	Operative Dentistry	Odontology	Operative Dentistry	Quintessence International	The Journal of Prosthetic Dentistry	Dental Materials: oficial publication of the Academy of Dental Materials	Clinical Oral Investigations	Operative Dentistry
Author	El-Damanhoury and Gaiintantzoupoulou	Marco M, et al,.	Carvalho A, et al,.	Rocca G, et al,.	El-Damanhoury, et al,.	Schmidlin P, et al,.	Gregor L, et al,.	Dejak B, et al,.	Ramírez-Sebastià A, et al,.	Ramírez-Sebastià A, et al,.
Aim of study	To evaluate the effect of immediate dentin sealing and the method of optical poder removal on the fracture resistance of CAD/CAM endocrowns.	To compare the fracture strength of endocrowns made of $Li_2Si_2O_5$ or multiphase resin composite and compare the results with natural teeth under axial and lateral forces, and to evaluate the failure types after testing.	To evaluate the influence of a 4-mm buildup, a 2-mm buildup or no buildup (endocrown) on the mechanical performance and failure mode of ETMs restored with lithium disilicate computer-aided design/computer-aided manufacturing (CAD/CAM) complete crowns placed with self-adhesive resin cement.	To evaluate the marginal accuracy of endocrowns made out of CAD/CAM resincomposite blocks (Lava Ultimate A1-HT/14L, 3M ESPE,Seefeld, Germany) to restore endodontically treated molars, before and after a thermo-mechanical fatigue test that simulates 2.5 years of clinical service. Different kinds of FRC-reinforced cores underneath the CAD/CAM restorations were tested.	To evaluated the microleakage, fracture resistance, and failure modes of three types of CAD/ CAM fabricated restorations when they were submitted to an oblique compressive force.	To evaluate the fracture resistance and failure types of modified H-designed intradental short retention preparation for computer-aided design/computer-assisted manufacture (CAD/CAM) restorations, in cases where no ferrule is possible.	To verify, by means of microhardness testing, the hardening of dual and light polymerizable luting resins polymerized with a high irradiance lightemitting diode (LED) (1200 mW/cm) through indirect composite resin and ceramic endocrowns.	To compare equivalent stresses in molars restored with endocrowns as well as posts and cores during masticatory simulation using finite element analysis.	To evaluate the fracture resis-tance of endodontically treated anterior teeth restored with crowns made of composite or ceramic and retained without the use of a post (endocrowns) or with posts of 5 mm (short) and 10 mm in length (long).	To compare the marginal adaptation between ceramic and composite CEREC crowns in endodontically treated teeth restored with endocrowns or with a short or a long post.
Methodology of analysis of samples	Fracture resistance Failure Mode	Fracture resistance Weibull analysis Failure Mode	Fracture resistance Failure Mode	Mechanical fatigue Marginal adaptation	Fracture resistance	Fracture resistance	Microhardness	3-dimensional FEA	Fracture resistance (45°)	Marginal adaptation
Number of samples	78 human molars	60 human molars	45 human molars	32 human molars	30 human molars	40 human molars	30 human molars	4 FE models	48 human maxillary incisors	48 human maxillary incisors
Grupos analisados	n.i	Group C: no preparation or restoration (control) Group L1: Endocrown made of lithium dissilicate material. Group LA: Endocrown made of multiphase resin composite material.	Group I: had 4-mm buildup (4-mm height from CEJ at cusp tips, 2-mm height from CEJ at central groove + complete crown restorations (1.5-mm thick); Group II: had 2-mm buildup (2-mm height from CEJ at cusp tips, 1-mm height from CEJ at central groove + complete crown restorations (2.5-mm to 3.5-mm thick) Group III: had endocrown restoration (about 5-mm to 5.5-mm thick)	Group 1 (control): hybrid resin composite Group 2: as group 1 but covered by 3 meshes of E-glass fibres; Group 3:FRC resin (EverX Posterior,GC) Group 4: as group 3 but covered by 3 meshes of E-glass fibres.	Group CB: endocrown with feldspathic block ceramic Group EX: endocrown with lithium-disilicate blocks Group LU: endocrown resin nanoceramic blocks.	Groups A: H-post with glass ceramic. Group B: H-post with lithium dissilicate ceramic. Group C: endocrown 2.5-mm depth, which was limited to 1-mm residual (negative control group) marginal dentin thickness. Group D: post and core 6-mm deep preparations for a glass fiber post (positive control group)	Group VA/compo: resin composite endocrown cemented by dual-polymerizable luting resin cement; Group TE/compo: composite resin endocrown cemented by light-polymerizable Restorative; Group VA/ceram: ceramic endocrown cemented by dual-polymerizable luting resin cement; Group TE/ceram: ceramic endocrown cemented by light-polymerizable restorative; Group VActr: control group Group TEctr: control group	Group A: intact tooth; Group B: tooth restored by ceramic endocrown; Group C: tooth with FRC posts, composite core and ceramic crown; Group D: tooth with cast post and ceramic crown.	Group LPCer: 10-mm glass fiber post (long)/composite core/ceramic crown; Group SPCer: 5-mm glass fiber post (short)/composite core/ceramic crown; Group LPCpr: 10-mm glass fiber pots (long)/composite core/composite crown Group SPCpr: 5-mm glass fiber post (short)/composite core/composite crown Group EndoCer: Ceramic endocrown Group EndoCpr: Composite endocrown	Group LPCer: 10-mm glass fiber post (long)/composite core/ceramic crown; Group SPCer: 5-mm glass fiber post (short)/composite core/ceramic crown; Group LPCpr: 10-mm glass fiber pots (long)/composite core/composite crown Group SPCpr: 5-mm glass fiber post (short)/composite core/composite crown Group EndoCer: Ceramic endocrown Group EndoCpr: Composite endocrown

