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Faculdade de Odontologia
Programa de Pós-Graduação em Odontologia

Tese

Comportamento biomecânico de dentes tratados endodônticamente reabilitados com próteses fixas múltiplas e unitárias

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Pelotas, 2019

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Orientador: Prof. Dr. César Dalmolin Bergoli

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Tese apresentada, como requisito parcial, para obtenção do grau de Doutor em Clínica Odontológica, Programa de Pós-Graduação em Odontologia, Faculdade de Odontologia de Pelotas, Universidade Federal de Pelotas.

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“No fim das contas o que vale é a jornada e não o destino.”

(Autor desconhecido)

Notas Preliminares

A presente tese foi redigida segundo o Manual de Normas para trabalhos acadêmicos da UFPel, adotando o nível de descrição em artigos. Disponível no endereço eletrônico: http://sisbi.ufpel.edu.br/arquivos/PDF/Manual_Normas_UFPel_trabalhos_acad%C3%AAmicos.pdf

O projeto de pesquisa referente a esta Tese, foi aprovado em 19 de dezembro de 2016, pela Banca Examinadora composta pelos Professores Doutores César Dalmolin Bergoli, Rafael Ratto de Moraes, Noéli Boscato e Tatiana Pereira-Cenci (suplente).

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Resumo

O Objetivo do presente trabalho foi avaliar o comportamento biomecânico de dentes tratados endodônticamente restaurados com diferentes tipos de retentores intrarradiculares. De forma que os retentores utilizados foram testados em diferentes modelos protéticos (próteses fixas unitárias e múltiplas de três elementos) variando seu material de confecção, sendo pino de fibra de vidro e núcleo metálico fundido. O trabalho foi dividido em três estudos: (1) um estudo *in vitro* que avaliou a influência do cimento e da presença ou ausência de férula, bem como a utilização resina composta direta sem o emprego de um retentor intrarradicular na reabilitação de dentes tratados endodônticamente; (2) uma revisão sistemática de literatura e meta-análise de um braço com o objetivo de averiguar as propriedades de resistência à fratura de materiais (zircônia, di-silicato de lítio e metalo-cerâmica) utilizados na fabricação de próteses fixas de três elementos; e (3) um estudo *in vitro* que determinou a resistência a fratura de próteses de três elementos, avaliando a influência de diferentes retentores intrarradiculares (pino de fibra de vidro e núcleo metálico fundido) e seu arranjo na prótese. O primeiro e terceiro estudo passaram por testes de sobrevivência seguidos pelo teste de fratura, sendo utilizado um nível de significância de 5% na análise estatística dos dados quantitativos. Já o estudo 2 foi descrito com base no PRISMA, buscando responder qual é a força de resistência a fratura dos diferentes materiais usados nas próteses de três elementos. Os resultados da meta análise mostraram valores globais de resistência à fratura maiores para as próteses metalo-cerâmicas. Já os resultados dos estudos *in vitro* mostraram que em próteses unitárias o material do retentor e a altura do remanescente influenciam diretamente nos valores de resistência à fratura, e que em próteses fixas de três elementos os não foram encontradas diferenças estatisticamente significativas independentemente da posição ou material do retentor utilizado. Como conclusão deste trabalho, constatou-se que que a reabilitação de dentes tratados endodônticamente pode ser realizada de diferentes formas mantendo as taxas das sucesso, de modo que a utilização de pinos de fibra de vidro e núcleos metálicos fundidos pode ser feita de forma satisfatória independentemente do tipo de espaço a ser reabilitado. E que os materiais disponíveis para próteses de três elementos, apresentam valores globais de caga para fratura satisfatórios.

Palavras chave: Retentores intrarradiculares; prótese fixa; cerâmica; Pino de fibra; Núcleo metálico

BRONDANI, Lucas Pradebon. **Biomechanical behavior of endodontically treated teeth rehabilitated with multiple and unitary fixed dental prostheses.** 2019. 107p. Thesis (PhD in Dentistry). Graduate Program in Dentistry. Federal University of Pelotas, Pelotas, 2019.

Abstract

The aim of the present study was to evaluate the biomechanical behavior of endodontically teeth treated with different of intracanal retainers. Thus, the retainers used were tested in different prosthetic designs (single and three-unit fixed dental prostheses) varying the material used, glass fiber post and cast post and core. The research was divided into three studies: (1) an in vitro study that evaluated the influence of cement and the presence or absence of ferule, as well as the use of direct composite resin without the use of an intracanal retainer in the rehabilitation of endodontically treated teeth; (2) a systematic literature review and an one-arm meta-analysis with the purpose of investigating the fracture resistance properties of materials (zirconia, lithium disilicate and metal ceramics) used in the manufacture of three-element fixed dental prostheses (FDP); and (3) an in vitro study that determined the fracture resistance of three-element FDP, assessing the influence of different intracanal retainers (glass fiber post and cast post and core) and their arrangement on the prosthesis. The first and third studies underwent survival tests followed by a fracture test, and a significance level of 5% was used in the statistical analysis of quantitative data. The study 2 was described based on PRISMA, seeking to answer which is the fracture strength of the different materials used for three-unit FDP. The meta-analysis results showed higher overall fracture strength values for the metal ceramic prostheses. The results of the in vitro studies showed that in unitary prostheses, the retainer material and the height of the remaining tooth structure directly influence the load to fracture values, and that in three-unit FDP no statistically significant differences were found regardless of position or material used for the retainer. In conclusion, it was found that the rehabilitation of endodontically treated teeth can be performed in different ways maintaining the success rates, also, the use of glass fiber post and cast post and core can be satisfactorily performed independently of the type of space to be rehabilitated. Additionally, the materials available for three-unit fixed dental prostheses present satisfactory overall fracture strength values.

Keywords: Intracanal retainers; fixed dental prostheses; ceramics; Glass fiber post; Cast post and core

Sumário

1. Introdução

As próteses parciais fixas (PPF) totalmente cerâmicas são uma alternativa protética viável comparadas as próteses metalo-cerâmicas (SAILER et al., 2015). Suas indicações ocorrem principalmente quando há, além de resistência, grande demanda estética do paciente, como em casos onde o envolvimento da região de incisivos até pré-molares está presente (CHRISTENSEN, 2011). Além disso, esse material pode ser utilizado como infraestrutura, associado a aplicação de cerâmica de cobertura, ou no formato monolítico podendo sua confecção se dar através da técnica da cera perdida ou pelo método CAD-CAM

Apesar do avanço dos materiais restauradores odontológicos, estudos clínicos têm observado que próteses parciais fixas apresentam consideráveis índices de falhas após intervalos de tempo de 5 e 10 anos (KERN, SASSE, WOLFART,2012; PIEGER, SALMAN, BIDRA, 2014, SOLA-RUIZ et al., 2013; PJETURSSON, et al., 2015), sendo um dos principais motivos relacionados a questões mecânicas da prótese (SHULTIES, et al., 2013).

Nos casos onde é indicada a confecção de próteses parciais fixas, é muito comum que os dentes pilares estejam tratados endodônticamente e necessitem da confecção de algum tipo de retentor intrarradicular (KERN, SASSE, WOLFART,2012; PIEGER, SALMAN, BIDRA, 2014; SOLA-RUIZ, et al 2013; PJETURSSON, et al 2015; FERREIRA, et al 1981). Como opção, os retentores a base de fibra de vidro possuem como vantagem a facilidade da técnica e módulo de elasticidade similar ao da dentina (LAMICHHANE et al., 2014), o que faz com que as forças recebidas sejam dissipadas de maneira uniforme pela raiz do remanescente. Os núcleos metálicos fundidos são outra opção restauradora muito utilizada, apresentando resistência mecânica superior aos pinos de fibra. No entanto, o alto módulo de elasticidade desse retentor faz com que as forças recebidas não sejam dissipadas de maneira homogênea, concentrando altos valores de tensão na raiz e elevando a chance de fraturas catastróficas do remanescente. Ademais, alguns autores (KRASTL et al, 2014) tem abordado a possibilidade de retenção intrarradicular com resina direta sem a utilização de um retentor.

Ainda, alguns estudos têm mostrado que tanto núcleo metálico fundido quanto pino de fibra não exercem influência sobre as taxas de sobrevivência de dentes restaurados com próteses fixas unitárias (SARKIS-ONOFRE, et al 2014). No entanto, existe uma lacuna grande na literatura, tanto clínica como laboratorial acerca do comportamento de diferentes retentores na distribuição de tensões e nas taxas de sobrevivência de dentes restaurados com próteses parciais fixas de três ou mais elementos. O conhecimento desse comportamento é de grande importância no dia-a-dia clínico, uma vez que a distribuição de tensão nessas próteses é muito diferente dos elementos unitários.

Materiais odontológicos tendem a falhar por fadiga, ou seja, quando repetidas forças estimulam a propagação de defeitos microscópicos existentes no interior do material, levando a sua fratura (WISKOTT, et al. 1995). Para reproduzir essa situação e conseguir tentar predizer a confiabilidade de algum material ou técnica restauradora, a utilização de testes de envelhecimento através de ciclagem dinâmicas é considerada uma ótima alternativa previamente aos testes de fratura (ANUSAVICE et al., 2008). Além disso, a utilização de testes não destrutivos, como a análise pelo método de elementos finitos, associados a testes laboratoriais, permite uma melhor compreensão dos fenômenos que ocorrem e um melhor entendimento do comportamento do sistema testado (SOARES et al., 2008; VERSLUIS et al., 2006). Tendo isso em vista, o teste pelo método de análise por elementos finitos propicia uma melhor compreensão da distribuição das tensões ao longo de uma interface ou de um material, permitindo verificar com mais precisão o comportamento do sistema (JIAN et al., 2019).

Dessa forma, este estudo objetiva avaliar o comportamento biomecânico de dentes tratados endodônticamente restaurados com diferentes tipos de retentores intrarradiculares utilizados em reabilitações protéticas fixas unitárias e múltiplas de três elementos.

2. Projeto de pesquisa

Introdução

As próteses parciais fixas (PPF) totalmente cerâmicas já são uma alternativa protética viável comparadas as próteses metalo-cerâmicas (SAILER et al., 2015). Suas indicações ocorrem principalmente quando há, além de resistência, grande demanda estética do paciente, como em casos onde o envolvimento de caninos e pré-molares está presente (CHRISTENSEN, 2011). Além disso, esse material pode ser utilizado como infraestrutura, associado a aplicação de cerâmica de cobertura, ou no formato monolítico podendo sua confecção se dar através da técnica da cera perdida ou pelo método *CAD-CAM* (DENRY, HOLLWAY, 2004).

Apesar do avanço dos materiais restauradores odontológicos, estudos clínicos têm observado que próteses parciais fixas apresentam consideráveis índices de falhas após intervalos de tempo de 5 e 10 anos (KERN, SASSE, WOLFART,2012; PIEGER, SALMAN, BIDRA, 2014, SOLA-RUIZ et al., 2013; PJETURSSON, et al., 2015), sendo um dos principais motivos relacionados a questões mecânicas da prótese.

Nos casos onde é indicada a confecção de próteses parciais fixas, é muito comum que os dentes pilares estejam tratados endodonticamente e necessitem da confecção de algum tipo de retentor intrarradicular (KERN, SASSE, WOLFART,2012; PIEGER, SALMAN, BIDRA, 2014; SOLA-RUIZ, et al 2013; PJETURSSON, et al 2015; FERREIRA, et al 1981). Como opção, os retentores a base de fibra de vidro possuem como vantagem a facilidade da técnica e módulo de elasticidade similar ao da dentina, o que faz com que as forças recebidas sejam dissipadas de maneira uniforme pela raiz do remanescente. Os núcleos metálicos fundidos são outra opção restauradora muito utilizada, apresentando resistência mecânica superior aos pinos de fibra. No entanto, o alto módulo de elasticidade desse retentor faz com que as forças recebidas não sejam dissipadas de maneira homogênea, concentrando altos valores de tensão na raiz e elevando a chance de fraturas catastróficas do remanescente.

Alguns estudos clínicos têm mostrado que diferentes tipos de retentores (núcleo metálico fundido e pino de fibra) não exercem influência sobre as taxas de sobrevivência de dentes restaurados com próteses fixas unitárias (SARKIS-ONOFRE, et al 2014). No entanto, existe uma lacuna grande na literatura, tanto clínica como laboratorial, sobre a influência de diferentes retentores na distribuição de tensões e nas taxas de sobrevivência de dentes restaurados com próteses parciais fixas de três ou mais elementos. Essa dúvida é extremamente pertinente, uma vez que a distribuição de tensão nessas próteses é muito diferente dos elementos unitários, principalmente se essas próteses envolverem dentes que apresentam relação direta com os movimentos de desoclusão e lateralidade.

É de conhecimento que os materiais odontológicos falham por fadiga, ou seja, quando repetidas forças estimulam a propagação de defeitos microscópicos existentes no interior do material, levando a sua fratura catastrófica (WISKOTT, et al. 1995). Para reproduzir essa situação e conseguir predizer a confiabilidade de algum material ou técnica restauradora, a utilização de testes de fadiga dinâmica é considerada uma ótima alternativa. Além disso, a utilização de testes não destrutivos, como a análise pelo método de elementos finitos, associados a testes laboratoriais, permite uma melhor compreensão dos fenômenos que ocorrem e um melhor entendimento do comportamento do sistema testado (SOARES et al., 2008; VERSLUIS et al., 2006). O teste pelo método de elementos finitos propicia uma melhor compreensão da distribuição das tensões ao longo de uma interface ou de um material, permitindo verificar com mais precisão o comportamento do sistema (FARAH et al., 1973).

Dessa forma, este estudo objetiva avaliar o comportamento biomecânico de dentes tratados endodônticamente restaurados com próteses parciais fixas de três elementos com diferentes retentores intrarradiculares nos dentes pilares. A hipótese a ser testada é de que tanto o material da prótese quanto o retentor não afetarão os resultados.

Objetivos

Objetivo geral

Avaliar o comportamento biomecânico de próteses parciais fixas metalo-cerâmicas e a base de di-silicato de lítio, variando o material do retentor intrarradicular nos dentes pilares.

Objetivos específicos

Avaliar a taxa de sobrevivência de próteses parciais fixas metalo-cerâmicas e a base de di-silicato de lítio, com diferentes retentores intrarradiculares nos dentes pilares.

Avaliar os valores de carga para fratura de próteses parciais fixas metalo-cerâmicas e a base de di-silicato de lítio, com diferentes retentores intraradiculares nos dentes pilares.

Avaliar a distribuição de tensão, pelo método de elementos finitos, de próteses parciais fixas metalo-cerâmicas e a base de di-silicato de lítio, com diferentes retentores intraradiculares nos dentes pilares.

Hipótese

A Hipótese nula a ser testada é a de que não haverá diferença no comportamento biomecânico dos diferentes tipos de próteses parciais fixas.

Artigos propostos

Serão propostos inicialmente, como fruto da tese, dois artigos científicos:

Artigo 1: Avaliação da resistência à fratura e distribuição de tensão de próteses parciais fixas metalo-cerâmicas e metal-free de três elementos utilizando diferentes retentores nos dentes pilares.

Artigo 2: Avaliação da distribuição de tensões em próteses parciais fixas à base de di-silicato de lítio com cinco elementos utilizando diferentes tipos de retentores.

Metodologias

4.1 Avaliação da resistência à fratura e distribuição de tensão de próteses parciais fixas metalo-cerâmicas e metal-free de três elementos utilizando diferentes retentores nos dentes pilares.

Cálculo amostral

A realização do cálculo amostral se deu tomando por parâmetro os valores obtidos na literatura (TAUFALL, et al 2016). Então, para um teste com poder de 95% e um nível de significância de 5% adotou-se o desvio padrão de 278 N sendo considerada estatisticamente significativa uma diferença de 300 N entre os grupos. Assim serão necessários 9 espécimes para cada grupo a ser avaliado.

Seleção e adequação da amostra

Para a realização deste estudo, serão selecionados 144 dentes bovinos (N=144) unirradiculares que serão limpos com lâminas de bisturi nº 11, e analisados por uma lupa com aumento de 4x (EyeMag® Pro, Carl Zeiss do Brasil Ltda, São Paulo, Brasil), para detecção de alguma fratura/fissura ou defeito de forma que possa comprometer o estudo. Os dentes serão armazenados por 2 horas em clorexidine 1,23% para desinfecção e armazenados em ambiente úmido, sob refrigeração (água destilada a 4°C), até a utilização no estudo.

A porção coronária dos dentes será seccionada de forma perpendicular ao longo eixo do dente, em plano reto, com ponta diamantada nº 3216 (KG Sorensen®, Medical Burs Ind. e Com. de Pontas e Brocas Cirúrgicas Ltda, Cotia - SP - Brasil) em alta rotação sob refrigeração de spray ar/água. Metade dos dentes será seccionado em 15mm de comprimento, de acordo com o tamanho médio de raízes de caninos inferiores, e a outra metade será seccionada em 13mm de comprimento, de acordo com o tamanho média de primeiros pré-molares inferiores. Os comprimentos estipulados para as raízes terão como objetivo simular espécimes sem remanescente coronário.

Para a padronização da amostra o diâmetro da porção coronária do conduto será utilizada como um fator de inclusão. Para isso o diâmetro mésio-distal e vestíbulo-lingual do canal radicular será medido com um paquímetro digital (Black Jack, Extra Power do Brasil Imp. Exp. LTDA) e se um dos diâmetros ultrapassar o diâmetro estimado dos futuros retentores nessa região (Ø= 2mm, correspondente ao diâmetro do pino de fibra de vidro White Post DC #3, FGM, Joinvile, SC, Brasil) o espécime será descartado e substituído por outro que preencha este requisito. Aferições dos diâmetros vestíbulo-lingual e mésio-distal das raízes também serão realizados para garantir que esses valores sejam correspondentes as médias dos diâmetros de caninos e primeiros pré-molares humanos (FERREIRA, et al 1981). Será considerada uma variação de 1mm para mais ou para menos desses valores.

