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TÉCNICAS DE RECOBRIMENTO CERÂMICO DE INFRAESTRUTURAS DE Y-TZP: INFLUÊNCIA NO COMPORTAMENTO MECÂNICO

Santa Maria, RS
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Tese apresentada ao Curso de Doutorado do Programa de Pós-Graduação em Ciências Odontológicas, Área de Concentração em Odontologia, ênfase em Prótese Dentária, da Universidade Federal de Santa Maria (UFSM, RS), como requisito parcial para a obtenção do título de **Doutora em Ciências Odontológicas.**

Orientadora: Profa. Dra. Liliana Gressler May

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Santa Maria, RS
2018

DEDICATÓRIA

Aos meu pais Carmem e Wilson, com amor e gratidão.

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(Madre Teresa de Calcutá)

RESUMO

TÉCNICAS DE RECOBRIMENTO CERÂMICO DE INFRAESTRUTURAS DE Y-TZP: INFLUÊNCIA NO COMPORTAMENTO MECÂNICO

AUTORA: Ana Maria Estivalete Marchionatti
ORIENTADORA: Liliana Gressler May

O presente trabalho, dividido em dois artigos, teve como objetivo avaliar a influência da técnica de recobrimento sobre o comportamento mecânico de estruturas cerâmicas com infraestrutura de Y-TZP. O primeiro artigo avaliou o efeito do método de cobertura na resistência flexural e carga à fratura de Y-TZP por meio de uma revisão sistemática com meta-análise. Foram realizadas buscas no PubMed/MEDLINE, Web of Science (Core Collection), Scopus e Embase. Dos 3242 artigos identificados, 241 foram selecionados para leitura na íntegra a partir da avaliação dos títulos e resumos segundo critérios de elegibilidade pré-definidos. Destes, 33 foram incluídos na revisão sistemática, sendo 32 considerados nas meta-análises. A busca manual nos artigos incluídos não resultou em estudos adicionais. Comparou-se o controle (estratificação manual) com a prensagem, fusão e cimentação da cobertura cerâmica. Para a resistência flexural, a meta-análise que comparou controle com prensagem não mostrou diferença estatística e os dois estudos que avaliaram cimentação tiveram resultados contraditórios, sendo que um favoreceu a estratificação manual e outro favoreceu a cimentação. Para a carga à fratura, foram realizadas três meta-análises: uma comparando estratificação manual com prensagem, uma com subgrupos para a técnica fusionada em comparação com estratificação manual e uma comparando a técnica cimentada com a estratificação manual. Houve semelhança estatística entre o controle e prensagem e entre controle e cimentação, porém a fusão com cerâmicas vítreas reforçadas por partículas foi estatisticamente superior ao controle. Concluiu-se que a fusão com cerâmicas reforçadas por partículas representa uma alternativa adequada para cobertura de Y-TZP. O segundo artigo investigou o efeito da técnica de cobertura cerâmica (fusão e cimentação) e o lado sob tração na resistência à fadiga de infraestruturas de Y-TZP com cobertura cerâmica em comparação com Y-TZP monolítica. Discos foram confeccionados de acordo com os grupos: M: zircônia monolítica, F-IT: técnica de fusão com infraestrutura sob tração, F-CT: fusão com cobertura sob tração, C-IT: técnica de cimentação com infraestrutura sob tração e C-CT: cimentação com cobertura sob tração. Foi realizado ensaio de fadiga (n=20) em água pelo método da escada em configuração *piston-on-three ball* (20 Hz por 750000 ciclos) e análise de elementos finitos. Houve diferença estatística entre todos os grupos. As médias de resistência à fadiga foram: M: 413,92 MPa, F-IT: 345,15 MPa, C-IT: 315,04 MPa, F-CT: 185,18 MPa e C-CT: 96,5 MPa. Os valores previstos pela análise de elementos finitos foram similares aos experimentais. Concluiu-se que a Y-TZP monolítica apresenta maior resistência à fadiga do que as demais técnicas e que o material sob tração influencia na resistência à fadiga, assim como a técnica de fusão apresenta maior resistência à fadiga do que a cimentação.