Material	Vitablocks Mark II (Vita Zahnfabrik, Bad Sackingen, Germany)	Lithium disilicate (IPS e.max CAD, Ivoclar Vivadent, Schaan, Liechtenstein) Nanoceramic Resin - Lava Ultimate (3MESPE,Bad Seefeld, Germany).	Lithium disilicate (IPS e.max CAD, Ivoclar Vivadent, Schaan, Liechtenstein)	Nanoceramic Resin - Lava Ultimate (3M ESPE, Bad Seefeld, Germany).	CEREC Blocks Sirona Dental Systems Lithium disilicate (IPS e.max CAD, Ivoclar Vivadent, Schaan,Liechtenstein) Nanoceramic Resin Lava Ultimate (3M ESPE, Bad Seefeld, Germany).	Glass-ceramic crowns (IPS Empress CAD Multi LT, Empress CAD, Ivoclar Vivadent), Lithium disilicate ceramic (e.max CAD, Ivoclar Vivadent).	Dual-polymerizable luting resin (Variolink II, Ivoclar Vivadent) Light-polymerizable restorative composite resin: (Tetric Ivoclar Vivadent)	Leucite-reinforced ceramics	Composite blocks (Paradigm MZ100 3M ESPE, Seefeld, Germany) Leucite ceramic blocks (IPS Empress CAD, Ivoclar Vivadent AG, Schaan, Lichtenstein) Fiber post (FRC Postec Plus (Ivoclar Vivadent, Schaan, Liechtenstein)	Composite blocks (Paradigm MZ100 3M ESPE, Seefeld, Germany) Leucite ceramic blocks (IPS Empress CAD, Ivoclar Vivadent AG, Schaan, Lichtenstein Fiber post (FRC Postec Plus (Ivoclar Vivadent, Schaan, Liechtenstein)
Stastically results	Fracture resistance of all IS groups was significantlty lower than DS group, except AW. The was no statistically significant difference between powdet removal methods.	Under axial loading, mean fracture strength (*N*) did not show significant difference between groups: LA_A (2675 ± 588)[a], LI_A (2428 ± 566)[a], C_A (2151 ± 672) [a] (*p* > 0.05) and under lateral loading, LA_L (838 ± 169)[A] presented significantly lower mean values than those of other groups: C_L (1499±418)[B], LI_L(1118±173)[B] (*p*<0.05). Both endocrown materials and the control group were more vulnerable to lateral loading than axial loading. Under axial loading, Weibull distribution presented higher shape (0) for Groups LI_A (5.35) and LA_A (5.08) than that of the control (3.97) and under lateral loading LI_L (7.5) showed higher shape ($_0$) thanthose of othergroups (4.69–6.46). After axial loading, failure types were mainly cohesive in the material and after lateral loading primarily adhesive between the material and dentinfor both LI and LA, most of which were repairable.	The survival rates after the fatigue test were 100%, 93%, and 100% for 4-mm, 2-mm, and no buildup (endocrown), respectively and were not statistically different (only one specimen failed with a 2-mm build under a crown that cohesively fractured at 1,400 N) .Post fatigue load to failure averaged 3181 N for 4-mm buildups (15 specimens), 3759 N for 2-mm buildups (12 specimens), and 3265 N for endocrowns (14 specimens). The 2-mm buildups were associated with higher loads to failure than endocrowns and 4-mm buildups, but no differences were found between 4-mm buildups and endocrowns (p,0.05.) One endocrown and 2 restorations with a 2-mm buildup survived the load-to-failure test (at 4500 N). Only catastrophic fractures occurred after the load to failure test.	For all the groups, the percentage values of perfect marginal adaptation after loading were always significantly lower than before loading (p \0.05). The marginal adaptation before and after loading was not significantly different between the experimental groups (p> 0.05).	LU showed significantly (p<0.05) higher fracture resistance and more favorable fracture mode (ie, fracture of the endocrown without fracture of tooth) as well as higher dy penetration than CB and EX.	The H-post group restored with lithiumdisilicate crowns (group B) presented higher fracture resistance compared to the H-post group with glass-ceramic crowns (group A) and the endocrowns (group C). Among the failure analysis, only specimens of group C were all repairable after fracture load test, while the specimens of remaining groups A, B, and D accounted for 90%, 70%, and 50% repairable fracture nmodes, respectively.	For the Vickers microhardness measurements of a dual-polymerizable luting cement, no differences (P>.05) were found between Vickers microhardness control values and values reported after polymerization through composite resin and ceramic endocrowns. For The Vickers microhardness measurements (_SD) of a light-polymerizable microhybrid composite resin, control values were significantly (P<.05) higher (111 _3.3) than those reported after polymerization through composite resin (100.5 _3.8) and ceramic (99.7 _2.3) endocrowns. However, the hardness values of The Vickers microhardness measurements of a light-polymerizable microhybrid composite resin polymerized through the endocrowns were approximately 10% to 12% lower than those of the control values. The effect of endocrown material was not significant (P>.05).	During masticatory simulation, the lowest mvM stresses in dentin arisen in molar restored with endocrown (Model B). Maximal mvM stress values in structures of restored molar were 23% lower than in the intact tooth. The mvM stresses in the endocrown did not exceed the tensile strength of ceramic. In the molar with an FRC posts (Model C), equivalente stress values in dentin increased by 42% versus Model B. In ceramic crown of Model C the stresses were 31% higher and in the resin luting cement were 61% higher than in the tooth with endocrown. Tensile contact stresses in the adhesive cement–dentin interface around FRC posts achieved 4 times higher values than under endocrown and shear stresses increased twice. The contact stress values around the appliances were several time smaller than cement–dentin bond strength.	Presence of post, post length, and crown material had no significant effect on the fracture resistance. Groups restored with endocrowns presented a higher number of repairable fractures in respect to the other groups.	Loading had a statistically significant effect (p,0.05) on the percentage of ‘‘continuous margin’’ in all groups. The LPCpr, SPCpr, and EndoCpr groups showed the highest percentage of continuous margin initially and after loading. The effect of the different post lengths on marginal adaptation was not significant (p.0.05).
Conclusion	Immediate dentin sealing does not improve fracture resistance of endocrowns restorations. Air-water spray washing is adequate to remove the optical poder after optical scanning impression taking.	Under axial loading, molars restored with endocrowns performed similar with both lithium dissilicate ceramic and multiphase resin composite but the latter was less durable under lateral loading.	The buildup design influenced the performance of endodontically treated molars restored with lithium disilicate CAD/CAM complete crowns placed with self-adhesive resin cement. The 2-mm buildups were associated with higher loads to failure than the endocrown and the 4-mm buildup, but all restoration designs survived far beyond the normal range of masticatory forces.	The use of FRCs to reinforce the pulp chamber of devitalized molars restored with CAD/CAM composite resin restorations did not significantly influenced their marginal quality.	Although using resin nanoceramic blocks for fabrication of endocrowns may result in better fracture resistance and a more favorable fracture mode than other investigated ceramic blocks, more microleakage may be expected with this material.	The modification of the short intracoronal restoration anchorage profile may be a valid concept to improve the retention and fracture resistance, given that the materials are adjusted for this purpose in terms of mechanical resistance and internal adaptation. Numerical evaluations and future in vitro studies may help to select the best designs and materials.	Under the conditions of this in vitro study, Vickers microhardness values of the dual-polymerizable resin cement and the light-polymerizable restorative composite resin irradiated for 3 _ 90 seconds with a high irradiancelight-emitting diode lamp through 7.5-mm-thick endocrowns reached at least 80% of the control Vickers microhardness values, which means that both materials can be adequately polymerized when they are used for luting thick indirect restorations.	Ceramic endocrowns in molars caused the lowest mvM stress levels in dentin compared to posts and cores. Molars restored with endocrowns are less prone to fracture than those with posts.	Presence of a post had no effect on the restorations' fracture strength. Although this in vitro study has some limitations in respect to its clinical relevance, the restoration of largely destroyed anterior teeth with the use of na endocrown or a short glass fiber post might have advantages over a large glass fiber post.	CAD-CAM crowns fabricated from millable composite resin blocks (Paradigm MZ100) offer a superior option to all-ceramic crowns (IPS Empress CAD).