Tratamento endodôntico, simulação do ligamento periodontal e embutimento

Após a seleção, todos os espécimes terão seus condutos instrumentados mecanicamente com instrumentos de NiTi (Dentsply Maillefer, Suíça) associados a irrigação com hipoclorito de sódio 2.5% durante o preparo endodôntico pela técnica coroa ápice. Os canais radiculares serão secos com pontas de papel absorvente (Dentsply Maillefer, Suíça), obturados com cone principal da 2ª série e cones de guta-percha acessórios (Dentsply Maillefer, Suíça) e cimento obturador a base de hidróxido de cálcio (Sealer 26, Dentsply Maillefer, Suiça), por meio da técnica de condensação lateral.
Para a simulação do ligamento cera 7(Lysanda, São Paulo, Brasil) será liquefeita em uma plastificadora (Polidora e plastificadora de godiva VH Essence Dental Araraquara, São Paulo) a temperatura de 70º. Após essa etapa as raízes serão individualmente fixadas a um delineador, de forma que o conjunto fique o mais paralelo possível ao eixo y, e serão inseridos no interior da plastificadora até 3mm da porção mais coronária. A espessura de cera aplicada ao redor da raiz será ferida com uso de paquímetro digital, até atingirmos a espessura de 0.3mm em todas as faces (Wandscher, et al. 2014). Após a aplicação da cera, as raízes serão inseridas no interior de matrizes plásticas e resina acrílica autopolimerizável será vertida (VIPI, Flash, VIPI, Pirassununga, SP, Brasil) até a região da aplicação da cera. Para garantir que os dentes estejam perfeitamente paralelos ao eixo vertical e perfeitamente paralelos entre si, o dente será fixado a um paralelômetro e com o auxílio desse será inserido no interior da matriz previamente citada. Dois paralelômetros serão utilizadas concomitantemente para que seja feito o embutimento da raiz correspondente ao canino e ao

segundo pré-molar. A distância entre a face mesial da raiz correspondente ao canino e a face distal da raiz correspondente ao segundo pré-molar será de aproximadamente 23mm, que é média das medidas mésiodistais de humanos adultos descrita na literatura (Fernandes, et al 2013), bem como o diâmetro da área de pôntico.

Após a polimerização da resina, os dentes e a cera serão removidos do espaço criado no acrílico, formando assim um “falso alvéolo”. Após essa etapa será aplicado adesivo de poliéter no interior do espaço criado, o material elastomérico (Impregum F, 3M-Espe, Seefeld, Germany) será inserido nesse espaço e o dente reposicionado. Após a presa do material os excessos do elastômero serão removidos com lâmina de bisturi, finalizando assim a simulação do ligamento periodontal.

Randomização dos espécimes e delineamento experimental

Após o embutimento os espécimes serão alocados randomicamente em 8 grupos experimentais (tabela 1). Para isso os corpos de prova serão numerados de 1 a 80 e 8 sequências numéricas aleatórias de 10 números serão geradas pelo programa de computador Random Allocator.

Tabela 1: Delineamento experimental do estudo.

<table>
<tr><th rowspan="2">Material da Prótese Parcial Fixa</th><th colspan="3">Dentes Pilares</th></tr>
<tr><th>Canino</th><th>Segundo Pré-Molar</th><th>Grupos</th></tr>
<tr><td rowspan="4">Metalo-cerâmica</td><td>Pino de Fibra</td><td>Pino de Fibra</td><td>Gr 1</td></tr>
<tr><td>Pino de Fibra</td><td>Núcleo Metálico Fundido</td><td>Gr 2</td></tr>
<tr><td>Núcleo Metálico Fundido</td><td>Pino de Fibra</td><td>Gr 3</td></tr>
<tr><td>Núcleo Metálico Fundido</td><td>Núcleo Metálico Fundido</td><td>Gr 4</td></tr>
<tr><td rowspan="2">Di-silicato de Lítio</td><td>Pino de Fibra</td><td>Pino de Fibra</td><td>Gr 5</td></tr>
<tr><td>Pino de Fibra</td><td>Núcleo Metálico Fundido</td><td>Gr 6</td></tr>
</table>

	Núcleo Metálico Fundido	Pino de Fibra	Gr 7
	Núcleo Metálico Fundido	Núcleo Metálico Fundido	Gr 8

Preparo dos condutos

Todos os espécimes serão preparados com a broca nº 3 do sistema de pinos de fibra White Post DC (FGM, Joinville, SC, Brasil) acoplada a contra angulo em baixa rotação. A profundidade de desobturação respeitará o comprimento de 2/3 do comprimento do conduto, mantendo sempre, no mínimo, 3 mm de selamento apical.

Confecção das estratégias restauradoras

Núcleo metálico fundido em liga de Níquel/Cromo

O interior radicular de cada raiz será lubrificado e a resina acrílica (Duralay, Reliance Dental, USA) aplicada com auxílio de um pincel fino e pinos plásticos pré-fabricados (Pinjet, Ângelus, Londrina, Brasil), a fim de moldar toda a extensão do preparo realizado. O núcleo coronário será padronizado com a utilização de matrizes plásticas simulando um munhão compatível ao de caninos e segundos pré-molares. Os padrões em resina serão fundidos com ligas de níquel-cromo, seguindo as recomendações do fabricante, sendo esse procedimento realizado na própria instituição executora do estudo.

Os núcleos metálicos fundidos serão avaliados quanto à adaptação com carbono líquido e como tratamento de superfície o pino será limpo com álcool isopropílico e sua porção radicular jateada com partículas de óxido de alumínio (110µm, pressão: 2.8 bars, 10mm de distância por 15 segundos). Para a cimentação será realizado o condicionamento da dentina radicular e/ou coronária com ácido fosfórico a 37% por 15s, limpeza com água em abundância durante 10 s e após certificar-se que todo o ácido foi retirado procederá a secagem do conduto com cones de papel #80 (Dentsply Indústria e Comérco Ltda, Petrópolis, Brasil). Após o condicionamento um sistema adesivo autopolimerizável de três passos será aplicado de acordo com o fabricante. A seguir um cimento resinoso de cura dual será manipulado e inserido no interior do conduto com auxílio de pontas misturadoras/aplicadoras. Por fim os núcleos serão posicionados, o excesso de cimento removido e a foto-ativação realizada por 40s em cada face. Todos procedimentos adesivos serão realizados por apenas um operador previamente treinado.

Pinos de Fibra Pré-Fabricados

Previamente a cimentação todos os pinos serão seccionados com pontas diamantadas em alta rotação de acordo com o comprimento do preparo e padronizando em 4 mm a altura do pino na porção coronária. Após essa etapa estes serão limpos com álcool etílico 70% e silanizados com o agente de união silano. Para a cimentação os procedimentos serão semelhantes ao descrito anteriormente quanto ao condicionamento, limpeza, aplicação do sistema adesivo e cimento resinoso.

Após a cimentação dos pinos de fibra, a qual será feita seguindo mesma metodologia descrita para os NMF, será feita a reconstrução da porção coronária com resina composta micro híbrida, utilizando para isso as mesmas matrizes plásticas utilizadas nos grupos anteriores. Todos procedimentos adesivos serão realizados por apenas um operador previamente treinado.

Preparo coronário

Os núcleos, que foram previamente confeccionados com o auxílio de matrizes plásticas, terão seus preparos refinados para que as faces axiais apresentem inclinações adequadas para propiciar ao preparo características de retenção e estabilidade. Para isso, a inclinação do terço cervical deve ficar entre 2 a 5° em direção incisal e a inclinação nas paredes axiais no terço incisal deve ser de 5 a 10° (PEGORARO, 2013). Dessa forma, os preparos coronários serão feitos com as pontas 4138F e 4138FF e 3118 F e 3118FF (KG Sorensen®, Medical Burs Ind. e Com. de Pontas e Brocas Cirúrgicas Ltda, Cotia - SP - Brasil). A espessura de desgaste dos preparos será padronizada em 1,2 mm em todas as regiões e os preparos serão feitos manualmente por apenas um operador previamente treinado.

Confecção e cimentação das próteses metálo-cerâmicas

Após o preparo dos espécimes todos serão moldados com silicone de adição e modelos de gesso pedra tipo IV serão obtidos. Esses modelos serão duplicados com material refratário. Sobre os modelos refratários será realizada a aplicação de uma camada de espaçador, seguido do isolamento com vaselina sólida e por fim o enceramento das infraestruturas com cera para fundição. A espessura das infraestruturas nos dentes pilares e nas regiões de conector e pôntico obedecerão aos preceitos mecânicos existentes na literatura (PEGORARO, 2013). Por fim os padrões de cera serão fundidos com ligas de níquel-cromo, seguindo as recomendações do fabricante. Após o processo de fundição as infraestruturas serão examinadas quanto à adaptação e posteriormente jateadas com óxido de alumínio (partículas de 150μm). Sobre as infraestruturas será realizada a aplicação e queima da cerâmica feldspática de cobertura seguido da aplicação da camada de glaze.

Para padronização das dimensões e anatomia de todas as próteses será realizado inicialmente um enceramento, respeitando as dimensões e anatomia dos dentes envolvidos no estudo (FERREIRA, et al 1981). Sobre esse enceramento será confeccionado uma muralha de silicone de adição, a qual será posicionada sobre os modelos durante a aplicação da cerâmica para garantia de padronização das anatomias.

Para a cimentação, a região interna das coroas será apenas limpa com álcool 70%. Sobre a porção coronária dos preparos será aplicado um sistema adesivo dual de condicionamento ácido total de 2 passos, seguindo as recomendações do fabricante. Todos procedimentos adesivos serão realizados por apenas um operador previamente treinado.

Confecção e cimentação das próteses a base de di-silicato de lítio

Para a confecção das próteses a base de di-silicato de lítio os modelos de gesso pedra tipo IV serão isolados com vaselina, uma pequena camada de espaçador será aplicada sobre os dentes pilares e será realizado o enceramento de prótese parciais fixas de três elementos. O formato e anatomia das próteses será idêntico ao das próteses metalo-cerâmicas, utilizando para isso a mesa guia de silicone que serviu de base para a aplicação da cerâmica de cobertura nos grupos anteriores.

Após o enceramento das restaurações canais de alimentação para a injeção da cerâmica (*sprues)* serão unidos à restauração, seguindo protocolo fornecido pelo fabricante da cerâmica. Após a fixação dos *sprues* à restauração o conjunto será fixado em uma base plástica de um anel de revestimento. As proporções pó e líquido do revestimento serão manipuladas em equipamento a vácuo e o material será vertido no interior do anel sob vibração constante, tomando o cuidado para não gerar deslocamento dos enceramentos.

Antes do tempo máximo de pressa do material de revestimento (45 min) o anel será inserido em um forno para queima da cera, previamente aquecido a temperatura de 850ºC, sendo mantido durante o tempo mínimo de 60 minutos. Após a queima da cera será realizada a injeção das pastilhas de cerâmica a base de di-silicato de lítio (IPS e.max Press A3, Ivoclar Vivadent, Schaan, Lietchteinstein). Para isso o anel de revestimento será removido do forno de queima da cera e levado imediatamente até o forno de injeção (Programat EP 5000, Ivoclar Vivadent, Schaan, Lietchteinstein), o qual já estará com a programa de injeção previamente selecionada. Nesse momento serão introduzidas as pastilhas de cerâmica no interior do canal de alimentação do anel de revestimento, será posicionado o êmbolo (Alox Plunger, Ivoclar Vivadent, Schaan, Lietchteinstein) e dado início ao ciclo de injeção da cerâmica.

Após a injeção será realizada a desinclusão das restaurações do interior do anel de revestimento. Primeiramente um corte circular no anel será realizado com um disco diamantado, em uma região correspondente ao final do êmbolo de injeção. Depois, a desinclusão inicial do revestimento será feita por meio de jateamento com partículas de óxido de alumínio (150 µm) a uma pressão de 4 bar e a desinclusão final será realizada pelo jateamento de partículas de óxido de alumínio (50 µm) a uma pressão de 2 bar, até a total remoção do revestimento e exposição da restauração cerâmica.

Após a desinclusão o canal de alimentação será removido com um disco diamantado, a restauração será provada no troquel e o restante do canal de alimentação removido com auxílio de pedras abrasivas. Por fim o glazeamento da peça protética será realizado.

Para a cimentação os remanescentes coronários dos dentes pilares serão condicionados da mesma maneira que os grupos das restaurações metalo-cerâmicas. Já a superfície interna das restaurações serão condicionadas com ácido fluorídrico a 10% (Cond AC Porcelana, FGM, Joinvile, SC, Brasil) por 20 s, lavada abundantemente com água e seca com jatos de ar. Após, a superfície cerâmica receberá a aplicação de um agente de união silano e será aguardado

3 min. Um cimento resinoso convencional dual será inserido na superfície interna da restauração, esta será posicionada sobre os dentes preparados, até seu completo assentamento, os excessos de cimento serão removidos e será efetuada a fotoativação de cada face pelo tempo de 20 s (Radii Cal, SDI, Austrália).

Envelhecimento por ciclagem mecânica e avaliações periódicas.

Após a cimentação das restaurações cerâmicas os espécimes serão posicionados em um simulador de fadiga mecânica (Instron Electropuls E3000 (Instron, Massachusetts, USA), imersos em água a temperatura constante de 37ºC (±2ºC). Um pistão, simulando a relação oclusal dos dentes antagonistas aplicará uma força de 250 N, a uma frequência de 10 Hz, por um período máximo correspondente a 3.000.000 de ciclos. Entre o pistão e a restauração será posicionada uma tira plástica de poliéster para evitar o contato direto entre o pistão e a restauração cerâmica.

Para a análise de sobrevida os espécimes serão avaliados a cada 500.000 ciclos por um único operador, em estereomicroscópio (Discovery V-20, Zeiss, Goettingen, Germany) a um aumento de 15-75x.

Teste de carga para fratura

Os espécimes que sobreviverem ao envelhecimento por ciclagem mecânica serão submetidos ao teste de carga para fratura em máquina de ensaio universal (DL-1000, Emic, São José dos Pinhais, Brasil) à velocidade de 1 mm/min até a ocorrência de fratura catastrófica. O pistão para aplicação da força será idêntico ao utilizado para a ciclagem mecânica.

Tanto os acompanhamentos periódicos como o teste de carga para fratura serão realizados por operador cego em relação aos grupos experimentais.

Análise de falha

As falhas que vierem a ocorrer durante os testes serão classificadas em reversíveis (chipping da cerâmica, decimentação do conjunto, fratura da restauração, fratura do pino e fratura radicular acima do ligamento periodontal) e irreversíveis (fratura radicular abaixo do ligamento periodontal). A análise será realizada com estereomicroscópio (Discovery V20, Carl Zeiss, Alemanha) sob aumento de até 75x. Imagens de falhas representativas serão obtidas com microscópio eletrônico de varredura.

Análise estatística

A análise de sobrevivência dos espécimes será realizada pelo método de Kaplan Meyer (α=0.05). A análise dos valores de carga para fratura será realizada através do teste paramétrico ANOVA-2 fatores e posteriormente teste de Tukey (α=0.05).

Avaliação pelo método de elementos finitos

Para essa análise, os modelos geométricos correspondentes ao osso mandibular e elementos dentários, serão adquiridos a partir de tomografia computadorizada (TC). As imagens tomográficas (em formato DICOM) serão importadas em software de processamento de imagem para desenho e modelagem tridimensional (Mimics®, versão 17.1, Materialise Co., Ltd.) para criar um modelo 3D em formato de estereolitografia (STL). Os modelos tridimensionais incluindo estruturas ósseas corticais e trabeculares e estruturas dentárias (conduto radicular, dentina e esmalte) serão gerados respeitando as dimensões utilizadas no teste laboratorial. Os modelos obtidos serão então editados em outro programa de desenho assistido por computador (CAD) 3D (SolidWorks®, Dassault-SystèmesSolidWorks Corp, 2013) de modo que os modelos geométricos sejam semelhantes as condições avaliadas nas análises laboratoriais.

O modelo 3D dos complexos restauradores avaliados (retentores, dimensões da infraestrutura metálica, dimensões das cerâmicas testadas) serão confeccionados manualmente utilizando o programa de desenho assistido por computador (CAD) 3D (SolidWorks®, Dassault-SystèmesSolidWorks Corp, 2013), também respeitando as dimensões utilizadas no teste *in vitro*.

Após a verificação da relação entre as estruturas será gerada a malha de elementos finitos dos modelos. Os elementos terão configuração tetraédrica e o tamanho final dos mesmos será definido através de teste de convergência da malha. Após a geração das malhas serão aplicadas as condições de contorno nos modelos, onde as superfícies externas da resina acrílica serão fixadas em todos os graus de liberdade (x, y, z), forças paralelas ao longo eixo dos dentes serão aplicadas nas mesmas regiões submetidas ao carregamento durante a ciclagem mecânica, em áreas de $1mm^2$. A força total aplicada será de 250N e será dividida entre as regiões de contato oclusal existentes. A maioria dos materiais serão considerados isotrópicos, homogêneos, lineares, com exceção do pino de fibra que será considerado ortotrópico, e todas superfícies serão consideradas perfeitamente unidas. As propriedades dos materiais serão estipuladas de acordo com dados da literatura.

No pós-processamento serão verificadas a distribuição da tensão máxima principal (σ1), a distribuição das tensões de Von Misses e a deformação em todas as estruturas do modelo.

4.2 Avaliação da distribuição de tensões em próteses parciais fixas à base de di-silicato de lítio com cinco elementos utilizando diferentes tipos de retentores.

Obtenção dos modelos tridimensionais

Serão confeccionados quatro modelos tridimensionais simulando próteses parciais fixas de cinco elementos, variando o tipo de retentor dos dentes pilares e o carregamento oclusal (tabela 1). Para a obtenção dos modelos geométricos para o osso mandibular e para os elementos dentários envolvidos, serão adquiridos a partir de uma tomografia computadorizada (TC). As imagens tomográficas (em formato DICOM) serão posteriormente importados para um programa de software de processamento de imagem para desenho e modelagem tridimensional (Mimics®, versão 17.1, Materialise Co., Ltd.) para criar um modelo 3D em formato STL. Os modelos tridimensionais incluindo estruturas ósseas corticais e trabeculares e estruturas dentárias (conduto radicular, dentina e esmalte) serão gerados respeitando as dimensões médias, descritas na literatura (MADEIRA, et al 2016). Os modelos obtidos serão então editados em outro programa de desenho assistido por computador (CAD) 3D (SolidWorks®, Dassault-Systèmes SolidWorks Corp, 2013).