Palavas-chave: CAD/CAM. Carregamento Cíclico. Resistência Flexural. Meta-Análise.

ABSTRACT

Y-TZP FRAMEWORKS VENEERING TECHNIQUES: INFLUENCE ON THE MECHANICAL BEHAVIOR

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The present study, divided in two articles, aimed to evaluate the influence of veneering ceramic techniques on the mechanical behavior of bilayer ceramic with Y-TZP frameworks. The first paper assessed the effect of the veneering method on the flexural strength and load to failure of Y-TZP by means of a systematic review and meta-analysis. Searches were performed on PubMed/MEDLINE, Web of Science (Core Collection), Scopus and Embase. From 3242 identified articles, 241 were selected for full-text analysis from titles and abstracts reviewing, according to pre-determined eligibility criteria. Thirty-three papers were included in the systematic review, from which 32 were considered in the meta-analyses. A manual search of the included studies did not retrieve additional studies. The control (hand-layered) was compared with pressed, fused and cemented veneering. Considering flexural strength, the meta-analysis comparing hand-layered and pressed methods did not show statistical difference and the two studies evaluating cemented method showed contradictory results, in which one of them favored the hand-layered and the other one favored the cemented technique. Regarding failure load, three meta-analyses were performed: one comparing hand-layered and pressed, one by subgroups for the fused technique in comparison with hand-layered and the other comparing cemented and hand-layered techniques. The results showed statistical equivalence between control and pressed and between control and cemented methods, but fused method with particle-filled glass ceramics was statistically superior to control. It was concluded that fused method with particle-filled glass ceramics represents and appropriate alternative for Y-TZP veneering. The second paper investigated the effect of the veneering technique (fused and cemented) and the side under tension on the fatigue strength of veneered Y-TZP in comparison with monolithic Y-TZP. Discs were fabricated according to the groups: Z: monolithic zirconia, F-FT: fused method with framework under tension, F-VT: fused with veneer under tension, C-FT: cemented method with framework under tension and C-VT: cemented with veneer under tension. Fatigue strength test (n=20) was performed in water using the staircase approach with piston-on-three ball design at 20 Hz and 750.000 cycles, as well as finite element analysis. There was statistical difference among all groups. Fatigue strength means were: Z: 413,92 MPa, F-FT: 345,15 MPa, C-FT: 315,04 MPa, F-VT: 185,18 MPa and C-VT: 96,5 MPa. Finite element analysis predicted values were similar to experimental values. It was concluded that monolithic Y-TZP has higher fatigue strength than the other methods and that the material under tension affects fatigue strength, as well as the fused technique presents higher fatigue strength than the cemented technique.

Keywords: CAD/CAM. Cyclic Loading. Flexural Strength. Meta-Analysis.

SUMÁRIO

1 INTRODUÇÃO

A zircônia tetragonal policristalina estabilizada por óxido de ítrio (Y-TZP) tem sido amplamente utilizada em tratamentos restauradores por apresentar características de biocompatibilidade, longevidade e resistência mecânica superior às demais cerâmicas odontológicas (NÄPÄNKANGAS; PIHLAJA; RAUSTIA, 2015). O desenvolvimento da tecnologia CAD/CAM (*Computer Aided Design/Computer Aided Manufacturing*) possibilitou a ampla aceitação do uso de Y-TZP como uma alternativa mais estética que o metal para infraestruturas de próteses fixas totalmente cerâmicas (PREIS et al., 2013; OH et al., 2015).