Title	Estimation of the failure risk of a maxillary premolar with different crack depths with endodontic treatment by computer-aided design/computer-aided manufacturing ceramic restorations.	Finite element analysis of adhesive endo-crowns of molars at different height levels of buccally applied load.	Comparison of fracture strength of endocrowns and glass fiber post-retained conventional crowns.	Evaluation of failure risks in ceramic restorations for endodontically treated premolar with MOD preparation.	Finite element and Weibull analyses to estimate failure risks in the ceramic endocrown and classical crown for endodontically treated maxillary premolar.	Estimation of the risk of failure for an endodontically treated maxillary premolar with MODP preparation and CAD/CAM ceramic restorations.	Non-linear elastic three-dimensional finite element analysis on the effect of endocrown material rigidity on alveolar bone remodeling process.	Influence of the type of post and core on in vitro marginal continuity, fracture resistance, and fracture mode of lithia disilicate-based all-ceramic crowns.	Evaluation of the biomechanical behavior of maxillary central incisors restored by means of endocrowns compared to a natural tooth: a 3D static linear finite elements analysis.
Year	2014	2012	2016	2016	2010	2009	2009	2008	2006
Journal	Journal of Endodontics	Journal dental Biomechanics	Operative Dentistry	Dental Materials: oficial publication of the Academy of Dental Materials	European journal of oral sciences	Journal of Endodontics	Dental Materials: oficial publication of the Academy of Dental Materials	The Journal of Prosthetic Dentistry	Dental Materials: oficial publication of the Academy of Dental Materials
Author	Lin CL, et al,.	Hasan I, et al,.	Biacchi GR, et al,.	Lin CL, et al,.	Lin CL, et al,.	Lin CL, et al,.	Aversa R, et al,.	Forberger N e Göhring TN	Zarone F, et al,.
Aim of study	To compare the stress distribution patterns and risks for failure by using both FE and Weibull analyses for a maxillary premolar with different crack depths, shearing toward the pulp chamber and restored by using CAD/CAM ceramic restorations with onlay, endocrown, and crown built up onto a metal post-core unit.	To investigate numerically the previously in vitro investigated two endocrown restoration systems and to analyse their fracture resistance and fracture modes with the variation of the position of the applied load from 5 to 8 mm. The developed three-dimensional (3D) finite element (FE) models were based on the parameter setting of the above-mentioned previous studies.	To evaluate the fracture strength of endodontically treated molars with extensive coronal loss, restored by the conventional technique (glass fiber post and ceramic crown) and by endocrowns, in addition to observing the failure mode when they are submitted to an oblique compressive force.	To evaluated the risk of failure for an endodontically treated premolar with MOD preparation and three CEREC ceramic restoration configurations.	To evaluated the failure risks of an endodontically treated premolar with severely damaged coronal hard tissue and restored with either a computer-aided design/computer-aided manufacturing (CAD/CAM) ceramic endocrown or a classical crown configuration.	To compare the stress distribution patterns and risks for failure by using both FE and Weibull analyses for a maxillary premolar with MODP preparation restored by using CAD/ CAM ceramic restorations with the onlay, endocrown, and crown built up on a metal post-core unit.	To assess the deformations transferred to surrounding bone by endodontically treated maxillary central incisors restored with endocrowns made up of high or low elastic modulus materials.	To evaluate marginal continuity, fracture modes, and loads to failure of rigid lithia disilicate-based all-ceramic crowns placed on endodontically treated premolars supported by different substructures	To compare the stress distribution patterns of a sound tooth with those of teeth restored with the following different material configurations: alumina endocrowns, feldspathic endocrowns, composite endocrowns and traditional crowns built up on glass post and core units.
Type of study	3-dimensional FEA	Fracture resistance Failure Mode	Fracture resistance Failure Mode	FEA Weibull analysis Acoustic emission	FEA Weibull analysis Fracture resistance (90°)	FEA Weibull analysis Fracture resistance (90°)	3D FEA	Fracture resistance (45°) Failure Mode	n.i
Number of samples	6 maxillary upper second premolar 3-dimensional FE models	2 human molar 3-dimensional FE models	30 human molars	3 3-dimensional models (molar)	2 3-dimensional models (premolar)	3 3-dimensional models (premolar) 5 human premolar	n.i	48 human premolars	n.i
Grupos analisados	Group AB Onlay: onlay restoration extended to above bone. Group BB Onlay: onlay restoration extended to bellow bone. Group AB Endocrown: endocrown restoration extended to above bone. Group BB Endocrown: endocrown restoration extended to bellow bone. Group AB Crown: crown built up onto a metal post and composite extended to above bone. Group BB Crown: crown built up onto a metal post and composite extended to bellow bone.	Group of endo-crown as a monobloc; Group of endocrown of a primary abutment; Group for a full crown.	Group (GE): Endocrown Group (CC): Conventional Crown Group (GC): intraradicular post group	Model ceramic inlay; Model ceramic endocrown; Model conventional ceramic crown.	Group conventional crown: fiber post + composite resin core + classical ceramic crown Group Endocrown: endocrown ceramic extending 5 mm in depth	Model ceramic onlay with mesio occlusodistal palatal (MODP) preparation; Model ceramic endocrown with MODP preparation; Model conventional ceramic crown.	Model MOD 0A: orthotropic model of cortical bone, human tooth without PDL. Model MOD 0B: isotropic model of cortical bone, human tooth in its own socket without PDL. Model MOD 1: (control system) human sound tooth with PDL. Model MOD: PDL-provided tooth restored with an alumina endocrown. Model MOD 3: PDL-provided tooth restored with a composite endocrown. Model MOD 4: PDL-unprovided (ankylosed system) tooth restored with an alumina endocrown. Model MOD 5: PDL-unprovided (ankylosed system) tooth restored with a composite endocrown.	Group untreated: intact tooth; Group comp: restored with resin composite; Group endocrown: restored with ceramic endocrown; Group frc-post: restored with fiber post and ceramic crown; Group zro-post: restored with zircônia ceramic post and ceramic crown; Group gold-post: restored with alloy post and ceramic crown.	Model MOD1: sound tooth. Model MOD2: restored with a glass fiber post + feldspathic crown. Model MOD3: restored glass fiber post + alumina crown. Model MOD4: core restored with a composite CAD-CAM + feldspathic crown. Model MOD5: : core restored with a composite CAD-CAM + sintered alumina crown. was considered. MOD6: restored with a feldspathic CAD-CAM endocrown. Model MOD7: restored with a sintered alumina CAD-CAM machined endocrown.