O modelo 3D dos complexos restauradores avaliados (retentores, dimensões da infraestrutura metálica, dimensões das cerâmicas testadas) serão confeccionados manualmente utilizando o programa de desenho assistido por computador (CAD) 3D (SolidWorks®, Dassault-SystèmesSolidWorks Corp, 2013), utilizando um diâmetro dos retentores (pino de fibra de vidro e núcleo metálico fundido) de 2 mm na porção mais cervical em dentes unirradiculares, sendo esses cônicos chegando a 1 mm na porção mais apical do elemento dentário e de 1 mm e dentes multirradiculares chegando a 0,5 mm na porção mais apical dos condutos radiculares; espessura da infra estrutura metálica 0,5 mm nos pilares e 2,5 mm de cinta lingual, os pônticos corresponderão a 75% do tamanho final do elemento; a espessura de cerâmica feldspática, utilizada para o grupo de próteses metálo cerâmicas será de 1,5 mm, para a cerâmica de di-silicato de lítio a espessura adotada será de 2 mm de espessura nos pilares 3 mm no cinta lingual e o pôntico corresponderá ao tamanho total do elemento faltante, uma vez que será feita no formato monolítico. Esses parâmetros serão utilizados por estarem de acordo com o previsto na literatura acerca da confecção de próteses fixas (PEGORARO, et al 2013).

Tabela 1: Modelos Tridimensionais.

Modelo	Especificação	Carregamento
1	PPF de di-silicato de lítio de cinco elementos (Canino + Pôntico + 2o Pré-Molar + Pôntico + 2o Molar) utilizando pino de fibra de vidro	Oclusal, simulando contatos em MIH
2	PPF de di-silicato de lítio de cinco elementos (Canino + Pôntico + 2o Pré-Molar + Pôntico + 2o Molar) utilizando pino de fibra de vidro	Borda incisal do canino, simulando guia de lateralidade
3	PPF de di-silicato de lítio de cinco elementos (Canino + Pôntico + 2o Pré-Molar + Pôntico + 2o Molar) utilizando núcleo metálico fundido	Oclusal, simulando contatos em MIH
4	PPF de di-silicato de lítio de cinco elementos (Canino + Pôntico + 2o Pré-Molar + Pôntico + 2o Molar) utilizando núcleo metálico fundido	Borda incisal do canino, simulando guia de lateralidade

Obtenção da malha

Para a obtenção da malha serão utilizados elementos tetraédricos. Após verificação dos contatos entre as superfícies serão realizados testes de convergência, usando como parâmetro a distribuição de tensões apresentadas na região cervical do dente, para definição do tamanho dos elementos a serem utilizados no estudo.

Aplicação das propriedades e condições de contorno

Com exceção do pino de fibra de vidro que será considerado ortotrópico, todos os outros materiais serão considerados isotrópicos, lineares e homogêneos e as propriedades dos materiais serão obtidas através da literatura. Os contatos entre todas as estruturas serão considerados perfeitamente unidas.

As superfícies do osso cortical serão consideradas fixas, com movimento restringido nos três eixos de liberdade (x, y e z), enquanto as demais superfícies estarão livres nos três eixos. Uma força de 250 N será aplicada ao conjunto em duas condições; (1) a força será aplicada verticalmente, paralela ao longo eixo dos dentes, em áreas de $1mm^2$, nas regiões correspondentes aos locais de contato das cúspides palatinas dos dentes superiores quando em máxima intercuspidação habitual (MIH) (WAGNER, et al 1998). O valor de 250 N será dividido de acordo com a quantidade de contatos existentes; (2) a força será aplicada em uma angulação de 45º, na borda incisal do canino inferior, simulando uma condição de guia de lateralidade.

Análise da distribuição de tensão

No pós-processamento serão verificadas a distribuição da tensão máxima principal ($\sigma 1$), a distribuição das tensões de Von Misses e a deformação em todas as estruturas do modelo.

Resultados e impactos esperados

Entender melhor o comportamento de próteses parciais fixas feitas com diferentes materiais e confeccionadas sobre diferentes retentores, a fim de aumentar a previsibilidade de sucesso e diminuir a chance de falhas. Além de obter modelos tridimensionais para utilização em estudos posteriores de elementos finitos.

Orçamento

Item	Justificativa	Valor
Kit para desgaste, polimento e acabamento de metal. Placas cerâmicas e pincéis para aplicação de cerâmica feldspática, motor elétrico de bancada, vibrador de gesso, espatulador a vácuo.	Será utilizado para confecção das infraestruturas metalo-cerâmicas	1.200,00
Placas cerâmicas e pincéis para aplicação de cerâmica feldspática	Serão utilizadas para aplicação da cerâmica de cobertura sobre a infraestrutura metálica	800,00
Vibrador de gesso	Para obtenção dos anéis de revestimento	600,00
Espatulador a vácuo	Será utilizado para obtenção de anéis de revestimento sem defeitos	1.400,00
Motor elétrico de bancada	Será utilizada para auxiliar nos desgastes e acabamentos das peças metálicas e cerâmicas	800,00
Produtos Odontológicos	Entre os materiais destacamos cerâmicas a base de di-silicato de lítio, pastilhas de metal Ni-Cr, revestimento para fundição, cerâmica feldspática, cimentos resinosos, sistemas adesivos, silanos, óxido de alumínio, resina composta, silicone de adição, cera para escultura, gesso pedra tipo IV, poliéter, cera utilidade, álcool 70%, glaze em pó, discos de corte de precisão, pontas diamantadas.	21.800,00
Microscopia eletrônica de varredura	Valor pago para utilização de microscopia eletrônica de varredura, para detecção da origem da fratura nos corpos de prova e obtenção de imagens representativas	2.000,00
TOTAL		28.600,00

Cronograma

Este estudo será desenvolvido durante o período de março de 2016 a dezembro de 2019, e será dividido de acordo com a tabela abaixo:

Meses* / Atividade	1-12	12-18	18-30	30-36	36-42	42-48
Seleção da amostra	x					
Obtenção núcleos metálico fundidos	x					
Confecção dos espécimes	X	X				
Realização dos testes mecânicos			X			
Realizaçaõ do teste de elementos finitos	x	x				
Análise dos resultados				X		
Apresentação dos resultados em eventos científicos					x	
Redação do artigo científico						X
Atualização bibliográfica	x	x	x	x	x	
Defesa da tese de doutorado do aluno						x

***** O período de 48 meses corresponde ao período máximo para obtenção do título de doutor do candidato.

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3. Relatório de campo

Tendo em vista as metodologias propostas no projeto de pesquisa, algumas modificações foram necessárias, em função das sugestões da banca e de limitações que surgiram no decorrer das pesquisas.

Incialmente a proposta de um estudo avaliando diferentes materiais de próteses de três elementos, bem como diferentes retentores intrarradiculares em diferentes posições havia sido feita no projeto de pesquisa. No entanto, devido a restrições no financiamento obtido, optou-se pela realização da pesquisa mantendo um único tipo de material para a prótese e a manutenção da avaliação de diferentes retentores, uma vez que não existem na literatura trabalhos realizando esse tipo de análise.

Outra modificação realizada nessa pesquisa, foi o tipo de teste, de modo que o teste de fadiga a ser realizado na máquina Instron ElectroPulse E300 não foi possível de ser desenvolvido. Dessa forma, os testes de ciclagem dinâmica foram realizados na cicladora mecânica Biocycle V2 e os testes de carga para fratura foram realizados na máquina de ensaio universal EMIC.

Adicionalmente, uma revisão sistemática foi proposta para elucidar o atual conhecimento disponível na literatura a respeito das propriedades dos materiais utilizados para a confecção de próteses de três elementos. Ainda uma avaliação *in vitro* e *in silico* (FEA) de reabilitações unitárias de dentes tratados endodônticamente foi adicionada para a complementação do trabalho proposto.

Por fim, o estudo avaliando próteses de cinco elementos através do método de análise por elementos finitos, foi removido do presente trabalho em função da falta temporária dos recursos de processamento necessários para o correto desenvolvimento desse teste.

Ademais, o presente trabalho desenvolveu-se de acordo com o cronograma proposto, seguindo o tema proposto, além de os resultados esperados no projeto de pesquisa terem sido atingidos.

4. Artigo 1

Effects of restoration strategy and height of the coronal structure on the biomechanical behavior of endodontically treated teeth: an *in vitro* study with 3D finite element analysis[1]

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Abstract

The maintenance of at least one coronal wall is key to the success of endodontically treated tooth restorations. However, it is not uncommon in clinical practice to find teeth with no coronal structure. In such cases, the use of an intracanal retainer may be indicated. Glass fiber posts (GFP) are widely used for this purpose, but new restorative techniques have been proposed, such as the use of composite resin to build the post and core. Thus, the aim of the present study was to evaluate the effects of the height of the coronal structure and restoration strategy on the survival rate of endodontically treated teeth using *in vitro* and *in silico* tests. Sixty specimens were randomized into six groups (n = 10) and divided according to the amount of remaining coronal structure (0 or 2 mm) and restoration strategy used (GFP + composite resin core; GFP + resin cement core; composite resin post and core). A total of 1,200,000 mechanical cycles were performed and the specimens that survived where subjected to the fracture test. Finite element analysis was performed on models with the same characteristics as the *in vitro* test. The Kaplan-Meier test revealed significant differences among the groups ($p = 0.01$). Two-way ANOVA showed that the restoration strategy ($p \leq 0.001$) and remaining height ($p = 0.002$) significantly affected the results of the fracture test. Finite element analysis revealed a greater concentration of tensile stress in the group with composite resin alone. Moreover, the absence of coronal structure concentrated more tensile stress on the middle and apical third of the remaining structure. In conclusion, independently of the post and core material, the use of GFP was more adequate for the reconstruction of endodontically treated teeth compared to composite resin, especially in the absence of remaining coronal structure.

Introduction

Endodontically treated teeth may have pronounced crown loss and the amount of remaining dentin exerts a direct influence on the survival of the restoration.[1,2] As the preservation of at least one coronal wall is critical to restorative success, the absence of coronal structure is unfavorable to dental reconstruction.[3] In such cases, the use of an intracanal retainer provides better stability and retention to the prosthetic restoration.

Glass fiber posts (GFPs) are widely used for the restoration of endodontically treated teeth due to the favorable esthetics and mechanical proprieties, such as the elasticity modulus (30 to 50 GPa) similar to that of dentin.[4] Moreover, a GFP requires few clinical steps. However, novel methods continuously emerge to improve the results of dental restorations. One recent technique is the use of composite resin to build the post and core with no other intracanal retainer, such as a GFP or cast post and core.[5] There are also other methods to restore endodontically treated teeth in a simplified way, such as the use of dual resin cements with more filling content, with which it is possible to cement the post and build-up the core with the same material.

Some authors[6,7] state that the presence of a ferrule in endodontically treated teeth improves the biomechanical behavior of the system by reducing the transmission of stress to the root structure and increasing fracture resistance.

Although clinical studies provide the highest degree of scientific evidence regarding the behavior of a restorative material or technique, such studies are time-consuming, difficult to execute and costly. Thus, laboratory tests are important assessment tools that enable a comparison of different materials under controlled conditions.[8]

It is vital to understand the biomechanical behavior of new restoration strategies for endodontically treated teeth and compare the results to those obtained with standard methods. Thus, the use of non-destructive tests, such as finite element analysis (FEA), combined with laboratory testing enables a better understanding of the distribution of forces and the behavior of a restorative system.

Therefore, the aims of the present study were to evaluate the effects of the height of the remaining coronal structure and restoration strategy on the survival rate of endodontically treated teeth submitted to mechanical cycling and determine both fracture resistance and stress distribution using finite element analysis. We test the null hypotheses that different restoration strategies and remaining dentin height do not influence the survival rate or the occurrence of fractures.

Materials and Methods

The sample size was calculated based on a statistically significant difference of 100 N between groups, a 5% significance level, 95% power and one-tailed hypothesis test. Using these criteria, the sample size was estimated to be 10 specimens per group.

Sixty bovine incisors were selected for the study and prepared according to the method described by Corrêa et al. (2018).[2] Specimens with coronal structure and samples without coronal structure were numbered from 1 to 30 and two random number sequences of 30 numbers were generated by the Random Allocator computer program to allocate the samples to the different groups (Table 1).

Table1: Study design

Groups (n = 10)	Restoration strategy	Coronal structure (mm)
GFc0	Glass fiber post + composite resin core	0
GFc2	Glass fiber post + composite resin core	2
GFrc0	Glass fiber post + resin cement core	0
GFrc2	Glass fiber post + resin cement core	2
IRc0	Intracanal restoration and composite resin core	0
IRc2	Intracanal restoration and composite resin core	2

Restoration strategies

All canals were prepared with the custom bur of the fiber post system (White Post DC #3 FGM, Joinville, SC, Brazil). This preparation had a length of 10 mm in the groups without remaining coronal structure and 12 mm in the other groups, always a 3-mm length of filling material left.

Prefabricated glass fiber posts

Before cementation, all posts were sectioned to a length of 15 mm, corresponding to 5 mm of the coronal portion. The posts were then cleaned with 70% alcohol and received the application of an MPS-based silane coupling agent (Prosil, FGM, Joinvile, SC, Brazil).

Root dentin and/or coronal dentin was etched with 37% phosphoric acid (Condac 37, FGM, Joinville, SC, Brazil) for 15 seconds, washed with water for 15 seconds and dried with paper points (Dentsply Indústria e Comércio Ltda, Petrópolis, RJ, Brazil). An adhesive agent (Ambar, FGM, Joinville, SC, Brazil) was applied with a microbrush. The excess was removed with paper cones and the adhesive was light-cured for 20 s with high power LED (KaVo Poly Wireless, KaVo, São Paulo, SP, Brazil). The resin cements Allcem for groups GFc0 and GFc2 and Allcem CORE (FGM, Joinville, SC, Brazil) for groups GFrc0 and GFrc2 were inserted into the canals with the aid of mixing tips. The posts were positioned. The excess cement was removed, and light-curing was performed in the cervical portion of the root for 40 seconds.

After cementation, the core was made with hybrid composite resin (Oppalis, FGM, Joinville, SC, Brazil) for groups GFc0 and GFc2 and Allcem Core resin cement (FGM, Joinville, SC, Brazil) for groups GFrc0 and GFrc2 using standardized translucent plastic matrices. The composite resin and resin cement were inserted into the matrix, which was placed over the post and tooth surface. Photoactivation was performed for 20 seconds on each face and the matrices were removed with a probe.

Intracanal restoration with composite resin core

The root/dentin etching was performed using the same technique employed in the other groups. The composite resin (Oppalis, FGM, Joinville, SC, Brazil) was applied directly into the root canal using the incremental technique with the aid of a magnifying lens (EyeMag® Pro, Carl Zeiss of Brazil Ltda, São Paulo, SP, Brazil) and light-cured for 40 s per increment. After the restoration of the canal, the cores were built-up using the same plastic matrices described above.

Preparation and cementation of crowns

Sixty metallic crowns were made following the anatomy of a maxillary central incisor with a standard height of 10 mm and mesio-distal dimension of 8.5 mm.[9] For the crowns, an impression was made of each tooth (Express XT,3M ESPE, Saint Paul, MN, USA) and a master die was obtained in type IV dental stone (Durone, Dentsply Indústria e Comércio Ltda, Petrópolis, RJ, Brazil). Each crown was waxed on a die (Newwax, Technew, Campo Grande, MS, Brazil) using standardized maxillary incisor plastic matrices. The waxed crowns were fused according to the manufacturer's instructions using a NiCr alloy (Wironia Light, Bego, Bremen, Germany). The crowns were examined for adaptation and then abraded with 50-μm aluminum oxide particles (Microjato, Bio-Art Equipamentos Odontológicos Ltda, São Carlos, SP, Brazil). For luting, the coronal structure was etched with 37% phosphoric acid for 20 seconds, followed by rinsing and drying with absorbent paper. The adhesive system (Ambar, FGM, Joinville, SC, Brazil) was then applied and light-cured for 20 s with high-power LED (KaVo Poly Wireless, KaVo, São Paulo, SP, Brazil). Finally, the dual resin cement (Allcem CORE, FGM, Joinville, SC, Brazil) was inserted into the crown and positioned. The excess was removed, and light-curing was performed for 40 seconds on each face.

Mechanical cycling

For mechanical cycling in the fatigue machine (ER 11000, Erios, São Paulo, SP, Brazil), the specimens were subjected to the following protocol: angle of 45°, water immersion at 37°C, load pulses of 0 to 100 N, frequency of 4 Hz and 1,500,000 cycles at a point located 2 mm below the incisal edge on the lingual surface. For survival analysis, roots were evaluated every 500,000 cycles by a trained, blinded operator for the following outcomes: cracking in the dental structure, reversible fracture of the dental structure (above the periodontal ligament), irreversible fracture of the dental structure (below the periodontal ligament), crown fracture, decementation of the crown and decementation of the restorative set (crown + post). When one of the outcomes was found, the number of cycles was recorded, and cycling was interrupted. Failures were examined under a stereomicroscope (Discovery V20, Carl Zeiss Microscopy, Göttingen, NI, Germany) with magnification of 50x.

Load to fracture

Specimens that survived the mechanical cycling were subjected to the fracture test in a universal testing machine (DL-1000, Emic, São José dos Pinhais, PR, Brazil) at a 45° inclination and crosshead speed of 1 mm/min until failure.

Failure analysis

Using a stereomicroscope (Discovery V20, Carl Zeiss Microscopy, Göttingen, NI, Germany) with magnification 7.5x to 50x, all fractured specimens were classified into different modes: favorable/restorable (root fracture above the simulated periodontal ligament, adhesive failure of the crown, dislodgment of crown/core, adhesive failure of the post) or unfavorable (root fracture below the simulated periodontal ligament).