Mesmo com a possibilidade de fabricação de restaurações de zircônia monolítica, por apresentar estrutura altamente cristalina, a Y-TZP é opaca e a cobertura por uma vitro-cerâmica melhora suas propriedades estéticas (BEUER et al., 2012; PREIS et al., 2013). Nesse sentido, a principal causa de falhas clínicas de restaurações de Y-TZP com cobertura cerâmica é o *chipping* (fratura dentro da cerâmica de cobertura) ou delaminação (fratura na interface infraestrutura/cobertura) (MORÁGUEZ; WISKOTT; SCHERRER, 2015; MONACO et al., 2013; NÄPÄNKANGAS; PIHLAJA; RAUSTIA, 2015; PJETURSSON et al., 2015). Tais complicações ocorrem com maior frequência que com próteses metalo-cerâmicas (PJETURSSON et al., 2015). Além dos fatores relacionados ao paciente, como características físico-químicas do ambiente oral e variáveis mecânicas da mastigação, a fratura da cerâmica de cobertura pode ser influenciada por tensões residuais introduzidas no sistema cerâmico como consequência do comportamento térmico dos materiais (diferença de difusividade térmica e do coeficiente de expansão térmica entre as duas cerâmicas, taxa de aquecimento, gradientes de temperatura no resfriamento), por espessura, por anatomia da restauração, por diferença de módulo de elasticidade e por técnica de processamento (COSTA et al., 2014; LIMA et al., 2013; OH et al., 2015; PREIS et al., 2013). Assim, esforços foram orientados para o desenvolvimento de materiais e técnicas de processamento para otimizar a performance de restaurações de Y-TZP/cobertura cerâmica e reduzir a ocorrência de eventos relacionados à fadiga (COSTA et al., 2014; GUESS et al., 2013).

Deve-se considerar que as cerâmicas são materiais friáveis suscetíveis à fadiga, que, por definição, é a fratura progressiva do material sob cargas repetidas (WISKOTT; NICHOLLS; BELSER, 1995). Clinicamente é mais provável que ocorram fraturas resultantes de cargas repetidas com intensidade abaixo da resistência nominal durante um longo período que fraturas após carga intensa e súbita (ZHANG; SAILER; LAWN, 2013; WISKOTT; NICHOLLS; BELSER, 1995). No ambiente oral, as restaurações são submetidas a cargas mecânicas mastigatórias e à presença de umidade, levando ao fenômeno de crescimento lento de trincas (*slow crack growth*), com redução da resistência ao longo do tempo (GONZAGA et al., 2011). As moléculas de água agem na ponta da trinca sob tensão, quebrando ligações coesivas e causando o crescimento lento da trinca até o tamanho crítico para fratura (ZHANG; SAILER; LAWN, 2013; GONZAGA et al., 2011). Assim, considerando-se os desafios aos quais os materiais cerâmicos estão sujeitos no ambiente oral, torna-se necessária a avaliação do comportamento das cerâmicas com testes de fadiga para estimar mais precisamente seu comportamento em longo prazo.

Apesar de haver estudos avaliando resistência flexural e carga à fratura de espécimes de zircônia, comparando-se as técnicas de aplicação de cerâmica de cobertura, não está estabelecido na literatura o método mais favorável para o comportamento mecânico das estruturas cerâmicas. Assim, no presente trabalho, serão apresentados dois artigos avaliando o efeito da técnica de recobrimento de Y-TZP no comportamento mecânico de estruturas cerâmicas. Por haver uma quantidade considerável de artigos com achados divergentes avaliando a influência da técnica de cobertura cerâmica na resistência flexural e carga à fratura, observou-se a necessidade de realização de uma revisão sistemática para sintetizar a evidência existente sobre o assunto. Os achados dos estudos serão reportados em detalhes no primeiro artigo, intitulado "***Does veneering technique affect the flexural strength or load to failure of bilayer Y-TZP? A systematic review and meta-analysis***", que objetivou avaliar o efeito da técnica de cobertura cerâmica na resistência flexural e carga à fratura de estruturas cerâmicas com infraestrutura de Y-TZP. A partir dos resultados desse estudo, observou-se que a técnica por CAD/CAM fusionada é promissora, porém há carência de estudos avaliando resistência à fadiga com esse método. Além disso, a técnica por CAD/CAM cimentada mostrou-se inconclusiva, havendo necessidade de mais estudos avaliando tal método. Assim, o segundo artigo, intitulado "***Fatigue flexural strength and finite element analysis of monolithic and multilayer Y-TZP***", teve como objetivo avaliar as técnicas de fusão e cimentação da cobertura cerâmica sobre infraestruturas de Y-TZP, assim como a influência da cerâmica testada sob tração, em comparação com zircônia monolítica.