Material	Alumina silicate ceramic (Vitablocs Mark II; Vita Zahnfabrik)	Alumina silicate ceramic (Vitablocs Mark II; Vita Zahnfabrik)	Lithium disilicate (IPS e.max Press, Ivoclar Vivadent, Schaan, Liechtenstein)	n.i	Alumina silicate ceramic (Vitablocs Mark II; Vita Zahnfabrik)	Alumina silicate ceramic (Vitablocs Mark II; Vita Zahnfabrik)	Alumina silicate ceramic (Vitablocs Mark II; Vita Zahnfabrik)	Hybrid composite resin (Tetric Ceram; Ivoclar Vivadent) Lithia disilicate-based ceramic material (Experimental press, Ivoclar Vivadent)	Composite block (Paradigm MZ100, 3M-ESPE, Germany)
Stastically results	The stress values on the enamel, dentin, and luting cement for endocrown restorations exhibited the lowest values relative to the other 2 restoration methods. Weibull analysis revealed that the overall failure probabilities in a shallow cracked premolar were 27%, 2%,and 1% for the onlay, endocrown, and conventional crown restorations, respectively, in the normal occlusal condition. The corresponding values were 70%, 10%, and 2% for the depth cracked premolar.	No differences were observed for the two endocrowns Concerning restoration displacement and the distribution of equivalent von Mises stress and total equivalent strain. Shifting the position of the applied load to 8 mm resulted in an increase in the displacement from 25 to 42 µm and Na increase of equivalent von Mises stress concentration at the tooth.	Significant differences between the two groups (p=0.002), with Group GE shown to be more resistant to compressive forces than Group GC	Simulation results indicated that the stress values on the enamel, dentin and luting cement for endocrown restorations were the lowest ones among the corresponding values for inlay and conventional crown restorations. Weibull analysis indicated that failure probability was 95%, 2% and 2% for the inlay, endocrown and conventional crown restorations, respectively, for normal biting. AE analysis revealed that, although the significantly least load was required for the first AE activity for inlay configuration, the endocrown and conventional crowns did not significantly differ from each other.	The results indicated that the stress values on the dentin and luting cement for the endocrown restoration were lower than those for the crown configuration. Weibull analysis revealed that the individual failure probability in the endocrown dentin and luting cement diminished more than those for the crown restoration. While the overall failure probabilities for the endocrown and the classical crown were similar, fatigue fracture testing revealed that the endocrown restoration had higher fracture resistance than the classical crown configuration (1,446 vs. 1,163 MPa).	The stress values on the enamel, dentin, and luting cement for endocrown restoration were the lowest values relative to the other 2 restorations. Weibull analysis revealed that the individual failure probability in the endocrown enamel, dentin, and luting cement obviously diminished more than those for onlay and conventional crown restorations. The overall failure probabilities were 27.5%, 1%, and 1% for onlay, endocrown, and conventional crown restorations, respectively, in normal occlusal condition.	Strain values in cortical bone, spongy bone, alveolar cortex and tooth were evaluated. PDL allowed models to homogeneously transfer loads to bone. Strains developing in highly rigid restorations were estimated to activate bone modeling and remodeling.	Initially, mean values (SD) between 72.4 (15.8)% (ENDOCROWN) and 94.8 (3)% (FRC-POST) for continuous Margins were found. With TCML, marginal continuity decreased Significantly only in FRC-POST, to 75.5 (8.4)%, and in endocrown, to 44.7 (14.5)%. Mechanical load testing measured mean loads to failure between 1092.4 (307.8) N (FRC-POST) and 1253.7 (226.5) N (ZRO-POST) Without significant differences between groups. Deep root fractures were observed in half of the specimens, irrespective of their groups.	High modulus materials used for the restoration strongly alter the natural biomechanical behavior of the tooth. Critical areas of high stress concentration are the restoration–cement–dentin interface both in the root canal and on the buccal and lingual aspects of the tooth–restoration interface. Materials with mechanical properties underposable to that of dentin or enamel improve the biomechanical behavior of the restored tooth reducing the areas of high stress concentration.
Conclusion	This numeric investigation suggests that the endocrown provides sufficient fracture resistance only in a shallow cracked premolar with endodontic treatment. The conventional crown treatment can immobilize the premolar for different cracked depths with lower failure risk.	Load distribution in the remaining tooth is similar with a monobloc and an endo-crown with primary abutment. For both endo-crowns, the region of load application plays a major role for their survival. The closer the region of the applied load to the restoration–tooth junction, the more desirable is the distribution of the load in the rest of the restored tooth.	Endocrown restorations presented greater fracture strength than indirect conventional crowns associated with glass fiber posts and resin composite filling cores. For both groups, the failure pattern was characterized by fracture of the tooth associated with displacement of the restoration on the opposite side.	The endocrown is na alternative to conventional treatment, and should be considered as a feasible conservative and esthetic restorative approach for endodontically treated premolars.	This investigation implies that the endocrown can be considered as a conservative, aesthetic, and clinically feasible restorative approach for endodontically treated maxillary premolars.	This numeric investigation suggests that endocrown and conventional crown restorations for endodontically treated premolars with MODP preparation present similar longevity.	The higher deformability of composites could enable restorative systems to transfer limited strains to compact and spongy bone of tooth socket. Composites could not prevent the physiological resorption of the alveolar bone, they could successfully reduce strain arising in tooth socket when compared to alumina. The PDL prevented bone to undergo high deformations, resulting in natural flexural movements of teeth.	Marginal continuity of the crowns studied was better and more stress resistant when posts and cores were included in the restoration of endodontically treated teeth with complete ceramic crowns. The placement of a post-and-core foundation did not influence the pattern of failure.	The use of endocrown restorations present the advantage of reducing the interfaces of the restorative system. The choice of the restorative materials should be carefully evaluated. Materials with mechanical properties similar to those of sound teeth improve the reliability of the restoartive system.

Table 2– “in vivo” studies

Title	Chairside Computer-Aided Design/Computer-Aided Manufacture All-Ceramic Crown and Endocrown Restorations: A 7-Year Survival Rate Study.	No post-no core approach to restore severely damaged posterior teeth an up to 10-year retrospective study of documented endocrown cases.	Management of large class II lesions in molars: how to restore and when to perform surgical crown lengthening?	Lithium silicate endocrown fabricated with a CAD-CAM system: A functional and esthetic protocol.	Using modified polyetheretherketone (PEEK) as an alternative material for endocrown restorations: A short-term clinical report.	CAD/CAM Endocrown Fabrication from a Polymer-Infiltrated Ceramic Network Block for Primary Molar: A Case Report.	Endocrown with Leucite-Reinforced Ceramic: Case of Restoration of Endodontically Treated Teeth.
Year	2017	2017	2017	2016	2016	2016	2015
Journal	The international journal of prosthodontic	Journal of dentistry	Restorative Dentistry Endodontics	The Journal of Prosthetic Dentistry	The Journal of Prosthetic Dentistry	The Journal of Clinical Pediatric Dentistry	Case reports in dentistry
Author	Fages M, et al,.	Belleflamme M, et al,.	Blanco A, et al,.	Cunha L, et al,.	Zoidis P, et al,.	Bilgin M, et al,.	Da Cunha L, et al,.
Aim of study	The objective of the present study was to analyze the clinical outcomes of 447 monoblock ceramic chairside computer-aided design/computer-aided manufacture (CAD/CAM) reconstructions over a 7-year functional period. Of these reconstructions, 212 were peripheral crowns and 235 were endocrowns	To evaluate the documented cases of lithium-disilicate reinforced glass-ceramic, artisanal composite and CAD-CAM composite endocrowns performed in the Department of Fixed Prosthodontics of the University of Liège using the IDS procedure; (correlate failures with clinical parameters such as residual tooth tissue amount, tooth preparation characteristics and occlusal parameters.	To present a decision tree for decision making for class II cavities on molars with increasingly large vertical dimensions. We aim to classify schematically from a multidisciplinary perspective, the best treatment option in each case, including both the choice of restoration (direct or indirect) and the management of the cavity margin (DME or surgical crown lengthening [SCL]) if necessary.	To presents a protocol for the fabrication of a lithium silicate-based endocrown, using the CAD-CAM biogeneric technique.	To describes the use of a modified polyetheretherketone PEEK (BioHPP) framework material veneered with indirect light-polymerized composite resin for the fabrication of an endocrown restoration.	To present the case of a primary second molar with profound caries treated first with pulpotomy, followed by restoration with a CAD/CAM PICN endocrown and 6 months of successful follow-up.	To describes an aesthetic and conservative posterior endocrown restoration of a nonvital tooth using VITA-PM9.
Type of study	Retrospective (7 years)	Retrospective (10 years)		Dental thecnique	Clinical Report	Case report	Case report
Number of samples	447 restorations	447 restorations	7 molars	Right mandibular first molar	Right maxillary second molar	Right mandibular first molar from children	Right mandibular first molar
Inclusion Criteria	Between 2003 and 2008, 323 patients received 447 crowns or endocrowns on molars in a private dental practice by the same dentist.	In function of the level of damage of residual tooth tissues after preparation, from 1 to 3.	n.i	n.i	n.i	n.i	n.i
Exclusion Criteria	tooth absence on the opposing arch, parafunctions, bruxism, psychologic disorders, and inability to return for follow-up visits for 5 years after prosthesis placement	n.i	n.i	n.i	n.i	n.i	
Groups Analysed	212 peripheral crowns 235 endocrowns	n.i	1-Supragingival caries does not reach the pulp – direct restoration. 2-Supragingival caries invading the pulp tissue - Direct or indirect restoration 3-Juxta-gingival decay that reaches the pulp - direct restoration or endocrown. 4-Caries invades the gingival sulcus and the pulp chamber – endocrown. 5-Caries with a margin in the junctional epithelium and reaching the pulp - endocrown. 6- Caries invades the connective tissue and pulp – endocrown. 7- Decay that reached the bone level and invaded the pulp chamber – endocrown.	n.i	A 35-year-old man patient	A 7-year-old male patient	A 23-year-old female patient