Finite element analysis

Six three-dimensional models were obtained using design software (SolidWorks 2013®). All parameters (root length, periodontal ligament, dimensions of the post, acrylic resin and metal crown) were simulated in an identical scenario to that used in the laboratory test. The thickness of the resin cement between the post and root dentin and between the crown and core was set to 0.1 mm. After modeling, geometries were imported to a post-processing software (ANSYS 13.0, Canonsburg, PA, USA), using the *.stp* format for meshing and applying boundary conditions (Figure 1). After convergence tests, the element size was set to 0.25 mm, except for resin cement layers and the acrylic resin base, which were refined up to a size of 0.1 mm and 0.5, respectively, with a tetrahedral format, resulting in a mesh with approximately 834,000 elements and 1,232,000 nodes. Interfaces were considered bonded and the edges of acrylic resin were considered fixed to the x, y and z axes. A 100 N force was applied at a point located 2 mm below the incisal edge on the palatal face at a 45° angle. The fiber posts were considered orthotropic and other materials were considered isotropic. The properties of the resin cements (Allcem and Allcem CORE, FGM, Joinville, SC, Brazil) and composite (Oppalis, FGM, Joinville, SC, Brazil) were obtained using the natural wave propagation method in accordance with ASTM standard E-1876 (2007) with the Sonelastic® device (ATCP Physical Engineering, São Carlos, SP, Brazil). The properties of other materials were obtained from the literature (Table 2). All materials were homogeneous and linear. Maximum principal stress ($\sigma 1$) was analyzed at the root and the resin core material.

Table 2: Materials, Properties and references used for finite element analysis.

Material	Young Modulus (E)	Poisson ratio	References
Fiber post	Ex= 37000 MPa Ey= 9500 MPa Ez= 9500 MPa Gxy= 3.1 Gxz= 3.5 Gyz= 3.1	Vxy= 0.27 Vxz= 0.34 Vyz= 0.27	Lanza A et al. 2005[28]
Acrylic resin	2700 MPa	0.35	Ebadian B et al. 2012[29] .
Polyether	0.05 MPa	0.45	Farah JW et al. 1981[30]
Dentin	18600 MPa	0.31	Peyton FA et al. 1952[31] .
Gutta-percha	0.69 MPa	0.45	Ko CC et al. 1992[32]
Nickel-chrome	200000 MPa	0.31	Williams KR et al. 1987[33]
Composite resin (Oppalis®)	4800 MPa	0.33	Sonelastic Analysis
Resin cement (Allcem CORE®)	4447 MPa	0.33	Sonelatic Analysis
Resin cement (Allcem®)	9800 MPa	0.3	Sonelastic Analysis

Results

Analysis of survival data (Kaplan-Meier method)

The Kaplan-Meier test showed significant differences among the groups ($p = 0.01$) (Figure 2). The IRc0 group had values lower than other groups after 1.5 million cycles. Only four failures occurred during the mechanical cycling and all four specimens were from the IRc0 group. Three failures occurred before the initial 500,000 cycles and the other occurred between 500,000 and 600,000 cycles.

Analysis of load to fracture

The normality ($p = 0.075$) and homoscedasticity ($p = 0.056$) tests showed that the data were parametric. Two-way ANOVA revealed that restoration strategy ($p \leq 0.001$) and remaining coronal height ($p = 0.002$) significantly affected the fracture results, but there was no influence of the interaction on the outcomes ($p = 0.227$). Tukey's test (Table 3) showed that the GFc2 and GFrc2 groups had similar values and both differed from the IRc0 group. Moreover, the GFc0, GFc2 and IRc2 groups had similar values to each other and to the previous groups.

Table 3. Mean and standard deviation (SD) of load-to-fracture values after Tukey's test.

Strategy	Remaining coronal structure	Load (Newton)
GFc0	No	437.7 (114.3) [a]
GFc2	Yes	617.5 (342.1) [a]
GFrc0	No	397.3 (69.0) [ab]
GFrc2	Yes	451.1 (143.9) [a]
IRc0	No	104.8 (22.4) [b]
IRc2	Yes	397.1 (262.4) [ab]

Modes of failure

The most frequent failure was reversible fracture of the remaining coronal structure, followed by fracture of the retainer (Table 4).

Table 4 - Descriptive analysis of failure modes in each group.

	Reversible fracture				Irreversible fracture
Groups	Crack/fracture of remaining dental structure	Retainer fracture	Crown fracture	Decementation of restorative set	Crack/fracture of remaining dental structure
GFc0	7	-	-	2	1
GFc2	4	-	-	5	1
GFrc0	2	-	-	8	-
GFrc2	10	-	-	-	-
IRc0	-	10	-	-	-
IRc2	6	4	-	-	-
Total	30 (48%)	14 (24%)	0	16 (26%)	2 (2%)

Finite element analysis

Finite element analysis revealed a greater concentration of tensile stress in the groups with composite resin alone as the root canal and core restorative material (Figure 3). Moreover, the specimens that had dual resin cement with filling content as cementation and core build-up material had less stress distribution on the remaining tooth structure. A higher remaining coronal structure concentrated the tensile stress on the coronal and medium third of the tooth, whereas the absence of coronal structure concentrated more tensile stress on the middle and apical thirds of the remaining structure.

Discussion

The results of the present study showed that both restoration strategy and height of remaining dental structure directly affected the outcome. Thus, the null hypothesis was rejected.

Glass fiber posts and cast posts and cores have been widely tested as restoration strategies for endodontically treated teeth.[7,9,10,11] However, few studies have evaluated the use of composite resin alone as a possible retainer material.[5,12] Moreover, evaluating the presence of different remaining coronal heights is important, as this factor may also affect the choice of the restoration method.

During the mechanical cycling test, four failures occurred in the IRc0 group (intracanal restoration and core build-up using composite resin alone with no prefabricated retainer). These failures led to a lower survival rate in this group compared to the other groups (Figure 2). It is possible that the absence of an intracanal retainer reduced the internal strength of the post and core. We may also associate the results with the intracanal restoration fabrication method, which may have incorporated bubbles inside the canal (Figure 4). There is also the difficulty of achieving the complete light-curing of the composite in the apical third of the root. Another important factor is the absence of remaining coronal structure, as no losses occurred during mechanical cycling when this restoration strategy was combined with the presence of remaining coronal structure.

Restoration strategy and height of the coronal structure also exerted a direct influence on the fracture outcomes. Once again, the worst results were found for the group with no remaining coronary structure and restored with composite resin alone (Table 2). These results seem to be directly related to the brittleness of this strategy on this kind of substrate, since the failure analysis showed that all fractures occurred on the retainer. On the other hand, the group with 2 mm of remaining coronal structure (ferrule) restored with composite resin alone had statistically a similar result to those found in the groups with prefabricated fiber posts. These findings are in agreement with previous studies in the literature,[5,12] showing that this strategy is a possible restorative option in the presence of a ferrule.

Concerning the concept of restoration strategy, the material for cementation and core build-up when associated with a glass fiber post had no influence on the survival or fracture outcomes. Thus, a reinforced resin cement may be used for this purpose without compromising the restorative set, which is in agreement with data reported by Bergoli et al. (2018)[13] in a randomized clinical trial.

The presence of a 2-mm ferrule led to higher fracture resistance values compared to the groups without this remaining coronal structure. This result is in agreement with several laboratory and clinical studies, which show that the presence of coronary remnants is an important factor to fracture resistance and the longevity of endodontically treated teeth.[3,7,14,15]

An important finding that merits attention is the fact that 98% of the failures were considered reversible (above the periodontal ligament). This fact may be explained by the distribution of stress above the periodontal ligament seen in the finite element analysis, especially on specimens with the presence of a ferrule (Figure 3). Moreover, there was no damage to the specimen in 50% of the failures, suggesting that the material fails before the dental structure under high loads, preserving the tooth and enabling new restorations. According to some studies,[2,16] endodontically treated teeth restored with a cast post and core are more prone to catastrophic failures when submitted to the fracture test.

The fracture patterns varied depending on the remaining coronal structure, similar to the sequence of events described by Corrêa et al. (2018),[2] in which the ferrule serves as a lever arm, hindering the progression of the fracture. In contrast, some specimens without a ferrule first experienced adhesive failure on the lingual surface at the crown/root interface, followed by the retainer becoming loosened in the canal and no longer forming a single structure(wandscher [18]); the predominant stress was compressed and failure evolved to total root fracture on the buccal surface.

This was an *in vitro* study and therefore has limitations that should be considered, despite conducting the tests with extreme care and using randomization. As the oral environment has particularities that cannot be reproduced in laboratory tests or computer-assisted tests, the present findings should be interpreted with caution. Clinical studies are needed to clarify these issues.

Conclusion

The use of a glass fiber post, independently of the post and core material, was more adequate for the reconstruction of endodontically treated teeth compared to composite resin, especially in the absence of remaining coronary structure. The presence of a 2-mm ferrule increase fracture resistance compared to specimens without this structure. Moreover, the use of resin materials for the restoration of endodontically treated leads to reversible failures, as confirmed by the results of the finite element analysis.

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Figures

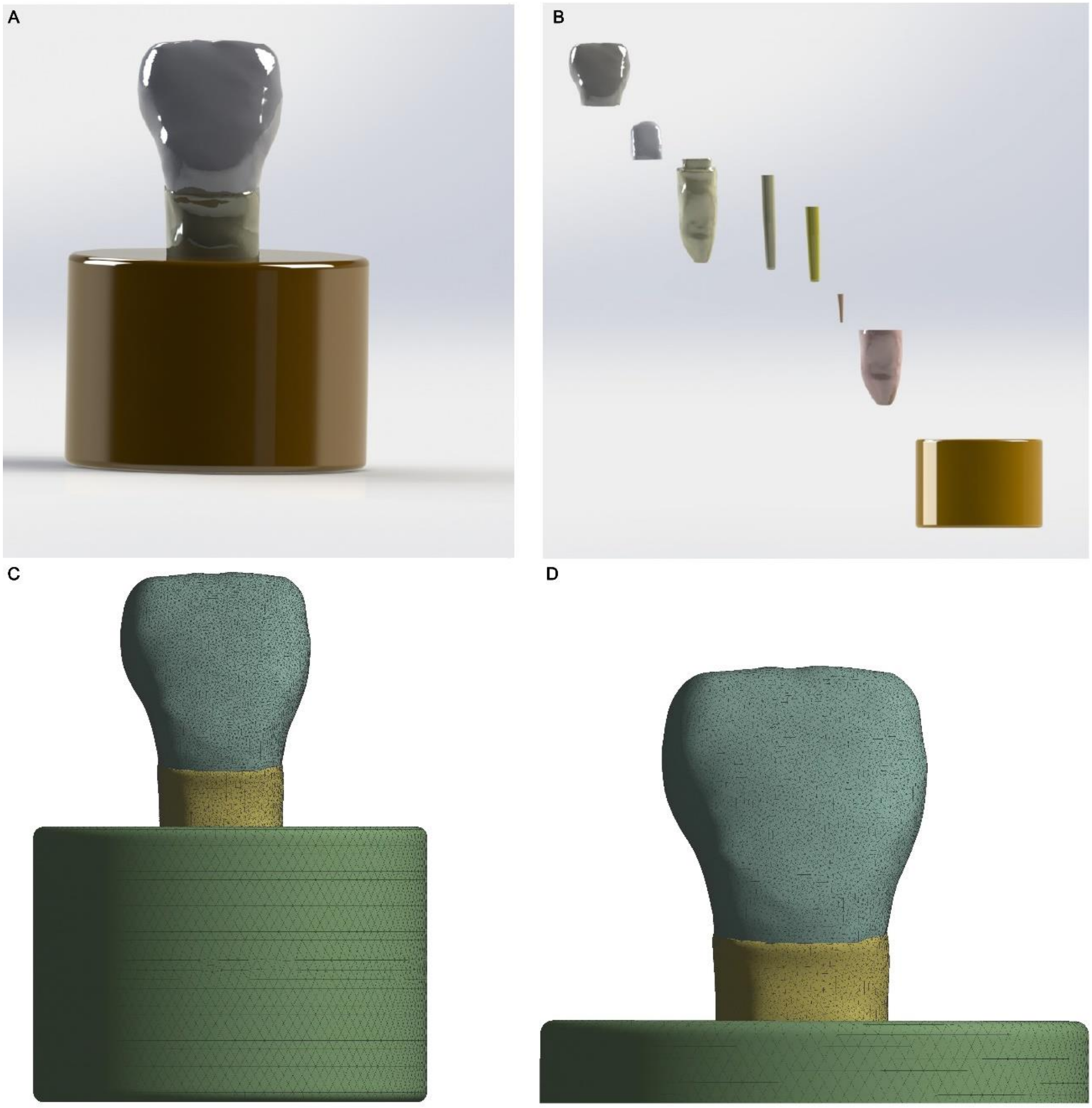

Figure 1: Representative images of FEA models. (A): Rendered complete model; (B) Rendered parts of model representing specimen with remaining coronal structure; (C): Mesh applied on model; (D) Amplified view of mesh.

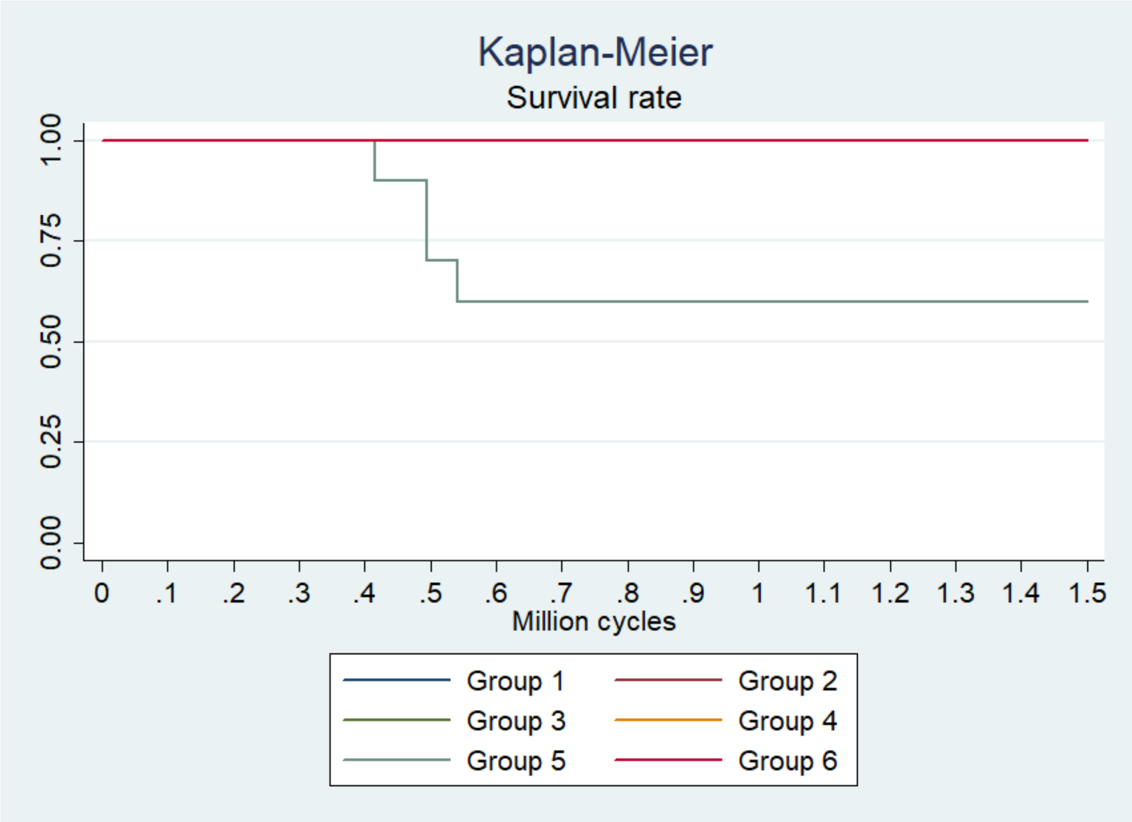

Figure 2: Kaplan-Meier survival curves for the comparison between restoration strategies.

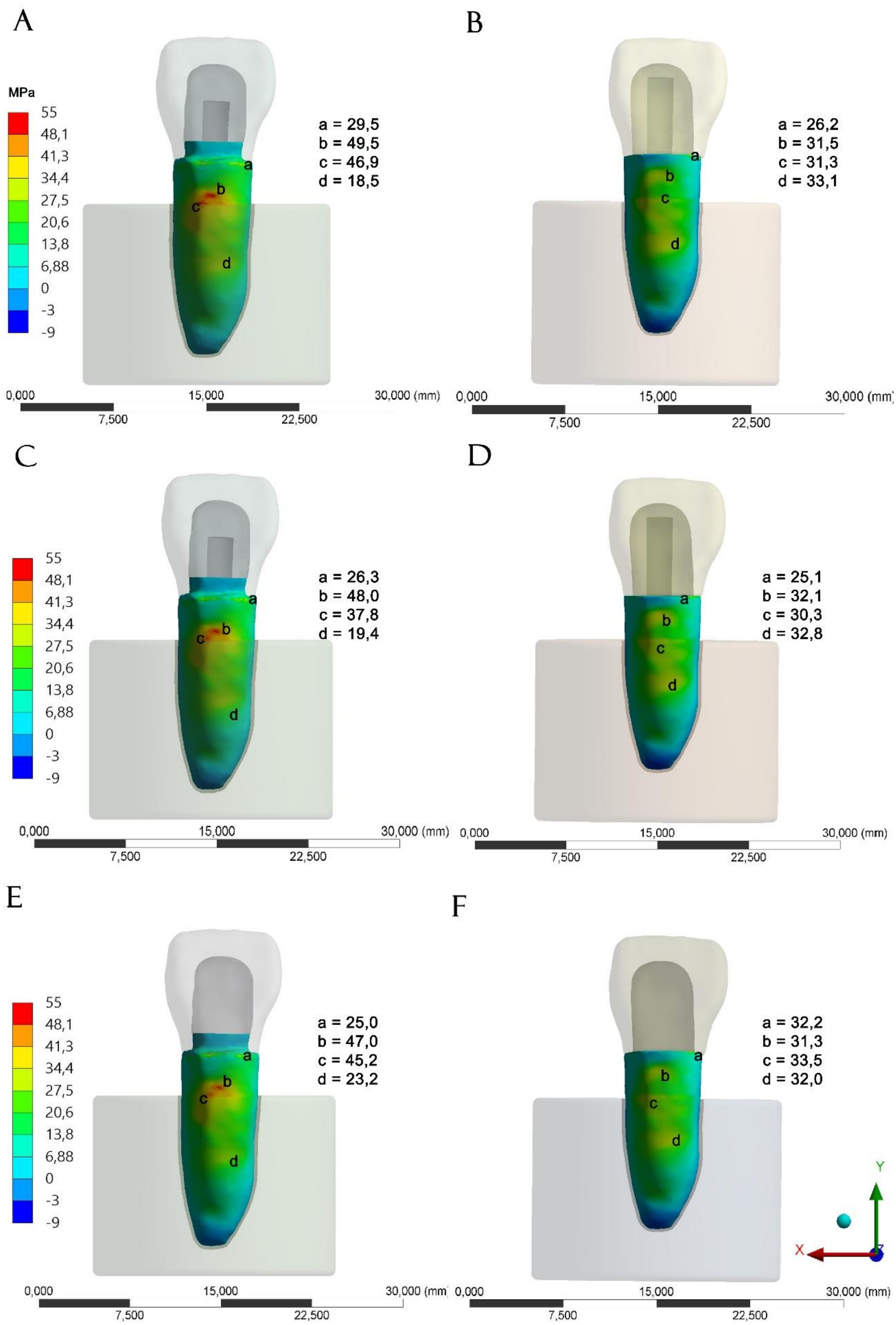

Figure 3: Image showing distribution of stress in different groups. Higher stress values concentrated on coronal and middle third of tooth in groups with remaining coronal

structure (A: GFr2; C: GFrc2; E: IRrc2); higher stress values found on middle and apical thirds in groups without coronal structure (B: GFr0; D: GFrc0; F: IRrc0).