2 REVISÃO DE LITERATURA

2.1 MÉTODOS DE COBERTURA DE Y-TZP

Em sistemas cerâmicos que apresentam Y-TZP como infraestrutura, a mesma é usinada em estado densamente ou pré-sinterizado e então é feita a cobertura cerâmica por meio de diversas técnicas (COSTA et al., 2014). A técnica de cobertura deve otimizar a resistência dessa camada e reduzir tensões residuais geradas por diferentes gradientes térmicos (SILVA et al., 2017).

O método de cobertura de infraestruturas de Y-TZP mais tradicional é a estratificação manual, em que o pó da cerâmica é misturado ao líquido modelador e a mistura é aplicada sobre a Y-TZP em tamanhos maiores que a restauração para compensar a contração que ocorre no forno durante a sinterização (STAWARCZYC et al., 2011). A principal vantagem dessa técnica é a estética, pois as cerâmicas predominantemente vítreas são as que melhor mimetizam as propriedades ópticas de translucidez e cor da estrutura dental (KELLY, 2004). Essa técnica é considerada sensível, pois são necessárias várias queimas até a obtenção do elemento final, com sucessivos ciclos de sinterização e resfriamento (LIMA et al., 2013), além da alta probabilidade de gerar defeitos de processamento, impurezas e porosidades que podem potencialmente causar concentração de tensões e falha do material restaurador (STAWARCZYC et al., 2011; SILVA et al., 2017). Outra desvantagem é o alto custo em função do longo tempo consumido em sucessivas queimas (BEUER et al., 2012).

Para o recobrimento por prensagem ou injeção, é realizada a ceroplastia da cobertura cerâmica com a forma final da restauração e então o conjunto é incluído em anel de revestimento, para então se realizar a injeção da cerâmica sobre a infraestrutura (KANAT-ERTÜRK et al., 2015; LIMA et al., 2013) minimizando a ocorrência de porosidades (LIMA et al., 2013). Segundo Stawarczyc et al. (2011), essa técnica é mais fácil e rápida, não há contração de sinterização e há menor influência do operador em comparação com a estratificação manual.

Além dos métodos mais comuns, recentemente foram desenvolvidas técnicas de cobertura por CAD/CAM (também conhecidas como "*file-splitting*"), que consistem na usinagem da cobertura cerâmica e posterior união à infraestrutura por meio de uma cerâmica de fusão (KANAT et al., 2014; NOSSAIR; ABOUSHELIB; MORSI, 2015; SCHMITTER; MUELLER; RUES, 2012) ou cimentação com cimento resinoso (ALBRECHT et al., 2011; KANAT-ERTÜRK et al., 2015; PHARR et al., 2016; SCHMITTER; MUELLER; RUES, 2013), na tentativa de reduzir tensões residuais (SILVA et al., 2017). Esse método reduz o número de etapas laboratoriais (KANAT-ERTÜRK et al., 2015) e permite controle preciso do perfil de emergência e oclusão com os antagonistas pelo uso do *software* (NOSSAIR; ABOUSHELIB; MORSI, 2015). Um desses sistemas é o *Rapid Layer Technology*, da Vita, em que a infraestrutura de Y-TZP e a cobertura de cerâmica feldspática usinadas são unidas por um cimento resinoso dual (VITA, 2011). Outro *CAD-on*, da Ivoclar Vivadent, em que a cobertura é unida à Y-TZP por uma cerâmica de fusão, o *Crystall./Connect* (IVOCLAR VIVADENT, 2015). Nessa técnica, a cobertura é usinada a partir de um bloco de dissilicato de lítio, que possui propriedades mecânicas superiores às cerâmicas feldspáticas (SILVA et al., 2017). Ainda, para o sistema Lava DVS, da 3M ESPE, que não está mais disponível no mercado, a infraestrutura de Y-TZP e cobertura de cerâmica vítrea são unidas pela cerâmica de fusão *Lava DVS Fusion Porcelain* (3M ESPE, 2010).