Material	Alumina silicate ceramic (Vitablocs Mark II; Vita Zahnfabrik)		Composite Ceram.X mono M2 (DeTrey Dentsply) Lava Ultimate CAD/CAM, 3M ESPE, St. Paul, MN, USA	Lithium disilicate (Suprinity 1M1 HT; VITA Zahnfabrik)	Peek ceramic fillers (BioHPP; Bredent GmbH)	CAD/CAM PICN block (VITA ENAMIC; VITA Zahnfabrik H. Rauter GmbH & Co. KG, Bern, Switzerland)	Leucite-reinforced ceramic (VITA-PM9; Bad Sackingen, Germany)
Stastically results	Of the 447 restorations, only 6 failures occurred, resulting in a success rate of 98.66%. All of the failures were the result of a partial ceramic fracture. Of the six ceramic fractures, five appeared on peripheral crowns and one on an endocrown. All fractures appeared in the first 24 months, including two in the first month. Log-rank test comparing incidence rates between crowns and endocrowns showed no significant differences (*P* = .08).	48.4% of patients were shown to present occlusal risk factors. 75.8% of restorations were Class 3 endocrowns. 56.6% were performed on molars, 41.4% on premolars and 2.0% on canines. 84.8% were performed in lithium-disilicate glass-ceramic and 12.1% in Polymer-Infiltrated Ceramic Network (PICN) material. The survival and success rates of endocrowns were 99.0% and 89.9% respectively, while the 10-year Kaplan-Meier estimated survival and success rates were 98.8% and 54.9% respectively. Ten failures were detected: periodontal disease (n=3), endocrown debonding (n=2), minor chipping (n=2), caries recurrence (n=2) and major fractures (n=1). Due to the reduced amount of failures, no statistical correlation could be established with clinical parameters.	n.i	n.i	The elastic modulus of the polyetheretherketone framework (4 GPa) veneered with indirect composite resin could dampen the occlusal forces protecting tooth structures better than ceramic materials.	Over the 9-month follow-up period, no pulpal or periradicular pathology was observed on radiographs. Regarding the crown, the marginal fit was excellent, the anatomical form was protected, and no discoloration occurred.	The VITA-PM9 system, a leucite-reinforced glass ceramic, has been increasingly used in a variety of clinical situations due to its satisfactory physical-mechanical and aesthetic properties.
Conclusion	This survival rate study reinforced the use of CAD/CAM full ceramic crowns and endocrowns on molars, showing a much more favorable survival rate for endocrowns.	Endocrowns were shown to constitute a reliable approach to restore severely damaged molars and premolars, even in the presence of extensive coronal tissue loss or occlusal risk factors, such as bruxism or unfavorable occlusal relationships.	Controlled clinical trials should be conducted to achieve a high level of evidence in this field.However, within the limits of this study, the type of restoration in molars of class II will depend on the amount of healthy tooth structure remaining. Whenever we can use a matrix that allows raising the margin predictably, we can perform a DME. In cases with invasion of the connective tissue or bone crest or those with deeper margins, crown lengthening surgery is indicated (whenever periodontally possible), as an attempt to achieve the highest possible long-term success of the restoration.	With this protocol, the occlusal anatomy can be easily adjusted before final sintering, and shade customization and predictable characterization can be performed in a single visit	PEEK could be considered an alternative framework material for endocrown restorations. Further long-term clinical evidence is required to demonstrate the use of this material as a substitute for conventional ceramic or metal ceramic crowns for endodontically treated teeth.	During follow-up, the CAD/CAM PICN block endocrown proved to be a good material for the short- to long-term treatment of a primary tooth. However, more clinical cases and follow-up are required to investigate the long-term on antagonist teeth from long-term wear.	Theendocrown ceramic restoration using the VITA-PM9 system is a feasible and conservative approach for mechanical and aesthetic restoration of nonvital posterior teeth.