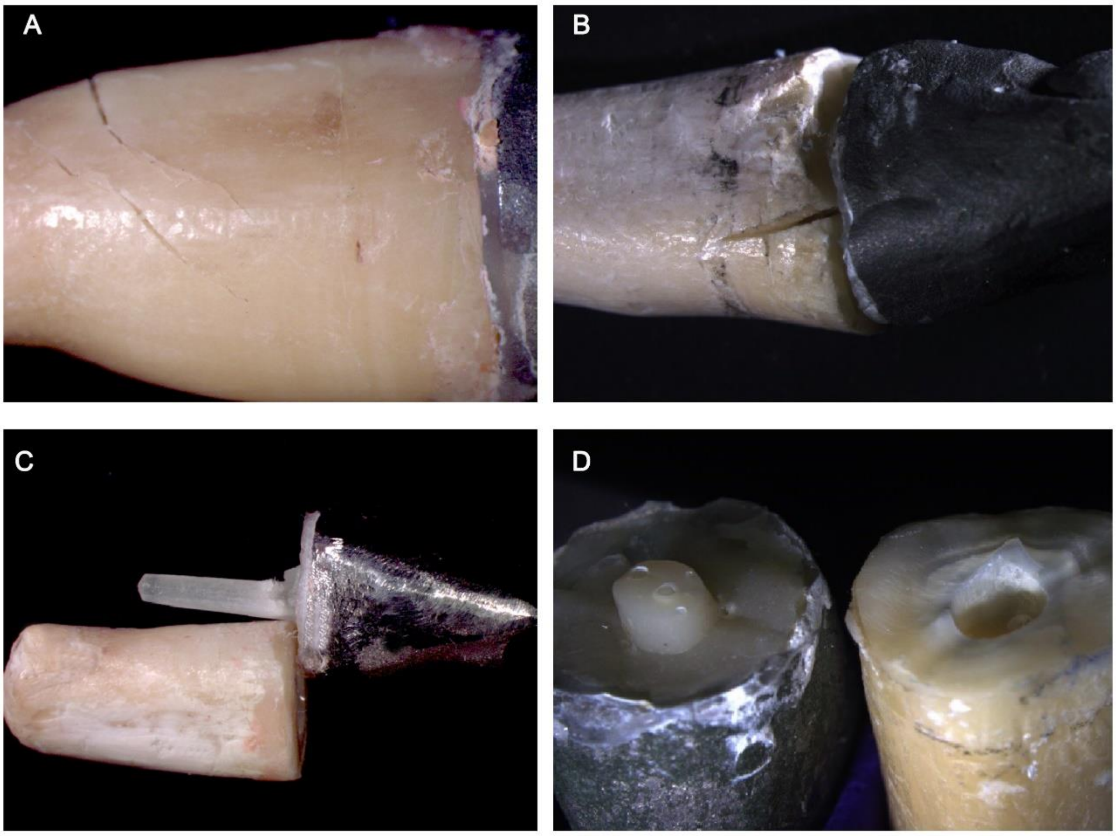

Figure 4: Representative images of failures. (A): Irreversible fracture of the specimen. (B): Reversible fracture of the dental structure. (C): Decementation of restorative set; (D) Retainer fracture.

5. Artigo 2

Load to fracture evaluation of different materials used for three-unit fixed dental prosthesis: a systematic review and single arm meta-analysis[2]

Running title: Fracture strength of 3-unit dental prosthesis materials

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Abstract

Purpose: This systematic review of in vitro studies aimed to analyze the load to fracture of different materials used on the manufacture of three-unit fixed dental prosthesis luted on natural teeth.

Methods: Online database and hand searches were systematically performed to identify studies reporting the load to fracture of zirconia, lithium disilicate and metal ceramic three-unit dental prosthesis luted on natural teeth. The risk of bias was assessed using the modified Consolidated Standards of Reporting Trials (CONSORT) checklist. The meta-analysis owas performed. Statistical analyzes of the meta-analysis were performed, considering the fracture strength of zirconia, lithium disilicate and metal-ceramic. The global analysis was carried out using fixed and random-effects model, and a 95% confidence interval.

Results: This systematic review yielded 4074 articles, after the complete reading, 8 articles were included in the study. Regarding the risk of bias, from a total of 104 entries, 68 (65%) were well reported. Random effect models and fixed effect models presented respectively the following fracture strength global means for zirconia 1394.00 [95% CI 1363.90-1424.10] and 1419.50 [IC95% 1319.52-1519.47] while lithium disilicate material was 842.34 N [95% CI 763.89-920.80] and 826.44 [95% CI 569.16-1083.71] and metal-ceramics was 1976.12 [95% CI 1720.81-2231.42] and 2124.19 [95% CI 1441.17-2807.21].

Conclusion: It was possible to conclude that the three types of materials presented in the studies included for three-element fixed prostheses confection presented satisfactory fracture strength values considering the means of human bite force. Only *in vitro* trials were included in this review.

Keywords: zirconia, lithium disilicate, metal ceramic, dental prosthesis, teeth, rehabilitation

Introduction

Three-unit fixed dental prosthesis (FDPs) are widely used considering dental rehabilitation after tooth loss. These FDPs have shown optimal survival rates, achieving more than 94% of success after 5 years of evaluation [1]. Also, the patients rehabilitated with FDPs exhibited higher levels of satisfaction and reports considerable improvement in the quality of life [2, 3]. Although the advent of osseointegrated dental implants has changed the perspectives of oral rehabilitation, the use of 3-unit FDPs remains indicated mainly in conditions where dental implants are not recommended, e.g. patients presenting severe bone loss, untreated systemic diseases, and others[4].

The metal-ceramic tooth-supported bridges were the most indicated material for several decades. These restorations frameworks were based on metallic materials and veneered with ceramics (e.g. feldspathic). Although these FDPs presents high survival rates (approximately 95% in a 5-year period)[1] , the absence of optimal esthetics due to the metal-framework additionally to the advances of ceramic materials after the introduction of CAD / CAM technologies, contribute to a shift of FDPs indications[5]. In this perspective, the all-ceramic FDPs offers superior aesthetics due to the color and translucency similar to natural teeth, as well as high biocompatibility [6]

This increased use of all-ceramic restorations occurred with the advance of computer-aided design and manufacturing (CAD / CAM) technologies, as well as a hardening transformation mechanism of yttria-stabilized tetragonal zirconia polycrystalline structures (Y-TZP) that enable zirconia to exhibit satisfactory mechanical properties [7]. Moreover, in recent years the mechanical properties of glass-reinforced ceramics (lithium disilicate) have improved considerably, which has increased their range of indications, enabling its use for posterior region PPFs [8]. On the other hand, also in pure ceramic dental prosthesis, the use of a feldspathic layer is commonly used to obtain sufficient veneer support and to improve esthetics [9].

The use of natural teeth could contribute to more precisely assess the load to fracture values of the prosthesis materials if compared to artificial substrates [10]. Besides, the comprehension of the load to fracture of different materials used for the 3-unit dental bridges may help on the decision making of which material should be used on different clinical situations. Thus, the aim of this systematic review of in vitro studies was to analyze the load to fracture of different materials used on the manufacture of three-unit fixed dental prosthesis luted on natural teeth.

METHODS

This systematic review is reported based on the Preferred Reporting Items for Systematic Reviews and Meta-Analysis (PRISMA) [11].

Eligibility criteria

The inclusion criteria were: 1) *in vitro* studies that evaluated three-unit FDP on posterior region teeth; 2) studies need to use human or bovine teeth on the test 3) the monotonic test should be realized on a perpendicular angle and with a maximum speed of 3 mm/min; 4) metal-ceramic or all-ceramic FDPs. It was excluded studies that used non biological models; or simulated anterior region; or evaluated FDPs greater than 3 unit; or evaluated cantilever FDP; or did not evaluate fracture strength. Also, prospective and retrospective clinical trials, as well as reviews, case reports or case series were not included.

PICO question

The following parameters were considered: (i) population: Three-unit fixed dental prothesis; (ii) intervention: restoration of posterior teeth with fixed dental prothesis; (iii) comparation: different FDPs materials; (iv) load to fracture obtained; (v) type of study: *in vitro*. So, the PICO question was: Which is the load to fracture of the different materials used for three-unit fixed dental prosthesis?

Search

Three electronic databases (PubMed/MedLine, Web of Science and Scopus) were systematically searched by two reviewers independently until November 2019, following the search strategy detailed in Supplementary Table 1, with no limit regarding the year of publication and language. The identified studies were imported into a reference manager software (Mendeley Desktop, version 1.17.11, Mendeley Ltd. George Mason University, USA) to remove duplicates. The references of the papers included in this review were hand searched for additional eligible studies.

Study selection

Titles and abstracts of all studies identified by the search strategy were read and reviewed independently by two authors (L.P.B. and M.A.K). Studies that seemingly met the eligibility criteria and those classified as unclear by title and abstract reading were selected for full-text assessment. Among the papers read in full, only those that fulfilled all the eligibility criteria were included in this systematic review and processed for data extraction, while reasons for exclusion were recorded (Figure 1). In each search step, the two reviewers compared their list of papers; in case of disagreement, a final decision of inclusion or exclusion was performed following discussion and consensus with a third author (C.D.B.).

Data collection process

Data from included papers were independently extracted and registered by two researchers. The reviewers inserted data in a spreadsheet in Excel format (Microsoft Corporation, Redmond, WA, USA). The authors, publication year, country, total sample, number of samples for each group, type of tooth used, luting material, tooth replaced by the pontic, FDP material, load used on aging, number of aging cycles, connector dimension, mean of fracture resistance and standard deviation (N) and failure mode. When the study did not present the numerical values of interest in tables, data were extracted from graphs whenever possible [12].

Data analysis

Statistical analyzes of the meta-analysis were performed in software R (Version 3.4.2, General Public License), considering the fracture strength of zirconia, lithium disilicate and metal-ceramic. The global analysis was carried out using fixed and random-effects model, and a 95% confidence interval. Heterogeneity was assessed using Cochran's Q test and I^2 inconsistency. Also, a qualitative analysis of the results was conducted.

Risk of bias in individual studies

The quality of studies was evaluated based on the modified Consolidated Standards of Reporting Trials (CONSORT) checklist [13]. The following parameters were considered: (1) Structured summary of trial design, methods, results, and conclusions; (2a) Scientific background and explanation of rationale; (2b) Specific objectives and/or hypotheses; (3) The intervention for each group, including how and when it was administered, with sufficient detail to enable replication; (4) Completely defined pre-specified primary and secondary measures of outcome, including how and when they were assessed; (5) How sample size was determined; (6) Method used to generate the random allocation sequence; (7) Mechanism used to implement the random allocation sequence (for example, sequentially numbered containers), describing any steps taken to conceal the sequence until intervention was assigned; (8) Who generated the random allocation sequence, who enrolled teeth; (9) If done, who was blinded after assignment to intervention (for example, care providers, those assessing outcomes), and how and who assigned teeth to intervention; (10) Statistical methods used to compare groups for primary and secondary outcomes; (11) For each primary and secondary outcome, results for each group, and the estimated size of the effect and its precision (for example 95% confidence interval); (12) Trial limitations, addressing sources of potential bias, imprecision and, if relevant, multiplicity of analyses; (13) Sources of funding and other support (for example suppliers of drugs), role of funders; (14) Where the full trial protocol can be accessed, if available. The parameters were judged as reported (Yes) or not reported (No) in each paper. The judgment was carried out independently by two reviewers (L.P.B and M.A.K). The assessments and consensus were discussed with a third researcher (C.D.B).

Results

Search strategy

After search 4074 articles were found. After duplicates removal, 2474 articles remained for titles and abstracts evaluation, remaining 38 articles that were complete read. After the full-text reading, 8 articles were included in the study (Figure 1).

Descriptive analysis

Eight studies investigating fracture strength of three-unit FDP cemented on natural teeth were published since 2007 (Table 2). The sample size ranged from 24 to 64 FDP's by study. A total of 352 FDPs were evaluated in this review, considering all included studies. Six studies analyzed FDP with the first molar as pontic, and two evaluated the substitution of the second molar. The dimensions of the connectors used on each study are described on Table 2. The included studies evaluated fracture strength, failure modes and aging of the specimen.

Data regarding to the studies groups of evaluation, materials evaluated, parameters of realized tests and main results are described on Table 3. Concerning to the failure modes, five articles presented the type of failure that occurred [14-18]: metal-ceramic prostheses had more crown fractures[16], lithium disilicate prostheses had more fractured connectors opposite the point of force application [16] and zirconia prostheses showed reports of fractures. chipping, failure of both connectors, and even core fractures [14, 15, 17-19].

The risk of bias is presented in Figure 2. From a total of 104 entries, 68 (65%) were well reported. Items related to the sample size, randomization, allocation, blinded parties, and full trial protocol access were not or unclearly reported in the included studies. All studies reported adequately items related to structured summary, scientific background and rationale, intervention for each group, measures of outcome, statistical methods, results for all outcomes and limitations and bias. While specific objectives and/or hypothesis (87,5%) and sources of founding and other support (62,5%) were not adequately reported.

Meta-analysis

In a general analysis of the three-element fixed prostheses using fixed and random effect models, the fracture strength of the zirconia was 1394.00 [95% CI 1363.90-1424.10] and 1419.50 [IC95% 1319.52-1519.47] (Figure 3), while lithium disilicate material was 842.34 N [95% CI 763.89-920.80] and 826.44 [95% CI 569.16-1083.71] (Figure 3)and the overall fracture strength of metal-ceramics was 1976.12 [95% CI 1720.81-2231.42] and 2124.19 [95% CI 1441.17-2807.21] (Figure 3).

Discussion

This systematic review of in vitro studies evaluated the fracture strength of three-units FDPs of different materials, metal ceramic, zirconia and lithium disilicate. These materials were chosen since they are the most studied and used for the multiple FDP rehabilitation [20-24]. Also, recent studies show that randomized clinical trials comparing these materials presented very low quality of evidences to support or refute any use of these materials and recommended that clinicians should use their own experience to decide [25]. So, an *in vitro* systematic was proposed to provide literature support for the clinicians' decisions.

Most of included studies evaluated zirconia-based FDP [14, 15, 17-19, 26, 27], presenting satisfactory fracture strength for posterior region. Furthermore, most of the studies showed no differences between fracture strength of the tested groups, and two studies presented statistically significant differences among the groups [17, 19], however just one of those evaluate different types of zirconia[17] presenting lower fracture strength values for glass infiltered zirconia in comparison with the high-strength, partially stabilized zirconium dioxide polycrystal ceramics (zirconia).

Zirconia-based FDP shows an esthetic improvement compared to the metal ceramic FDP with similar fracture strength [28, 29]. Also, clinical survival rates of Zirconia multiple FDP are estimated in 90,4% in a 5-year period. However, this type of rehabilitation may present a higher loss of retention in comparation with metal ceramic and lithium disilicate FDPs [1].

Lithium disilicate ceramic presents very satisfactory esthetic properties, being the most prescribed material for anterior single crowns [30]. Also, present good survival rates 89% in a 5-year period [1], 87, 9% in 10 years [31]. Nevertheless, recent literature shows drastic drop in survival rates of lithium disilicate three-unit FDP in molar region after an up to 15-year follow up (48.6%) with a 30.9% of success rate after the same period [32]. In the present review, the load to fracture values ranged from 699 N to 1900 N, with statistically significant differences between groups of monolithic and bi-layer lithium disilicate FDP [33].Additionally, considering the overall values presented, the manufacturer’s indication and the clinical outcomes of recent literature, lithium disilicate should be used only for anterior or premolar region.

Despite of inferior aesthetics characteristics, compared to all-ceramic FDP, metal ceramic FDP still are the gold standard, since it presents high overall fracture strength values, high survival rates (some clinical studies presented a 100% survival rate in 10 years [34]). Also, in a recent meta-analysis of clinical studies, the metal-ceramics FDP presented the higher survival rates and the lower rates of framework fractures [35]. In agreement with our analysis, lithium disilicate presented the higher rates of framework fractures, while zirconia presented framework fractures similar to metal ceramic FDPs. Importance should be given to the fact that our study considered in vitro studies, in opposite to a clinical *environment*, where a wide number of patients' conditions could contribute to the failure rates of these restorations.

Considering that, on average, the maximum bite force ranges from 180 N to 440 N on anterior region and from 600 to 730N on molar region [36], the mean fracture load for the materials found in the studies might be considered satisfactory. The values presented by lithium disilicate prostheses allow its indication for all buccal regions, since their limitations regarding the extension of PPFs are considered.

Furthermore, specimens included on meta-analysis were veneered with feldspatic ceramics, it can be highlighted that metal-ceramic prostheses did not present fractures of dental elements or infrastructures, unlike what can be seen in zirconia and lithium disilicate prostheses, which presented infrastructure and even core fractures (on zirconia groups), besides chipping.

One limitation of this study was the impossibility of performing the comparisons between groups, due to the absence of studies presenting these outcomes. Also, the restricted number of included studies may be explained by the lack of in vitro that uses natural teeth (bovine or human) as an abutment for tests that evaluate the mechanical properties of prosthodontics materials. Besides, regarding to the risk of bias assessment, although more than 60% of the entries were well reported, important issues as how sample size was determined, methods of randomization and allocation and blinded parties were neglected by all the included studies, showing report inconsistences and agreeing with the findings of Perroni et al., 2018 [37].