A microestrutura, composição e indicações clínicas para cobertura de Y-TZP de algumas cerâmicas disponíveis para cada técnica estão descritas na Tabela 1.

Tabela 1- Cerâmicas para cobertura de Y-TZP.

Estratificação manual

Cerâmica	Microestrutura	Composição	Indicações para cobertura de Y-TZP
IPS e.max Ceram (Ivoclar Vivadent)	Vítrea de nanofluorapatita	SiO_2, Al_2O_3, ZnO_2, Na_2O, K_2O, ZrO, CaO, P_2O_5, fluoreto e pigmentos (IVOCLAR VIVADENT, 2009)	Coroas e pontes fixas; estratificação de estruturas, pilares de implantes e supraestruturas de implantes
Vita VM9 (Vita)	Feldspática	SiO_2, Al_2O_3, Na_2O, K_2O, CaO, ZrO_2, B_2O_3 (VITA 2016)	Coroas e pontes fixas

Prensagem

Cerâmica	Microestrutura	Composição	Indicações para cobertura de Y-TZP
IPS e.max ZirPress (Ivoclar Vivadent)	Vítrea de fluorapatita	SiO_2, Li_2O, Na_2O, K_2O, MgO, Al_2O_3, CaO, ZrO_2, P_2O_5 e outros óxidos (IVOCLAR VIVADENT, 2009)	Coroas e pontes fixas; sobre estruturas de pontes retidas por inlays; sobre supraestruturas de implantes; sobre estruturas, pilares de implantes e supraestruturas de implantes
Vita PM9 (Vita)	Feldspática	SiO_2, Al_2O_3, K_2O, Na_2O, B_2O_3 (LIMA et al., 2013)	Coroas e pontes fixas (VITA 2009)

CAD/CAM (file-splitting)

Sistema	Cerâmica	Microestrutura	Composição	Indicações para cobertura de Y-TZP	Cerâmica de fusão ou cimento

CAD-on (Ivoclar Vivadent)	IPS e.max CAD (Ivoclar Vivadent)	Vítrea de dissilicato de lítio	SiO_2, Li_2O, K_2O, MgO, Al_2O_3, P_2O_5 e outros óxidos	Coroas e pontes fixas sobre dentes e implantes	Cerâmica IPS e.max CAD Crystall./Connect (Ivoclar Vivadent)
Vita Rapid Layer Technology (Vita)	VITABLOCS TriLuxe forte (Vita) e VITABLOCS Mark II (Vita)	Feldspática	SiO_2, Al_2O_3, Na_2O, K_2O, CaO, TiO_2 e outros óxidos (VITA 2012)	Coroas e pontes fixas	Cimento Panavia 21 (Kuraray), Panavia F 2.0 (Kuraray) ou RelyX Unicem 2 Clicker (3M ESPE)

2.2 ESTUDOS *IN VITRO* AVALIANDO MÉTODOS DE COBERTURA DE Y-TZP

Como será visto na revisão sistemática que compõe o primeiro artigo desta tese, muitos estudos *in vitro* compararam o efeito da técnica de cobertura na resistência flexural e carga à fratura de Y-TZP com testes monotônicos.

Ao comparar a técnica de estratificação manual, prensagem e CAD/CAM cimentado com cerâmica feldspática, Kanat-Erturk et al. (2015) e Al-Wahadni, Shahin e Kurtz (2016) encontraram maior carga à fratura de coroas em forma de molar cimentadas a núcleos de cromo-cobalto para a estratificação manual, seguida pela prensagem e então pela cimentação, com diferença estatística entre todos os grupos. Outro estudo avaliou a carga à fratura de espécimes compostos por pilares de zircônia para pré-molares unidos à cerâmica de cobertura: houve carga à fratura estatisticamente superior para a técnica CAD/CAM cimentada com cobertura de dissilicato de lítio e ausência de diferença estatística entre estratificação manual e prensagem (ALBRECHT et al., 2011). No estudo de Pharr et al. (2016), houve diferença estatisticamente significante entre todos os grupos, com a seguinte ordem decrescente de resistência flexural: estratificação manual, prensagem e CAD/CAM cimentado (cerâmica feldspática).