Title	Restoration of endodontically treated molars using all ceramic endocrowns.	The endocrown: an alternative approach for restoring extensively damaged molars.	Crown and post-free adhesive restorations for endodontically treated posterior teeth: from direct composite to endocrowns.	Fiber-reinforced resin coating for endocrown preparations: a technical report	Cerec3D endocrowns--two-year clinical examination of CAD/CAM crowns for restoring endodontically treated molars	Endocrowns: a clinical report.	Clinical evaluation of adhesively placed Cerec endo-crowns after 2 years--preliminary results.
Year	2013	2013	2013	2013	2010	2008	1999 *
Journal	Case reports in dentistry	Journal of esthetic and restoratorative dentistry	The European journal of esthetic dentistry	Operative Dentistry	International Journal of Computerized Dentistry	Quintessence International	Journal of Adhesive Dentistry
Author	Carlos R, et al,.	Biacchi G, et al,.	Rocca G and Krejci I	Rocca G, et al,.	Bernhart J, et al	Lander E and Diestschi D	Bindl A and Mörmann W
Aim of study	To present paper two ceramic endocrowns fabricated by different methods are presented as case reports.	To discuss the indication and use of the endocrown to replace single crowns with intraradicular retention, and present a clinical case report on the 3-year clinical follow-up of an endocrown restoration, fabricated from injected lithium disilicate ceramic (IPS e.Max Press/IvoclarVivadent), performed in a mandibular first molar with extensive coronal destruction from fracture.	To show amodern therapeutic approach based entirely on adhesive dentistry. The fabrication of direct and indirectadhesive restorationson endodontically treated teeth (ETT) is illustrated in somerepresentative clinical cases. A new rationale is also presented to help the operatorin choosing the correct adhesive restorationaccording to the tooth cavity configuration and the tooth's esthetic needs	To present a technique that will allow the reinforcement of the cavity of an ETT, as opposed to the restoration.	To evaluate the clinical suitabiliity of Cerec #D endocrowns over a period of two years.	To describes the rationale and clinical guidelines for the placement of endocrowns.	To evaluate the survival rate and the ciinical quality of CAD/CiM endo-crowns after 2 years.
Type of study	Case report	Clinical article	Clinical research	Technical Report	Clinical study	Clinical report	Clinical research
Number of samples	2 Lefts mandibular first molars	Left mandibular first molar	n.i	Right maxillary first molar	n.i	n.i	
Inclusion Criteria	n.i	n.i	n.i	n.i	- Patient at least 18 years old; - good compiance; - good oral hygiene	n.i	Ali patientsparticipated in an individual orai hygiene recall program monitored by adentai hygienist.The patientsWith Cerecendo-crowns thathad a servicetime ofmore than 14months were contacted. 13(4 female, 9 male) Out of 33 atients with 19 computer endo-crowns (4 premoiars, 15 moiars) Were examined. The recall rate was 40%, because the foilowup examination was done within a short period of three months. The Cerecendo-crow treatment inthese cases had beendone by 7 dentists,
Exclusion Criteria	n.i	n.i	n.i	n.i	- bruxism - occlusion disorders - periodontitis - increased risk of caries.	n.i	n.i
Groups Analysed	A 32-year-old female patien A 26-year-old female patient	A 52-year-old man patient	1-Class I, maxillary first molar restored by direct composite resin. 2-Class II (MO), maxillary first molar restored by direct composite resin. 3-Class II (MOD), maxillary second premolar restored by indirect composite resin. 4-Class II (ODP) maxillary first premolar restored by lithium dissilicate endocrown. 5- Class II (MOD) maxillary first molar restored by composite resin endocrown. 6- Class II (MODP)maxillary first premolar restored by composite resin endocrown.	A 32-year-old woman patient	O que devo colocar neste caso? Pois esse estudo foi feito uma análise com vários critérios de avaliação das endocrowns... Percurssão Color Surface Anatomic form Marginal adaptation Marginal discolorations Secundar caries	n.i	n.i

Material	Monolithic solid zirconia block (Metoxit AG, Thayngen, Switzerland); Lithium-disilicate glass ceramic ingots (IPS E.max Press HO. Ivoclar/Vivadent, Schaan/Liechtenstein)	Llithium disilicate-based ceramic (IPS e.Max Press, Ivoclar Vivadent)	(IPS e.max Press, IvoclarVivadent) .	composite resin block (LAVA Ultimate, 3M ESPE AG, Seefeld, German	Alumina silicate ceramic (Vitablocs Mark II; Vita Zahnfabrik)	IPS Empress 2 ceramic (Ivoclar Vivadent)	Ceram Alumina/Spinell (Vita Mark II/Zahnfabrik, Bad Säckingen, Germany)
Stastically results	The 28-month followup of both types of endocrowns showed no esthetic and functional degradation. These results are in agreement with the previous studies [2, 8, 9].	On 3-year follow-up, it was found that endocrown restorations could be made following the development of reinforced ceramics that can be acid etched, that have aggregate strength and esthetics, that bond to the dental structure, and that have developed from broader knowledge of the biomechanical behavior of depulped teeth restored with and without intraradicular posts.	n.i	n.i	The 2 year survival rate of the Cerec r endocrowns was 90%. Two out of 20 endocrowns werw assessed as failure because of fractures. The first fracture was observed after 12 months and the second fracture after 18 months. No recurrent caries was diagnosed. Slight percurssion symptoms were found on three restorations in the first weeks after placement.	The 3-year follow-up radiograph (a) and clinical views (b, c) show the satisfactory behavior of the restorations and their limited impact on marginal tissue health. In addition, one can appreciate the positive influence of adhesion on restoration stability and tissue preservation. The placement of conventional post and core on these teeth would lead to greater weakness and impaired biomechanical behavior.	The service time of the 19 endo-crowns was 14 to 35.5 (x ± SD: 26±6¡ months. One molar endocrown failed after 28 months because of recurrent caries.
Conclusion	Based on current evidence, endocrowns fabricated using CAD/CAM and pressable ceramic technology can be considered as a reliable option for the restoration of moderately mutilated endodontically treated posterior teeth. However,long-term followup and longitudinal clinical studies are needed to ensure their overall success.	Clinical studies haveshown that the endocrown has functional longevity, and has become a promising alternative in the esthetic and functional recovery of endodontically treated molar teeth.	By relying on adhesion, radicular posts are no longer necessary on devitalized molars, and at the present moment it is difficult to decide if posts are necessary on premolarsand front teeth. If yes, they may only be considered in the case of extreme coronal destruction, without having clear scientific evidence on their necessity and exact indication. If used, adhesive posts in a minimally invasive restorative concept do not represent a micromechanically retentive element. They serve much more as a glass fiber reinforcement of a short radicular inlay that searches to increase adhesive surfacewithin the root canal to increase adhesive retention. Finally, it is importante to note that accurate case selection and rigorous execution of adhesive procedures are essential for the accomplishment of this full adhesive strategy.	Adhesive overlays, often called endocrowns, are increasingly used as a restorative alternative to full crowns for nonvital teeth. Their advantages ar minimal invasiveness, simpler preparation, and optimal coronal seal. The risk associated with these restorations is rare but may result in a catastrophic vertical fracture of the tooth-restoration complex, often leading to the extraction of the tooth. The presented clinical technique with FRC reinforcement of the resin-coating layer was developed for use with CAD/CAM composite or ceramic restorations. It may reduce this risk of extensive fractures and thus improve the success rate of this type of restorationon nonvital teeth.	The results show that good esthetic and funcional results similar to those of other restoration types can be achieved with endocrowns and that CAD/CAM-fabricated crowns represent a very promising treatment alternative for endodontically treated molars.	This technique represents a promising and conservative alternative to full crowns for the treatment of posterior nonvital teeth that require long-term protection and stability	For the clinical retention of Cerec endo-crowns, a carefully controlled adhesive technique is essential. Though experience is still limited, the overall clini cal quality of the Cerec endo-crowns examined in this study may be rated as very good. The clinical application of Cerec endo-crowns is a promising and efficient treatment method for crown reconstruction of non-vital molars and premoiars.