In vitro studies were created to investigate dental materials indications, and to predict lifetimes and failure in order to support the clinical practice. Therefore, the *in vitro* tests should simulate as better as possible clinical conditions. So, the use of some parameters is essential to improve the predictability of an *in vitro* studies, e.g., the use of aging tests [38], or the use of natural teeth, bovine or human [39], that could directly influence the test results, since artificial teeth may cause an overvaluation on the material properties [10]. On the present review, all studies used human teeth as abutments for the three-unit dental prothesis. Besides, regarding to the materials, in our analysis higher values of fracture strength were demonstrated for metal-ceramic and zirconia, while lithium disilicate presented the lower values.

Conclusion

Considering the means of human bite force, it was possible to conclude that the three materials, zirconia, lithium disilicate and metal ceramic, evaluated in the included studies for three-element fixed prostheses confection presented satisfactory fracture strength values. However, more well-designed studies, clinical or *in vitro* using natural teeth and comparing these three materials are needed to improve the quality of the evidences available.

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Tables

Table 1. Search strategy used in PubMed (Medline) Search

Search	Terms
#4	#1 AND #2 AND #3
#3	Search (Three-unit fixed dental prostheses OR multiple fixed dental prosthesis OR 3-unit dental prostheses OR 3-unit dental bridge OR dental bridge OR fixed dental prostheses.)
#2	Search (Metal-ceramic OR Metal-Ceramic [MeSH] OR metal-free OR lithium di-silicate OR lithium disilicate OR zirconia OR zirconia [MeSH])
#1	Search (failure OR fracture strength OR load to fracture OR fracture load OR Fracture resistance OR aging OR aging [MeSH] OR cycling OR mechanical cycling

Table 2: Demographic data of the included studies.

Author	Year	Type of tested tooth	Pontic	Total sample (n per group)	Connector dimension (height X width mm mesial and distal)	Outcomes
Att et al.,	2007	Human	First molar	48 (8)	3x3 and 3x3	Failure load and failure modes before and after artificial aging
W. ATT et al.,	2007	Human	First molar	48 (8)	3x3 and 3x4	Fracture resistance and failure mode after fatigue loading
Chaar et al.,	2012	Human	First molar	48 (8)	$10mm^2$ and $12mm^2$	fracture resistance and failure mode before and after artificial aging
Chitmongkolsuk et al.,	2002	Human	First molar	48 (8)	3x1.5 and 3x1.5	Fracture resistance and failure mode before and after aging
Kobeck et al.,	2008	Human	First molar	24 (8)	.	Fracture limits and failure mode after aging
Rosentritt et al.,	2010	Human	Second molar	40 (8)	5 x 6 and 4.7x 6.1	Load to fracture and failure modes after aging
Rosentritt et al.,	2011	Human	Second molar	64 (16)	5 x 5 and 5x 5	Load to fracture and failure modes after aging
Schultheis et al.,	2012	Human	First molar	48 (16)	4x6 and 4X6	Load to fracture and failure modes before after aging

Table 3. Selected Studies description

Author	Groups (immediately vs aged)/ Luting material	Material (Core manufacturer/ Veneer manufacturer)	Aging: Machine; Cycles; frequency; antagonist diameter and material; Force applicated; local and angle of force application	Load to fracture: Machine; Test speed; Piston diameter and material; local and angle of force application	Periodontal ligament simulation material	Failure mode	Main results
Zirconia							
Att et al, 2007	DCS / Glass ionomer cement	Precident, / e.max Ceram; Ivoclar-Vivadent	**Aging** Willytech, Munich/1.2 million/1.6Hz/ 6mm Ceramic ball/ 49 N/ pontic occlusal surface 90º	**Load to fracture** Z010-TN2S, Zwick, Ulm/ 2 mm/min / - / pontic occlusal surface 90º	Gum resin (Anti-Rutsch-Lack, Wenko-Wenselaar GmbH, Hilden	1 abutment fracture and 7 distal connectors	No significant differences were found for comparisons between different groups before artificial aging
						4 distal connector and 4 both connector	
	Procera / Glass ionomer cement	Nobel Biocare / e.max Ceram; Ivoclar-Vivadent				2 distal connectors; 1 mesial connector; 5 both connectors	
						8 distal connectors	
	Vita CeranInLab / Glass ionomer cement	Vita Zahnfabrik/ e.max Ceram; Ivoclar-Vivadent				4 distal connectors; 3 mesial connectors;1 both	
						3 distal connector and 5 both	
Att et al., 2007	DCS / Glass ionomer cement	Precident, / e.max Ceram; Ivoclar-Vivadent	**Aging**	**Load to fracture**	Gum resin (Anti-Rutsch-Lack,	1abutment fracture; 4 distal connectors and 3 mesial connectors	No significant

			Willytech, Munich/1.2 million/1.6Hz/ 6mm Ceramic ball/ 49 N/ pontic ocllusal surface 90º	Z010-TN2S, Zwick, Ulm/ 2 mm/min / - / pontic occlusal surface 90º	Wenko-Wenselaar GmbH, Hilden	2 abutment, 5 distal connector and 3 mesial connectors	differences were found for comparisons between different groups before artificial aging
	Procera/ Glass ionomer cement	Nobel Biocare / e.max Ceram; Ivoclar-Vivadent				4 distal connectors; 3 mesial connectors; 1 both connector	
						1 abutment, 5 distal connectors; 2 mesial connectors; 1 both connector	
	Vita CeranInLab/ Glass ionomer cement	Vita Zahnfabrik/ e.max Ceram; Ivoclar-Vivadent				1 abutment, 6 distal connectors; 1 mesial connector;1 both	
						3 distal connector, 2 mesial connector and 3 both	
Chaar et al;2012	layering technique ⁄Vintage ZR/ self-adhesive resin cement	Zanotec bridge; 3shape D 700; Wieland / VINTAGE ZR; Shofu Dental GmbH	**Aging** CS-4 professional line; SD Mechatronik GmbH/1.2 million/1.6Hz/ 6-mm diameter ceramic ball/49 N/ pontic occlusal surface 90º	**Load to fracture** Z010-TN2S, Zwick, Ulm/ 2 mm/min / - / pontic occlusal surface 90º	Gum resin (Anti-Rutsch-Lack, Wenko-Wenselaar GmbH, Hilden)	NR	Artificial ageing significantly reduced the fracture resistance in groups veneered with the layering technique, whereas no significant effect was found in specimens veneered with the CAD⁄CAM and press over techniques.
	layering technique⁄ ZIROX / self-adhesive resin cement	Zanotec bridge; 3shape D 700; Wieland / ZIROX; 3shape D 700; Wieland					
	CAD⁄CAM and press-over techniques⁄ PressXZr / self-adhesive resin cement	Zanotec bridge; 3shape D 700; Wieland / PressXZr 3shape D 700; Wieland					
Kobeck et al, 2008	Cercon Base*/ RelyXUnicem	CerconBase; DeguDent / Cercon Kiss; DeguDent	**Aging** - /1.2 million/ -/human molar/ 50 N/ pontic center	**Load to fracture** UTM 1446: Zwick / 1mm/min / steel ball / Pontic center	Polyether (Impregum: 3M Espe)	NR	None of the dentures failed during TCML. And, all restoration alternatives showed sufficient fracture resistance for posterior regions.

Rosentritt et al, 2010	Laboratory A: zirconia substructures, veneering A * / Variolink2	ICE; Zirkonzahn / Silica-based veneering with firing temperature 780 ºC and thermal expansion 8.7×1.2×10−6/K	**Aging** Chewing simulator (EGO; Regensburg / 1.2 million/ -/human molar/ 50 N/ occlusal contacts	**Load to fracture** UTM 1446: Zwick / 1mm/min / 12 mm steel ball / Pontic center	Polyether (Impregum: 3M Espe)	3 chipping and 5 crown fractures	Statistically significant differences were found between groups “Laboratory B: zirconia substructures, veneering A*” and “Laboratory C: zirconia substructures, veneering B” The dimensions of the connector had no significant influence on the fracture results.
	Laboratory B: zirconia substructures, veneering A* / Variolink2	ICE; Zirkonzahn / Silica-based veneering with firing temperature 780 ºC and thermal expansion 8.7×1.2×10−6/K				4 chipping; 2 core fractures and 2 crown fracture	
	Laboratory C: zirconia substructures, veneering A* / Variolink2	ICE; Zirkonzahn / Silica-based veneering with firing temperature 780 ºC and thermal expansion 8.7×1.2×10−6/K				5 chipping, 2 core frac. And 1 crown frac	
	Laboratory C: zirconia substructures, veneering B* / Variolink2	ICE; Zirkonzahn / ICE Silica-based veneering with firing temperature 820 ºC and thermal expansion 9.6×1.2×10−6/K				1 chipping, 2 core frac. And 5 crown frac	
	Laboratory C: zirconia substructures without veneering* / Variolink2	Prettau zirconia; Zirkonzahn/ no veneering				2 core frac and 6 crown frac	
Rosentritt et al, 2011	Ceramill conv. Cementation* / zinc oxide–phosphate Cement	Ceramill, Amann-Girrbach / Zi-Creation, Willi Geller	**Aging** Chewing simulator (EGO; Regensburg / 1.2 million/ -/humam molar/ 50 N/ occlusal contacts	**Load to fracutre** UTM 1446: Zwick / 1mm/min / 12 mm steel ball / Pontic center	Polyether (Impregum: 3M Espe)	7 chipping and 1 core	The Vita zirconia group provided significantly lower fracture strength than the other groups. Regarding fracture resistance, adhesive bonding or conventional cementation of zirconia FPDs showed no restrictions for posterior application.
	Ceramill adhesive cement* / dual curing composite; Variolink II					2 chipping and 6 cores	
	Vita YZ conv. Cement.* / zinc oxide–phosphate	Vita YZ Cube, Vita Zahnfabrik / Vita VM 9, Vita Zahnfabrik				8 cores	

	Cement						
	Vita YZ adhesive cement* / dual curing composite; Variolink II					8 cores	
	Cercon Base conv. Cementation* / zinc oxide–phosphate Cement	Cercon Base, DeguDent/ Cercon Ceram S, DeguDent				3 chipping and 5 cores	
	Cercon Base adhesive cement*/ dual curing composite; Variolink II					3 chipping and 5 cores	
	Vita zirconia conv. Cementation* / zinc oxide–phosphate Cement	Vita zirconia, Vita Zahnfabrik/ Vita VM 7, Vita Zahnfabrik				2 chipping and 6 cores	
	Vita zirconia adhesive cement* / dual curing composite; Variolink II					8 cores	
Lithium disilicate							
Chitmongkolsuk et al; 2002	IPS Empress 2 / dual curing composite; Variolink II	IPS Empress 2 Ivoclar-Vivadent / empress ceram Ivoclar-Vivadent	**Aging** Willytech, Munich/1.2 million/1.6Hz/ 6mm	**Load to fracutre** Z010-TN2S, Zwick, Ulm/ 2 mm/min / - /	Gum resin (Anti-Rutsch-Lack,	2 mesial connector, 5 distal connector and 1 both connectors 8 mesial connectors	No significant difference in the fracture strength was demonstrated between the IPS Empress2 bridges with

	IPS Empress 2 with modified preparation / dual curing composite; Variolink II	IPS Empress 2; Ivoclar-Vivadent / Empress ceram Ivoclar-Vivadent	Ceramic ball/ 49 N/ pontic occlusal surface 90º	pontic occlusal surface 90º	Wenko-Wenselaar GmbH, Hilden	2 mesial connector, 5 distal connector and 1 both connectors	modified preparation and those with normal preparation.
						1 mesial connector, 5 distal connector and 2 both connectors	
Schultheis et al, 2012	Monolithic IPS e.max CAD(YES)/ dual curing composite; Variolink II	IPS emax CAD; Ivoclar-Vivadent / No veneering	**Aging** Willytech, Munich/1.2 million/1.6Hz/ 6mm Ceramic ball/ 49 N/ pontic occlusal surface 90º	**Load to fracutre** Z010-TN2S, Zwick, Ulm/ 2 mm/min / 6.36mm steel indenter/ occlusal central fossa of the FDP pontic 90 º	Gum resin (Anti-Rutsch-Lack, Wenko-Wenselaar GmbH, Hilden	NR	Irrespective of fatigue application monolithic FDPs revealed fracture load values that were significantly higher than those notified for Bi-Layer FDPs.
	IPS emax CAD cores veneered with hand layering technique / dual curing composite; Variolink II	IPS emax CAD; Ivoclar-Vivadent / IPS e.max Ceram, Ivoclar Vivadent					
Metal ceramic							
Chitmongkolsuk et al; 2002	Porcelain fused to metal / dual curing composite; Variolink II	Gold alloy, V classic / Vita Omega porcelain; Vita Zahnfabrik	**Aging** Willytech, Munich/1.2 million/1.6Hz/ 6mm Ceramic ball/ 49 N/ pontic occlusal surface 90º	**Load to fracutre** Z010-TN2S, Zwick, Ulm/ 2 mm/min / - / pontic occlusal surface 90o	Gum resin (Anti-Rutsch-Lack, Wenko-Wenselaar GmbH, Hilden	8 crown fracture	Posterior 3-unit PFM bridges have a significantly higher fracture strength than IPS Empress2 bridges both with and without fatigue loading in the artificial mouth;
						8 crown fracture	

Schultheis et al, 2012	Metal ceramic / dual curing composite; Variolink II	Ni-Cr-Mo alloy; 4all, Ivoclar Vivadent / IPS e.max Ceram, Ivoclar Vivadent	**Aging** Willytech, Munich/1.2 million/1.6Hz/ 6mm Ceramic ball/ 49 N/ pontic ocllusal surface 90º	**Load to fracutre** Z010-TN2S, Zwick, Ulm/ 2 mm/min / 6.36mm steel indenter/ occlusal central fossa of the FDP pontic 90º	Gum resin (Anti-Rutsch-Lack, Wenko-Wenselaar GmbH, Hilden	NR	Monolithic and Metal Ceramic FDPs revealed comparable fracture load values, that were significantly higher than those notified for Bi-Layer FDPs

*Only aged evaluated; NR: Not reported

Figures

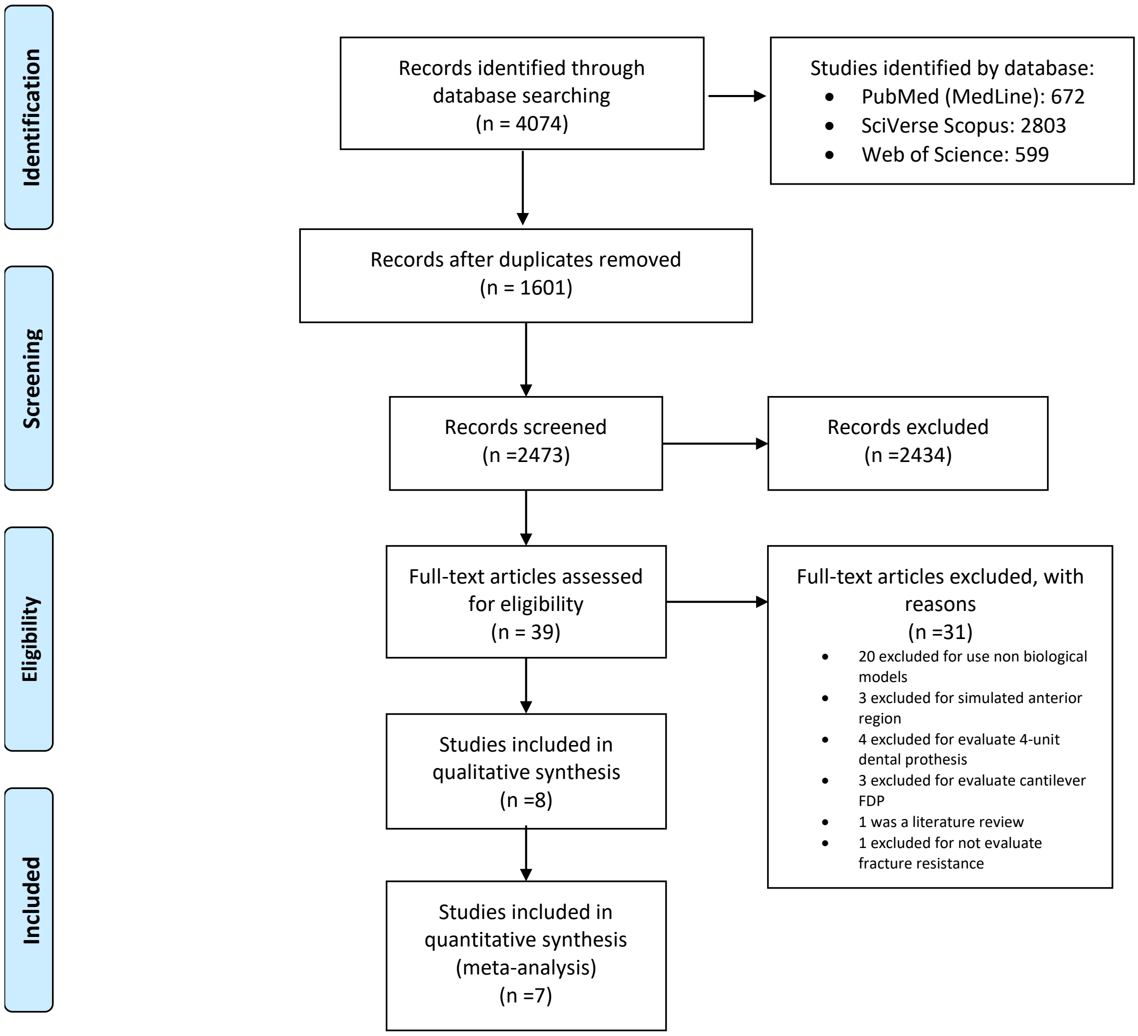

Figure 1. Flowchart of identification, screening, and assessing studies for inclusion eligibility