Dos estudos que compararam a estratificação manual e CAD/CAM cimentado com cobertura de cerâmica feldspática, Costa et al. (2014) encontraram resistência flexural estatisticamente superior para a técnica CAD/CAM, enquanto Schmitter, Mueller e Rues (2013) encontraram carga à fratura estatisticamente superior para a técnica de estratificação manual com coroas em forma de molar cimentadas a núcleos de cromo-cobalto.

Comparando-se a estratificação manual, prensagem e método CAD/CAM fusionado, o estudo de Beuer et al. (2009) mostrou maior carga à fratura de coroas em forma de molar cimentadas a núcleos de cromo-cobalto para o grupo CAD/CAM fusionado com dissilicato de lítio, seguido por estratificação manual e prensagem, com diferença estatística entre os grupos. Os estudos de Preis et al. (2013) e Kanat et al. (2014) encontraram carga à fratura estatisticamente similar para a técnica CAD/CAM fusionada (com cerâmica feldspática e dissilicato de lítio, respectivamente) e estratificação manual, assim como valor estatisticamente inferior para a prensagem. Foram usadas coroas em forma de molar cimentadas a núcleos resinosos e de aço, respectivamente. Kanat et al. (2014) também avaliaram resistência flexural, mostrando resultados estatisticamente similares para CAD/CAM e prensagem e inferior para estratificação manual. Choi et al. (2012) encontraram diferença estatística entre todos os grupos para coroas em forma de molar cimentadas a núcleos de titânio, sendo a prensagem superior, estratificação manual intermediária e CAD/CAM fusionado (vitro-cerâmica) inferior.

Alguns estudos compararam a técnica de estratificação manual e CAD/CAM fusionado. Obermeier et al. (2017) não encontraram diferença estatisticamente significante para carga à fratura de coroas em forma de molar parafusadas a implantes confeccionadas por estratificação manual e CAD/CAM fusionada com cobertura de dissilicato de lítio. No estudo de Schmitter et al. (2012), houve carga à fratura estatisticamente superior para o CAD/CAM com dissilicato de lítio em comparação com a estratificação manual para coroas em forma de molar cimentadas a núcleos de cromo-cobalto. Beuer et al. (2012) compararam carga à fratura de coroas em forma de molar cimentadas a núcleos metálicos confeccionadas pelas técnicas de estratificação manual e CAD/CAM fusionada com dissilicato de lítio. O CAD/CAM foi estatisticamente superior à estratificação manual. Outro estudo não mostrou diferença estatística entre estratificação manual e CAD/CAM fusionado com cerâmica feldspática para carga à fratura de coroas em forma de molar cimentadas a núcleos de resina composta (BALADHANDAYUTHAM; LAWSON; BURGESS, 2015).

No estudo de Schmitter et al. (2014), foi comparada a carga à fratura de coroas com forma de molar confeccionadas por CAD/CAM fusionado e cimentado com dissilicato de lítio cimentadas a núcleos de cromo-cobalto. Não houve diferença estatística entre os grupos para carga à fratura imediata, porém o grupo CAD/CAM fusionado foi estatisticamente superior quando a carga à fratura foi feita após ciclagem térmica e mecânica. Outro estudo avaliou a carga à fratura de pilares de zircônia com cobertura cerâmica pelas técnicas de estratificação manual, CAD/CAM fusionado e CAD/CAM cimentado. O grupo cimentado apresentou maior carga à fratura, seguido pela fusão e estratificação manual, com diferença estatisticamente significante entre todos os grupos (NOSSAIR, ABOUSHELIB e MORSI, 2015).