CONCLUSÕES

4. CONCLUSÕES

Dentro das limitações deste estudo, pode-se concluir que, o procedimento restauração indireta do tipo onlay, para os preparos mais conservadores, sem caixas proximais e oclusal tiveram melhor desempenho mecânico comparado as onlays converncionais. Além disso, os preparos conservadores apresentaram menores volumes de bolhas e porosidades no cimento resinoso quando comparados aos preparos com as caixas. Em relação ao material cerâmico, tanto no teste de resistência à fratura, quanto nas análises em elementos finitos e análise no microCT, as cerâmicas reforçadas por leucita influenciaram em menor resistência à fratura, menor tensão e menor porosidade e volume de bolhas, respectivamente, o que poderia ser considerado esta técnica clinicamente aceitável.

Das diversas opções restauradoras para dentes tratados endodonticament com ampla destruição coronária, a técnica para Endocrown permite a conservação da dentina e do esmalte periférico, mantendo a estabilidade marginal, a resistência às cargas mastigatórias, com preparos menos invasivos. O procedimento restaurador Endocrown apresenta boas perspectivas clínicas para tratamento de molares despolpados do ponto de vista funcional e estético devido aos resultados dos trabalhos laboratoriais., porém, como observado na revisão sistemática, é necessários mais estudos clínicos randomizados para a confirmação da eficácia e prognóstico desta técnica

REFERÊNCIAS

REFERÊNCIAS* - Introdução e referencial teórico

1. Abo-Hamar SE, Federlin M, Hiller KA, Friedl KH, Schmalz G. Effect of temporary cements on the bond strength of ceramic luted to dentin. Dent Mater 2005 Sep;21(9):794-803. PubMed PMID: 16005507. https://doi.org/10.1016/j.dental.2005.01.015

2. Abou-Madina MM, Özcan M, Abdelaziz KM. Influence of resin cements and aging on the fracture resistance of IPS e.max press posterior crowns. Int J Prosthodont. 2012 Jan-Feb;25(1):33-5. PubMed PMID: 22259793.

3. Ausiello P, Rengo S,Davidson Cl, Watts DC. Stress distributions in adhesively cemented ceramic and resin-composite Class II inlay restoration: a 3D-FEA study.Dent Mater 2004;20:862-72. https://doi.org/10.1016/j.dental.2004.05.001

4. Belli R, Petschelt A, Lohbauer U. Thermal-induced residual stresses affect the fractographic patterns of zirconia-veneer dental prostheses. J Mech Behav Biomed Mater 2013; 21:167-77. https://doi.org/10.1016/j.jmbbm.2012.10.022

5. Bindl A, Mörmann WH. Clinical evaluation of adhesively placed Cerec endo-crowns after 2 years — preliminar results. JAdhesDent. 1999;1(3):255–65.

6. Bindl A, Richter B, Mormann WH. Survival of ceramic computer-aided design/manufacturing crowns bonded to preparations with reduced macroretention geometry. Int J Prosthodont 2005; 18(3):219-24.

7. Chang CY KJ, Lin YS, Chang YH. Fracture resistance and failure modes of CEREC endocrowns and conventional post and core-supported CEREC

crowns. J Dent Sci 2009;4(3):110-117.
https://doi.org/10.1016/S1991-7902(09)60016-7

8. Clavijo, VGR. et al. Endocrown Crowns - An option for devitalized posterior teeth Intern. J of Braz. Dent. 2007;3(3):246-252.

9. Corazza PH, de Castro HL, Feitosa SA, Kimpara ET, Della Bona A. Influence of CAD-CAM diamond bur deterioration on surface roughness and maximum failure load of Y-TZP-based restorations. American journal of dentistry. 2015;28:95-9.

10. da Costa JB, Pelogia F, Hagedorn B, Ferracane JL. Evaluation of different methods of optical impression making on the marginal gap of onlays created with CEREC 3D. Oper Dent. 2010 May-Jun;35(3):324-9.
https://doi.org/10.2341/09-178-L

11. El-Damanhoury HM, Haj-Ali RN, Platt JA. Fracture resistance and microleakage of endocrowns utilizing three CAD-CAM blocks. Operative Dentistry 2015;40(2):201-10.
https://doi.org/10.2341/13-143-L

12. Giannini M, Soares CJ, de Carvalho RM. Ultimate tensile strength of tooth structures. Dent Mater.2004;20(4):322-9.
https://doi.org/10.1016/S0109-5641(03)00110-6

13. Khan KS, Riet G, Glanville J, Sowden AJ, Kleijnen J. Undertaking Systematic reviews of research on effectiveness. CRD report number 4. 2nd ed. York: York Publishing Services; 2001.

14. Krance A, DuVall N, Brewster J, Roberts H. Fracture resistance of all-ceramic crowns based on different preparation designs for restoring endodontically treated molars. J Esthet Restor Dent. 2018 Aug 25.

15. Krasanaki ME, Pelekanos S,Andreiotelli M, Koutayas SO, Eliades G. X-ray microtomographic evaluation of the influence of two preparation types on marginal fit of CAD/CAM alumina copings: a pilot study. The International Journal of Prosthodontics 2012;25:170-2.

16. Lazari PC, Oliveira RC, Anchieta RB, Almeida EO, Freitas Junior AC, Kina S, et al. Stress distribution on dentin-cement-post interface varying root canal and glass fiber post diameters. A three-dimensional finite elemento analysis based on micro-CT data. Journal of Applied Oral Science 2013;21(6):511-7. https://doi.org/10.1590/1679-775720130203

17. Lin CL, Chang YH, Liu PR. Multi-factorial analysis of a cusp-replacing adhesive premolar restoration: A finite element study. J Dent. 2008 Mar;36(3):194-203. https://doi.org/10.1016/j.jdent.2007.11.016

18. Lin TM, Liu PR, Ramp LC, Essig ME, Givan DA, Pan YH. Fracture resistance and marginal discrepancy of porcelain laminate veneers influenced by preparation design and restorative material in vitro. J Dent. 2012 Mar;40(3):202-9. https://doi.org/10.1016/j.jdent.2011.12.008

19. Liu Y, Gao S, Han Y, Yang Q, Arola D, Zhang D. Bearing capacity of ceramic crowns before and after cyclic loading: An in vitro study. J Mech Behav Biomed Mater. 2018 Nov;87:197-204. https://doi.org/10.1016/j.jmbbm.2018.07.036

20. Mondelli J, Steagall L, Ishikiriama A, de Lima Navarro MF, Soares FB. Fracture strength of human teeth with cavity preparations. J Prosthet Dent.1980;43(4):419-22.
https://doi.org/10.1016/0022-3913(80)90213-9

21. Mondelli J, Sene F, Ramos RP, Benetti AR. Tooth structure and fracture strength of cavities. Braz Dent J. 2007;18(2):134-8.
https://doi.org/10.1590/S0103-64402007000200009

22. Olkin I. Statistical and theoretical considerations in meta-analysis. J Clin Epidemiol. 1995; 48:133-46.
https://doi.org/10.1016/0895-4356(94)00136-E

23. Øilo M, Gjerdet NR. Fractographic analyses of all-ceramic crowns: a study of clinically fractured crowns. Dent Mater. 2013 Jun;29(6):e78-84.
https://doi.org/10.1016/j.dental.2013.03.018