	1	2a	2b	3	4	5	6	7	8	9	10	11	12	13	14
Att 2007 [1]	+	+	+	+	+	−	−	−	−	−	+	+	+	+	
Att 2007 [2]	+	+	−	+	+	−	−	−	−	−	+	+	+	+	
Chaar 2012	+	+	+	+	+	−	−	−	−	−	+	+	+	+	
Chitmongkolsuk 2002	+	+	+	+	+	−	−	−	−	−	+	+	+	−	
Kolbeck 2008	+	+	+	+	+	−	−	−	−	−	+	+	+	+	
Rosentritt 2010	+	+	+	+	+	−	−	−	−	−	+	+	+	−	
Rosentritt 2011	+	+	+	+	+	−	−	−	−	−	+	+	+	−	
Schultheis 2012	+	+	+	+	+	−	−	−	−	−	+	+	+	+	

Figure 2. Risk of bias assessment

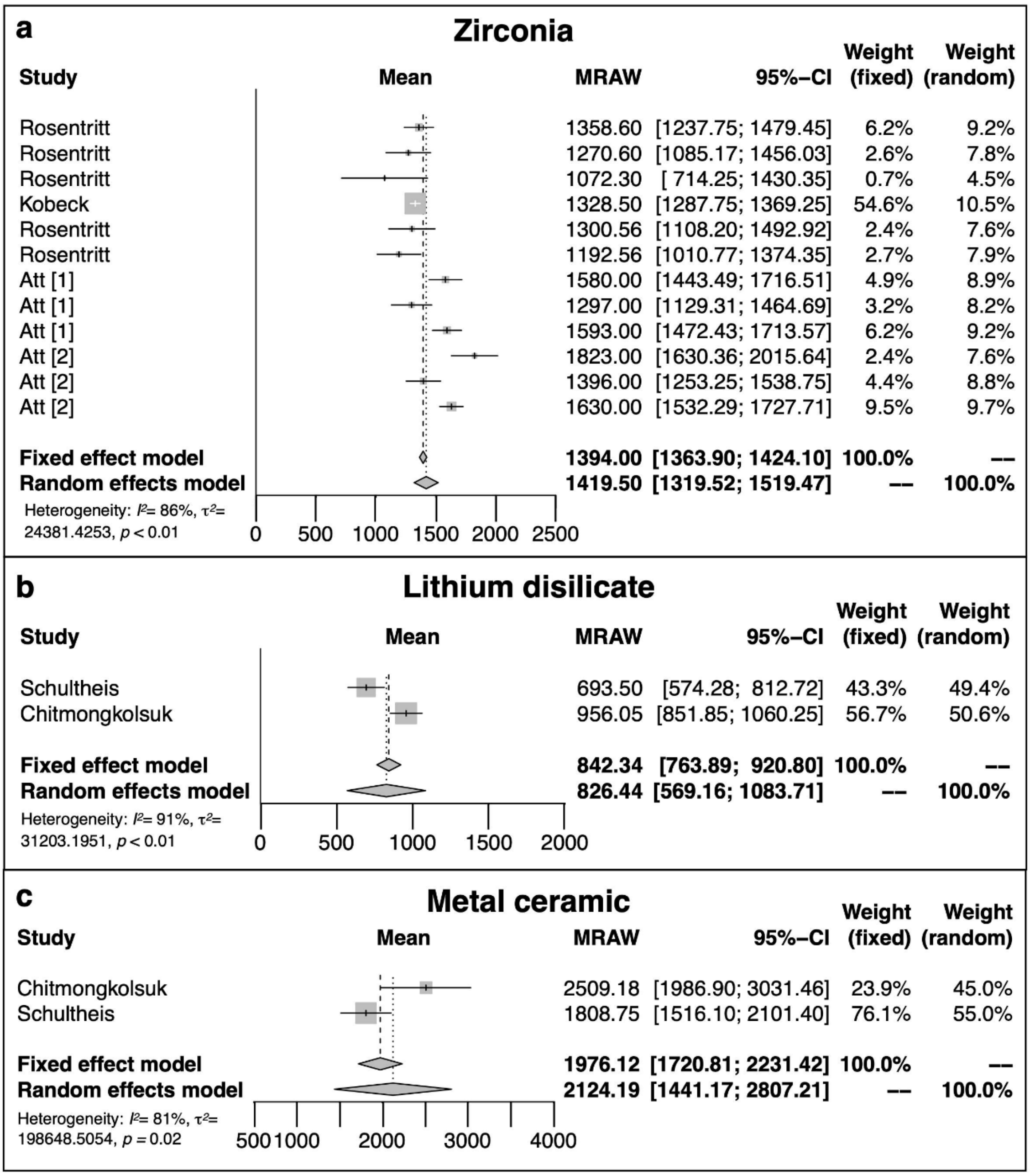

Figure 3: Fracture strength of the different analyzed materials: a) zirconia 3-unit fixed dental prosthesis; b) lithium disilicate 3-unit fixed dental prosthesis; c) of metal-ceramic 3-unit fixed dental prosthesis.

6. Capítulo 3

Mechanical behavior of three-unit fixed dental protheses restored with different endodontic retainers: an in vitro study and finite element analysis[3]

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[3]Artigo apresentado de acordo com as normas do periódico Clinical Oral Investigations.

Mechanical behavior of three-unit fixed dental protheses restored with different endodontic retainers: an *in vitro* study and finite element analysis

Abstract

Objective This study aimed to assess the effect of different retainers and their positions on the fracture strength of three-unit monolithic all ceramic rehabilitation of endodontically treated teeth (ETT).

Material and methods Three-unit fixed dental prosthesis (FDP) were confectioned to rehabilitate ETT restored with different intrarradicular retainers. Glass fiber post (GFP) and Cast post and core (CPC) were used in four different groups (n=80) according to their arrangement (Both abutments with GFP or CPC, Canine with CPC or GFP and second premolar with GFP or CPC). Mechanical cycling was performed before load to fracture test and 3D finite element analysis (FEA) was made on models with same parameters of *in vitro* test. Data for survival rate and fracture load values were analyzed with Kaplan Meyer and Kruskal Wallis tests (α = 0.05) respectively. Descriptive analysis of the Maximum principal stress was made after FEA.

Results No statistically significant differences were found for both, survival, with 99% survival rate, and load to fracture analyses (p=0.977). The higher Maximum principal stress values were found on the FDP region (152.8 MPa) compared with those found on teeth (26.33 Mpa) and retainer regions (22.72 MPa).

Conclusion Post material and arrangement does not affect the load to fracture of three-unit all ceramic FDP, since, due to tensile stress concentration, lithium disilicate glass ceramic seems to fail before the intrarradicular retainer.

Clinical relevance Endodontically treated teeth may serve as abutment for multiple FDP, understand biomechanical behavior of intrarradicular retainers on these ETTs may help clinical decisions.

Introdution

Three-unit fixed dental prostheses (FDPs) are usually the treatment of eligibility for dental rehabilitation after a single tooth loss, when implants cannot be indicated. For tooth replacement FDPs have higher patients' satisfaction is more favorable than removable partial dentures[1]. Also, clinical studies and systematic reviews on FDPs revealed excellent survival rates even after long observation periods[2, 3].

Several materials are available for three-unit FDP fabrication, ranging from metal-ceramic to veneered or monolayer ceramics[4]. Among them, the use of lithium disilicate glass ceramic, bi or mono layered, is growing mainly due its mechanical, aesthetic properties and for the satisfactory clinical results presented for this type of restoration (approximately 90% in up to 10-year follow-up period)[5-8].

Furthermore, it is a widely held view that endodontically treated teeth (ETT) is less favorable as abutments than vital teeth[9]. However, frequently it is necessary to use ETT as abutments of FDPs. Thus, two types of intracanal retainers are the most used in dental practice, the glass fiber post (GFP) and the cast post and core (CPC). The current literature shows similar performance of both retainers in unitary rehabilitations[10], however few studies evaluate the influence of the retainer in three-unit fixed dental prosthesis [11], and currently there are no studies evaluating the influence of different kinds of intracanal retainers on conventional three-unit FDP.

Aiming to improve the assumptions based on *in vitro* test results, finite element analyses (FEAs) may be a useful tool to be conducted for an actual test setup in which essential variables of the study can be altered, also FEA can calculate the stress distribution within an FDP. With a mathematical design, all variables can be tested. Therefore, FEA contributes by reducing the number of laboratory test and thus supports more cost-efficient development of dental prostheses[12, 13].

Thus, the aim of the present study was to assess, through an *in vitro* and a finite element analyses, the effect of different types of retainers and their positions on the fracture strength of 3-unit monolithic all ceramic rehabilitation of endodontically treated teeth. Testing the null hypothesis that neither retainer type, nor retainer position would affect the fracture strength of the restorations.

MATERIALS AND METHODS

Selection, preparation and randomization of specimens

Initially, the sample size was calculated using the methods described by Corrêa et al., 2017[14], based on these criteria the sample size estimated was 20 specimens per group (n=20).

One hundred and sixty (160) bovine incisors were selected for the study. The teeth were cleaned with a scalpel blade and analyzed under magnification (4x) (EyeMag ® Pro, Carl Zeiss, Gottingen, Germany), to detect any fracture/fissure or defect that could interfere the results. The teeth were cleaned and stored in 0.5% chloramine-T solution for seven days. After selection, the coronal portion of the teeth was sectioned with a diamond bur using a high-speed handpiece with water cooling. Eighty teeth were sectioned in 15 mm (to simulate inferior canine) and eighty teeth in 13 mm (to simulate second inferior pre-molar). The diameter of the canals was used as inclusion factor, the mesiodistal and buccolingual diameter of root canal were measured with a digital caliper (Blackjack, Extra Power in Brazil Imp. Exp. LTDA). To homogenize the sample, 2 mm diameter (corresponding to the diameter of the glass fiber pin White Post DC # 3, FGM, Joinville, Brazil) was defined, if this parameter was not achieved, the specimen was replaced. Measurements of the buccolingual and mesiodistal root diameters were also performed to ensure that these values corresponded to the mean diameters of human canines and first premolars.

After sample selection, endodontic treatment of the roots was performed with NiTi instruments (Dentisply Maillefer, Switzerland), associated with sodium hypochlorite 2.5% irrigation, and obturated using gutta-percha cones (Dentsply Maillefer, Switzerland) and calcium hydroxide base cement (Sealer 26, Dentsply Maillefer) by the lateral condensation technique. A periodontal ligament (PDL) was made as described by Wandscher et al., 2014[15], the specimens were randomized in pairs (1 with 15 mm and 1 with 13 mm) and embed together in acrylic resin using a parallelometer to ensure the correct position. The distance between the mesial surface of the canine root and the distal surface of the second premolar was approximately 23mm, which is the mean of human adult first pre-molars described in the literature (Fernandes, et al 2013).

After embedding, the specimens were randomly allocated into 4 experimental groups (Table 1). For this, the specimens were numbered from 1 to 80 and 4 random numerical sequences of 20 numbers were generated by a computer software (Random Allocator).

All specimens were prepared with White Post DC Fiber Pin System Drill # 3 (FGM, Joinville, SC, Brazil). The depth was 2/3 of the length of the duct, always maintaining at least 3 mm of apical sealing.

Restorative Strategies

Cast post and core

The root interior of each root was lubricated with water soluble gel and the acrylic resin (Duralay, Reliance Dental, USA) applied with the aid of a thin brush and prefabricated plastic pins were used (Pinjet, Ângelus, Londrina, Brazil) to copy the entire length of the root. The core was standardized using plastic matrices simulating a canine and second premolars abutments. The resin patterns were then casted with nickel-chrome alloys.

The cast post and cores were evaluated for adaptation with liquid carbon, then cleaned with isopropyl alcohol and its root portion blasted with aluminum oxide particles (110µm, pressure: 2.8 bars, 10mm distance for 15s). For cementation procedures, the root and/or coronary dentin were conditioned with 37% phosphoric acid (Condac, FGM, Joinvile, SC, Brazil) for 15s, cleaned with water for 10s, and the conduit was dried with paper cones (Dentsply Industry and Trade Ltda, Petropolis, Brazil). After conditioning a two-step etch-and-rinse adhesive system was applied (Ambar, FGM, Joinvile, SC, Brazil) according to the manufacturer's instruction. Then a dual cure resin cement (Allcem, FGM, Joinvile, SC, Brazil) was inserted into the root canal with the aid of mixing/applicator tips. Finally, the cores were positioned, the excess of cement was removed, and the light-curing performed for 40s on each face. All adhesive procedures were performed by only a previously trained operator.

Prefabricated Glass fiber post

Prior to cementation all the posts were sectioned with diamond burs according to the length of the preparation and standardization at 4 mm coronal height. After this step, the posts were cleaned with 70% ethyl alcohol and a silane coupling agent was applied (Prosil, FGM, Joinvile, SC, Brazil). Cementations procedures were similar to the above described regarding the conditioning, application of the adhesive system and resin cement.

After GFP cementation, the coronary portions were reconstructed with micro-hybrid composite resin (Opallis, FGM, Joinvile, SC, Brazil), using the incremental technique and the same plastic matrices used on the other groups to standardize the abutments.

Coronary Preparation

The cores were refined so that the axial faces have adequate inclinations to provide the retention and stability characteristics. Thus, the coronary refinements were made with 4138F, 4138FF, 3118F and 3118FF diamond burs (KG Sorensen®, Medical Burs Ind. And Com. Of Tips and Drills Surgical Ltda, Cotia - SP - Brazil). The preparations depth was standardized in 1.2 mm on the margins and 1.5 mm in all other regions.

Fabrication and cementation of lithium disilicate prostheses

For the manufacture of lithium disilicate prostheses, all specimens were scanned with an optical scanner (InEos Blue; Dentsply Sirona). A three-unit fixed dental prosthesis simulating mandibular left canine, first and second premolars was designed (inLab SW4.0; Dentsply Sirona) for each one of the specimens, and 80 special acrylic polymer blocks (Vita CAD-Waxx for inLab, VitaZahnfabrik) were milled on CAD/CAM (inLab MCXL; Dentsply Sirona). The anatomy was standardized as well as the thickness of the ceramic on the abutments and the connectors dimensions (figure 1).

After waxing of the restorations, feeder channels for the ceramic injection (sprues) were attached to the restoration. After fixing the sprues to the restoration, the assembly was fixed to a plastic base of an injection ring and invested with an investment material (Pressvest, Ivoclar Vivadent, Schaan, Lietchteinstein) and then the wax patterns were heated. Lithium disilicate-based ceramic ingots (IPS e.max Press A3.5, Ivoclar Vivadent, Schaan, Lietchteinstein) were injected on an injection furnace (Programat EP 5000, Ivoclar Vivadent, Schaan, Lietchteinstein). After injection, the restorations were removed from the investment rings and cleaned. All the procedures were made following the protocols described by the manufacturer.

For cementation, coronary remnants of the teeth abutment received phosphoric acid and adhesive using the same protocol as on the root canal. The internal surface of the restorations was conditioned with 10% hydrofluoric acid (Cond AC Porcelain, FGM, Joinvile, SC, Brazil) for 20s, washed abundantly with water and dried with air jets. Afterwards, Silane (Prosil) was applied on the ceramic surface and waited a 3 minutes-drying-period. A dual cure conventional resin cement (Allcem, FGM) was inserted into the inner surface of the restoration that was placed on the prepared teeth, until its complete adaptation. Exceeding cement was removed, and each face was light cured for 40s (Radii Cal, SDI Australia).

Mechanical cycling aging

After preparation, the specimens were placed in a mechanical fatigue simulator (Biocycle V2; Biopdi, São Carlos, SP, Brazil), immersed in water at a constant temperature of 37 ºC (± 2ºC). A piston (6mm) simulating the occlusal relationship of the antagonist teeth applied a force of 125 N at a frequency of 4 Hz for a maximum period of 1,200.000 cycles. Between the piston and the restoration, a polyester plastic strip was positioned to prevent direct contact between the metallic piston and the ceramic restoration.

For survival analysis specimens were evaluated every 500,000 cycles by a single operator on stereomicroscope (Discovery V-20, Zeiss, Goettingen, Germany) at a magnification of 15-75x.

Fracture load test

Specimens that survived aging by mechanical cycling were subjected to load testing for fracture in a universal testing machine (DL-1000, Emic, Sao Jose dos Pinhais, Brazil) at a speed of 1 mm/min until catastrophic fracture occurs. The force application piston and position were identical to those used for mechanical cycling.

Both, periodic follow-ups and fracture load testing, were performed by blind operator in relation to the experimental groups.

Failure analysis

Failures that occurred during testing were classified as reversible (ceramic fracture, restoration fracture, post fracture, and root fracture above the periodontal ligament) and irreversible (root fracture below the periodontal ligament). Analysis was performed with stereomicroscope (Discovery V20, Carl Zeiss, Germany) up to 75x magnification.

Statistical analysis

Specimen survival analysis was performed by the Kaplan Meyer method followed by the log rank test (α = 0.05). The analysis of the fracture load values was made by the Kruskal-Wallis test.

Analysis by Finite Element Method

Four three-dimensional models were obtained by design software (SolidWorks®, Dassault-Systèmes SolidWorks Corp, 2013). All parameters were simulated (roots lengths, periodontal ligament, dimensions of the posts, acrylic resin and ceramic FDP) in an identical scenario to those used in the laboratory test. One specimen was scanned to obtain a digital model with the exact dimensions of the *in vitro* test. The thickness of resin cement was determined as 0.1 mm (Figure 2).

After models' preparation, all the geometries were imported to a post-processing software (ANSYS 13.0, Houston, Texas), using the *stp* format, for meshing and boundary conditions application. (Figure 3). The interfaces were considered bonded and the edges of acrylic resin were considered fixed on the axes x, y and z. A 500 N force was applied at a point located on the occlusal portion of the distal connector, with a perpendicular angle with the occlusal surface, identically to the *in vitro* test. The fiber posts were considered orthotropic and other materials isotropic. The properties of all materials used in the models were obtained in the literature (Table 2). All materials were homogeneous and linear. The values of maximum principal stress ($\sigma 1$) were analyzed at the ceramic FDP, root and at the post material.

Results

Mechanical cycling aging

On the mechanical cycling test one FDP of the Gfgf group (Table 1) presented a failure, resulting in 99% of survival rate after 1.2 million cycles, and the log rank analysis showed no statistically significant differences between groups (p=0,392) as shown in Figure 4**.**

Load to fracture

Load to fracture values of all groups after fatigue are described in Table 3.

No statistically significant differences were found between the groups (p=977) as shown in table 3. The lowest fracture load value was 500,61 N in the group GfGf, while the highest load to fracture value was 2838,75 N in the group CpCp.