24. Pagani C, Miranda CB, Bottino MC. Relative fracture toughness of differents dental ceramics. J Appl Oral Sci.2003 Mar;11(1):69-75.
https://doi.org/10.1590/S1678-77572003000100012

25. Palin WM, Fleming GJ, Nathwani H, Burke FJ, Randall RC. In vitro cuspal deflection and microleakage of maxillary premolars restored with novel low-shrink dental composites. Dent Mater. 2005;21:324-35.
https://doi.org/10.1016/j.dental.2004.05.005

26. Rocca GT, Saratti CM, Poncet A, Feilzer AJ, Krejci I. The influence of FRCs reinforcement on marginal adaptation of CAD/CAM composite resin endocrowns after simulated fatigue loading. Odontology. 2016 May;104(2):220-32.
https://doi.org/10.1007/s10266-015-0202-9

27. Rodrigues FP, Li J, Silikas N, Ballester RY, Watts DC. Sequential software processing of micro-XCT dental-images for 3D-FE analysis. Dent Mater. 2009 Jun;25(6):e47-55.
https://doi.org/10.1016/j.dental.2009.02.007

28. Roscoe MG, Noritomi PY, Novais VR, Soares CJ. Influence of alveolar bone loss, post type, and ferrule presence on the biomechanical behavior of endodontically treated maxillary canines: strain measurement and stress distribution. The Journal of Prosthetic Dentistry 2013;110(2):116-26.
https://doi.org/10.1016/S0022-3913(13)60350-9

29. Schmitter M, Mueller D, Rues S. Chipping behaviour of all-ceramic crowns with zirconia framework and CAD/CAM manufactured veneer. J Dent. 2012 Feb;40(2):154-62.
https://doi.org/10.1016/j.jdent.2011.12.007

30. Seo D, Yi Y, Roh B. The effect of preparation designs on the marginal and internal gaps in Cerec3 partial ceramic crowns. J Dent. 2009 May;37(5):374-82.
https://doi.org/10.1016/j.jdent.2009.01.008

31. Sevimli G, Cengiz S, Oruc S. Endocrowns: review. J Istanbul Univ Fac Dent 2015;49(2):57–63.
https://doi.org/10.17096/jiufd.71363

32. Silva LHD, Lima E, Miranda RBP, Favero SS, Lohbauer U, Cesar PF. Dental ceramics: a review of new materials and processing methods. Dent Mater 2017; 31:133-46.
https://doi.org/10.1590/1807-3107bor-2017.vol31.0058

33. Soares CJ, Castro CG, Santos Filho PC, Soares PV, Magalhaes D, Martins LR. Two-dimensional FEA of dowels of different compositions and external surface configurations. J Prosthodont. 2009 Jan;18(1):36-42. https://doi.org/10.1111/j.1532-849X.2008.00367.x

34. Soares CJ, Martins LR, Fonseca RB, Correr-Sobrinho L, Fernandes Neto AJ. Influence of cavity preparation design on fracture resistance of posterior Leucite-reinforced ceramic restorations. J Prosthet Dent. 2006;95(6):421-9. https://doi.org/10.1016/j.prosdent.2006.03.022

35. 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 Aug;15(4):341-50.

36. Soares PV, Santos-Filho PC, Gomide HA, Araujo CA, Martins LR, Soares CJ. Influence of restorative technique on the biomechanical behavior of endodontically treated maxillary premolars. Part II: strain measurement and stress distribution. J Prosthet Dent. 2008b Feb;99(2):114-22. https://doi.org/10.1016/S0022-3913(08)60027-X

37. Straus SE, Richardson WS, Glasziou P, Haynes RB. Evidence-based medicine: how to practice and teach EBM. 3rd ed. Philadelphia: Elsevier Churchill Livingstone; 2005.

38. Tekçe N, Pala K, Demirci M, Tuncer S. Influence of different composite materials and cavity preparation designs on the fracture resistance of mesio-occluso-distal inlay restoration. Dent Mater J. 2016;35(3):523-31. https://doi.org/10.4012/dmj.2015-287

39. Valdivia ADCM, Rodrigues MP, Bicalho AA, Van Meerbeek B, Sloten JV, Pessoa RSE, Soares CJ. Biomechanical Effect of Ferrule on Incisors Restored

with a Fiberglass Post and Lithium-Disilicate Ceramic Crown after Thermal Cycling and Fatigue Loading. J Adhes Dent. 2018;20(2):133-142.

40. Walton TR. An up to 15-year longitudinal study of 515 metal-ceramic FPDs: Part 2. Modes of failure and influence of various clinical characteristics. Int J Prosthodont 2003; 16(2):177-82.

41. Wu XP, Li DS, Zhang J, Ma X, Zhao K, Zhang XP. Effects of different die materials on fracture and failure behaviors of all-ceramic crowns. Zhonghua Kou Qiang Yi Xue Za Zhi. 2009 Aug;44(8):483-7.

42. Zhu Z, Dong XY, He S, Pan X, Tang L. Effect of Post Placement on the Restoration of Endodontically Treated Teeth: A Systematic Review. The International Journal of Prosthodontics 2015;28(5):475-83. https://doi.org/10.11607/ijp.4120

ANEXOS

ANEXOS

UNIVERSIDADE FEDERAL DE UBERLÂNDIA/MG

Comitê de Ética em Pesquisa

PARECER CONSUBSTANCIADO DO CEP

DADOS DO PROJETO DE PESQUISA

Título da Pesquisa: Efeito da morfologia do preparo cavitário para onlays na resistência à fratura, adaptação marginal e comportamento biomecânico.

Pesquisador: Célio Jesus do Prado

Área Temática:

Versão: 3

CAAE: 10157913.6.0000.5152

Instituição Proponente: Universidade Federal de Uberlândia/ UFU/ MG

Patrocinador Principal: Financiamento Próprio

DADOS DO PARECER

Número do Parecer: 307.608

Data da Relatoria: 14/06/2013

Apresentação do Projeto:

Segundo apresenta o protocolo:

As cerâmicas são materiais utilizados na odontologia há tempos mas ainda há necessidade de estudos sobre a sua longevidade em determinadas situações. É sabido que a adaptação marginal é um dos principais fatores responsáveis pela longevidade das restaurações fixas, pois a presença de fendas marginais com grande dimensão acarretará maior exposição do agente cimentante no meio oral e sua dissolução. Esta consequente micro infiltração levará ao acúmulo de biofilme nesta região resultando em inflamação gengival, cárie e lesões pulpares (FELTON et al11, 1991). A dimensão da desadaptação marginal das restaurações fixas é dependente dos vários passos envolvidos nos processos clínicos e laboratoriais podendo ser traduzida como uma somatória de distorções. A resistência à fratura de um dente está diretamente relacionada à quantidade de estrutura sadia remanescente que o mesmo possui. A remoção das cristas marginais, o aumento na largura do istmo e o aumento na profundidade do preparo no sentido ocluso-gengival são as principais razões para a diminuição dessa resistência.

Objetivo da Pesquisa:

Avaliar a influência dos materiais restauradores e do preparo de caixas proximais e oclusais em restaurações do tipo onlay na resistência à fratura, adaptação marginal e comportamento

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