Fracture Analysis

All failures occurred in the present test were classified as reversible, since there were no failures below the periodontal ligament. Concerning to the reversible failures, 90 failures occurred in 79 specimens, 94.4% (85) occurred on the ceramic, 4.4% (4) in the core and 1.1% (1) on the retainer, as shown in table 4.

Finite element analysis

The analysis showed a similar stress distribution in all groups, a greater concentration of tensile stress occurred on the ceramic at the lower region of distal connector (Figure 5). Moreover, the stress generated on the teeth structure was similar comparing the groups, with the point of higher tensile concentration on crestal bone height. Regarding to the posts, the group restored with glass fiber post in both teeth presented the lower stress concentration values if compared with the other groups, also this concentration occurred in the coronal portion of the GFP. The groups restored with at least a CPC, the tensile concentration values were higher mainly on the interface between the post and remaining coronal part of the tooth (Figure 5).

Discussion

In this study, the survival rate and the fracture strength of 3-unit FDP confectioned in endodontically treated teeth restored with different types of intrarradicular retainers was assessed, using a model that tried to simulate all the oral conditions, like presence of periodontal ligament, oral temperature and masticatory force and frequency. The posts varied according to their material (glass fiber post with a composite resin core and metal cast post and core) and according to the tooth restored with each post (GFP in both abutment teeth; CPC in both abutment teeth; CPC in canine and GFP in second premolar and GFP in canine and CPC in second premolar). The main objective of this study was answer if different retainers would influence on the fracture strength of 3-unit FDP. Based on the results found in this study, the null hypothesis that there are no statistically significant differences for the fracture load of the different tested materials was accepted.

In vitro studies tests, despites their limitations, were created to investigate new dental materials, indications, to foresee longevity and failures [16]. Several precautions should be taken to ensure a study is as close to reality as possible, e.g. the use of mechanical loading, which increase predictive power of the *in vitro* test regarding to the clinical survival of restorations[17]. Also, the standardization of the specimen is essential to reach reliable results, so the use of CAD/CAM improves the accuracy of parameters for all specimens[18].

Several studies had evaluated the influence of different intrarradicular retainers and their conditions on unitary restorations [10, 14, 19-22], but few studies evaluated the influence of the post on three-unit cantilever FDP [11], and up to now there are no studies evaluating the influence of different types of posts on full-contour three-unit FDP, making it difficult to compare the results of the present study. However, on multiple FDP, it seems that endodontically treated teeth presents the same behavior as in unitary restoration, since no statistically significant differences were found between CPC and GFP agreeing with the findings described by Sarkis-Onofre et al., 2014[10]. ETT restored with three-unit FDP, the material of the prosthesis apparently is more influent than the type and arrangement of the retainers.

Regarding to the FDP material, lithium disilicate glass ceramic demonstrated satisfactory survival rates when used for three-unit FDPs [5], however these survival rates seems to decrease after aging as reported on the study of Garling et al, 2019 [7]. In the present study, the survival rate after mechanical cycling was 99%, only one failure occurred during the test, suggesting that it may have occurred an injection flaw which might generate a bubble inside the ceramic structure causing the premature failure [23]. Furthermore, the lower load to fracture presented was 500,61 N (on GfGf group), which is higher than the mean of human bite force on premolar region that ranges between 282 to 428N[24, 25], supporting the ceramic manufacturer’s indications that pressed lithium disilicate should only be used for three-unit FDP to restore anterior or premolar region.

The finite element tests may act as a complementary test, to validate the laboratory test findings[12]. Also, in this study, linear elasticity and isotropic behavior were assumed for almost all materials, except for glass fiber post which was considered anisotropic. This agrees with former FEA studies [26, 27], but still it is a limitation of this study. The *in vitro* test results can be explained by the stress distribution found on the FEA (Figure 5), since the ceramic maximum principal stress (σ) was much higher than those noted on the posts or on the tooth. Peaks of tensile stress were observed on the basal portion of the connector, these stresses concentration may be responsible for the failure of the prostheses by a crack propagation from the high tensile stress region up to the occlusal surface. These results are in agreement with those found by other researchers [13, 28].

Conclusion

Based on the results of the present study, it was possible to conclude that, post material and arrangement does not affect the load of the fracture of three-unit all ceramic FDP, since, due to the tensile stress concentration, lithium disilicate glass ceramic seems to fail before the intrarradicular retainer or remaining teeth structure. However, further studies, mostly clinical trials, on this topic should be developed.

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Tables

Table 1: Study design.

FDP material	Abutment teeth		
	Canine	Second Pre-Molar	Groups
Lithium disilicate	Glass fiber post	Glass fiber post	Gfgf
	Glass fiber post	Cast post and core	Gfcp
	Cast post and core	Glass fiber post	Cpgf
	Cast post and core	Cast post and core	Cpcp

Table 2: Materials, properties and references used for the finite element analysis

Material	Young Modululs (E)	Poison	Reference
Glass fiber post	Ex= 37.000 MPa Ey= 9.500 MPa Ez= 9.500 MPa Gxy= 3.1 Gxz= 3.5 Gyz= 3.1	Vxy= 0.27 Vxz= 0.34 Vyz= 0.27	Lanza et al., 2005[29]
Acrylic resin	2700 MPa	0.35	Ebadian, et al. (2012)[30]
Polyeter	0.05 MPa	0.45	Farah, et al.(1981)[31]
Dentin	18600 MPa	0.31	Ma et al., (2013)[32]
Gutta-percha	0.69 MPa	0.45	Ko, et al.32 (1992)[33]
Nickel-chrome	200000 MPa	0.31	Williams, et al.(1987)[34]
Composite resin (Oppalis)	4800 MPa	0.33	Correa et al 2018[14]
Resin cement (Allcem)	9800 MPa	0.3	Correa et al 2018[14]
Lithium disilicate	95000 MPa	0.25	Ma et al., (2013)[32]

Table 3: Load to fracture values (N)

Lithium Disilicate FDP			
Retainer	Median (25%/75%)	Mean (SD)	p value
CpGf	1252.58(1111.58/1644.48)	1382.05(513.70)	p= 0.977
GFCP	1315.58(1013.84/1880.94)	1449.61(528.98)	
GfGf	1329.60(1053.07/1885.18)	1431.85(479.43)	
CpCp	1315.58(1013.84/1796.55)	1429.54(500.84)	

SD= Standard deviation

Table 4. Failure modes occurred after load to fracture test

Reversible Failures										
Group	**Ceramic**						**Core Material**		**Retainer**		
	Crown		**Connector**			**Pontic**	**Canine**	**2º Premolar**	**Canine**	**2º Premolar**	**Total**
	Canine	**2º Premolar**	**Mesial**	**Distal**	**Both**						
CpGf	0	4	1	12	4	1	0	1	0	0	23
GfCp	1	4	1	8	8	1	1	0	1	0	25
GfGf	0	6	1	7	5	0	0	1	0	0	20
CpCp	0	1	1	13	4	2	0	0	0	0	21
Total	1	15	4	40	21	4	1	2	1	0	**89**

Figures

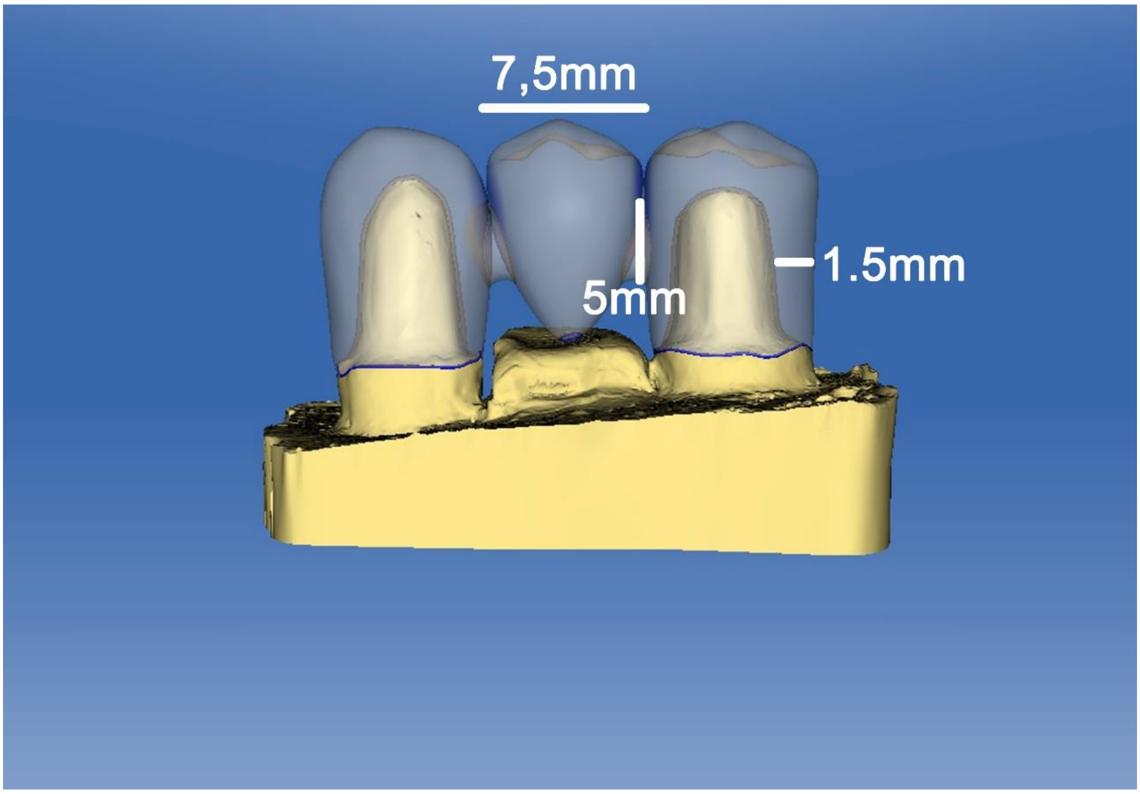

Figure 1: FDP standardized measures..

Figure 2: Three-dimensional model used for the FEA analysis

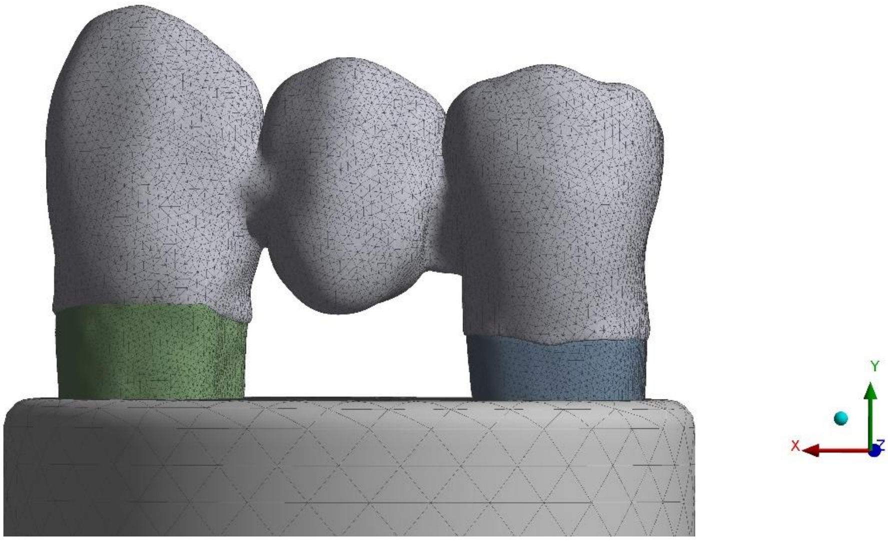

Figure 3: Geometric models after mesh application

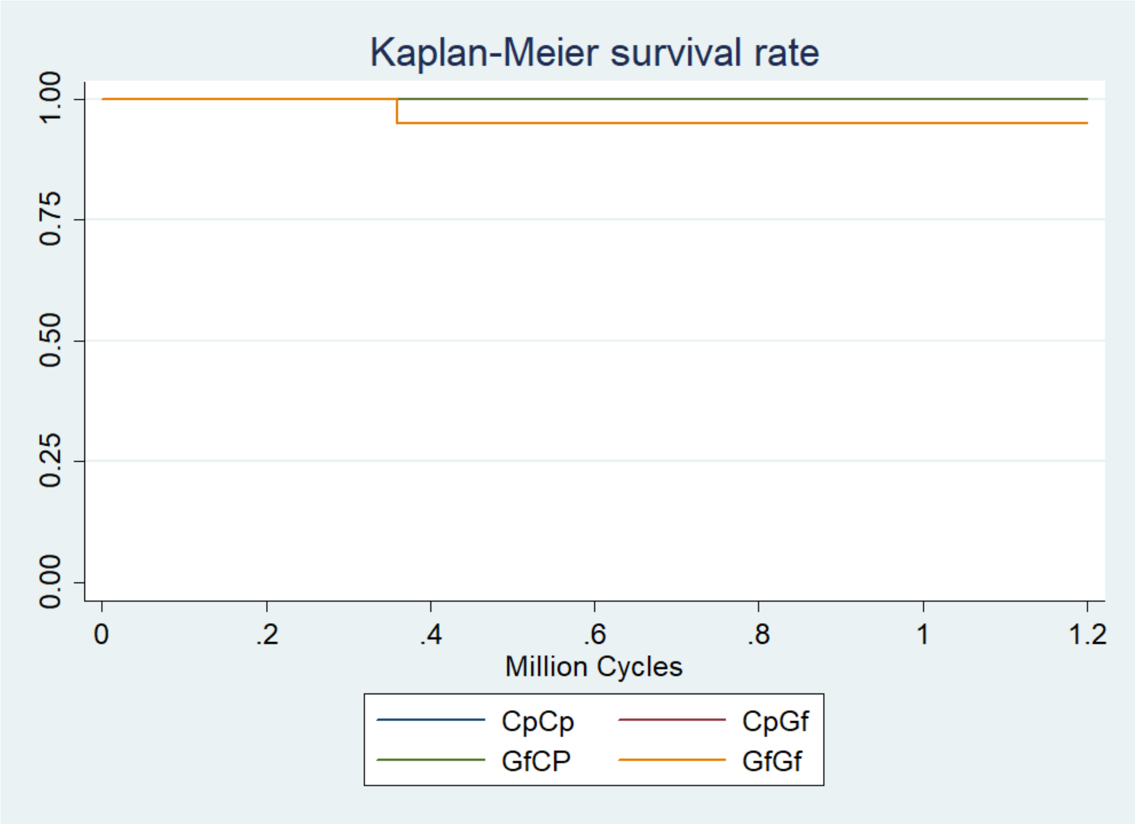

Figure 4: Kaplan-Meier survival curves

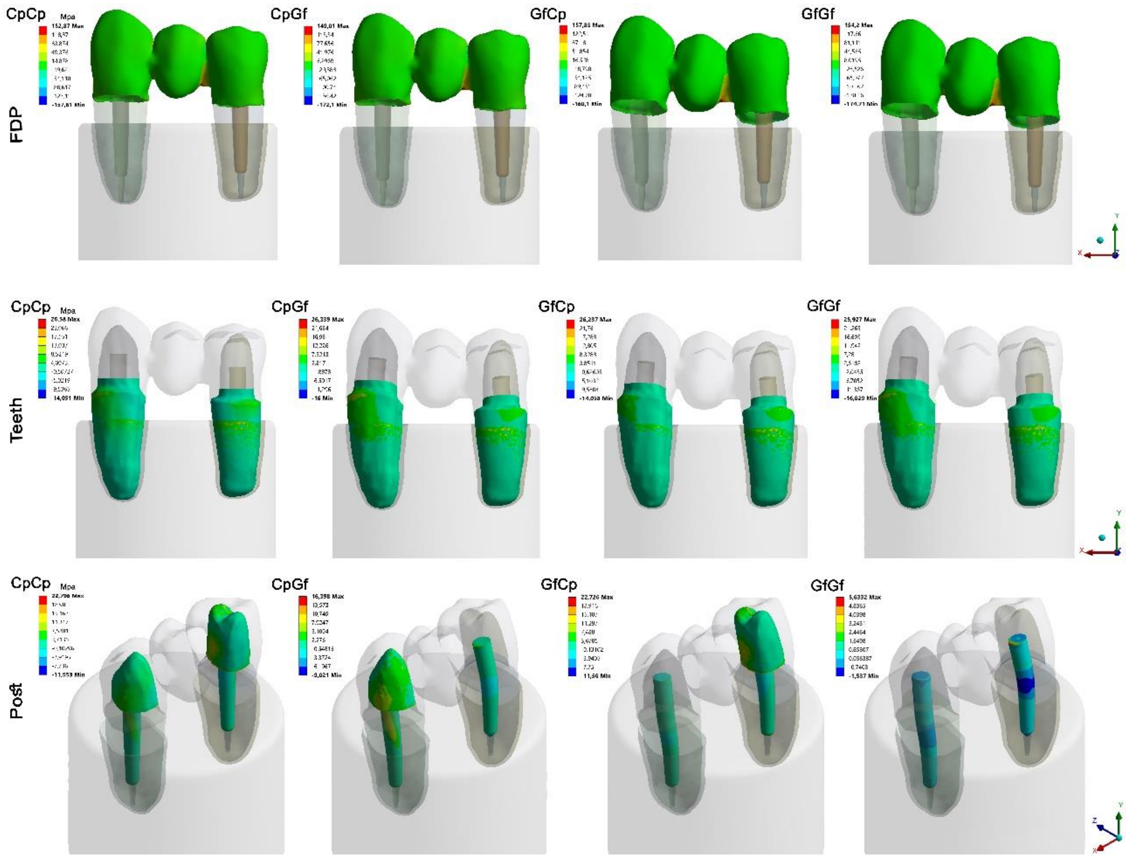

Figure 5: Maximum principal stress distribution after FEA analysis on different areas A) FDP: Fixed dental prosthesis; B) Remaining teeth structures; C) Posts used for each group.

7. Considerações finais

Tendo em vista os resultados apresentados no presente trabalho, pode-se concluir que a reabilitação de dentes tratados endodônticamente pode ser conduzida de formas distintas mantendo as taxas das sucesso, de modo que a utilização de pinos de fibra de vidro e núcleos metálicos fundidos pode ser utilizado de forma satisfatória independentemente do tipo de espaço a ser reabilitado. Além disso, os materiais disponíveis para a confecção de próteses fixas em cerâmica apresentam valores de resistência à fratura adequados, se respeitadas as corretas indicações dos materiais.

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