Güngor e Nemli (2017) avaliaram a carga à fratura de coroas com forma de molar cimentadas em núcleos de resina após ciclagem mecânica e térmica. Foram comparadas as técnicas de cobertura por estratificação manual com cerâmica feldspática, prensagem com dissilicato de lítio, CAD/CAM fusionado com dissilicato de lítio, CAD/CAM cimentado com dissilicato de lítio e CAD/CAM cimentado com cerâmica feldspática. Como resultados, não houve diferença estatística entre os grupos CAD/CAM fusionado e cimentado com dissilicato de lítio. O grupo CAD/CAM fusionado com dissilicato de lítio foi estatisticamente superior aos grupos CAD/CAM cimentado com cerâmica feldspática, prensagem e estratificação manual, os quais foram similares.

O estudo de Basso et al. (2015) mostrou resultados semelhantes para a resistência flexural uniaxial, resistência característica e módulo de Weibull de Y-TZP monolítica e com cobertura pela técnica CAD/CAM fusionada com dissilicato de lítio. Os autores justificaram o desempenho comparável da técnica CAD/CAM à zircônia monolítica em função de a Y-TZP ter sido testada sob tração em ambos os casos, gerando um comportamento mecânico similar da zircônia monolítica e com cobertura cerâmica. Além disso, explicou-se que o conjunto formado pela Y-TZP coberta com a técnica CAD-on comportou-se como uma estrutura homogênea, sem sofrer deflexão ou delaminação na interface. Alessandretti et al. (2017) também encontraram carga à fratura estatisticamente similar para discos de Y-TZP monolítica e com cobertura pelo método CAD/CAM fusionado com dissilicato de lítio cimentados a núcleos de resina epóxi reforçada por fibras de vidro, porém superior à estratificação manual.

As cerâmicas são suscetíveis à fadiga, que é a degradação estrutural por tensões mecânicas abaixo da resistência do material e pela ação da água em defeitos pré-existentes, o que leva ao crescimento lento de trincas ao longo do tempo (GONZAGA et al., 2011; KELLY et al., 2017). Os ensaios de fadiga são mais capazes de produzir uma condição de acúmulo de dano que ensaios monotônicos (ZHANG; SAILER; LAWN, 2013; KELLY et al., 2017). Apesar de haver estudos com envelhecimento prévio ao teste monotônico, há poucos estudos comparando técnicas de recobrimento por meio de ensaios de fadiga. Como será visto, na revisão sistemática no capítulo seguinte, o estudo de Baldassarri et al. (2011) indica que os valores de carga para fratura para a técnica de estratificação manual foram estatisticamente superiores em relação à prensagem com o método de fadiga *step-stress*. Ainda, nos estudos de Guess (2009) e Guess et al. (2013), o método *step-stress* foi utilizado para cálculo da confiabilidade, a qual foi comparável para estratificação manual e prensagem (GUESS, 2009), usando-se desenho anatômico da infraestrutura, e superior para estratificação manual em comparação à prensagem, usando-se infraestrutura com desenho convencional (GUESS et al., 2013).

Considerando-se o método CAD/CAM, Basso et al. (2016) determinaram o módulo de Weibull de pontes fixas de três elementos confeccionadas pela técnica CAD/CAM fusionada com dissilicato de lítio cimentadas em pilares de epóxi reforçada por fibras de vidro, o qual foi superior com teste monotônico rápido em comparação ao teste de fadiga *step-stress*, mostrando que restaurações confeccionadas com tal técnica apresentam aumento da variabilidade quando submetidas à fadiga cíclica.

2.3 ESTUDOS CLÍNICOS AVALIANDO MÉTODOS DE COBERTURA DE Y-TZP

Existem poucos estudos clínico comparando técnicas de cobertura de Y-TZP. Grohmann et al. (2015), por meio de um ensaio clínico randomizado multicêntrico, avaliaram a sobrevivência e complicações de 60 pontes fixas de três elementos confeccionadas pela técnica de estratificação manual (n=30) e por CAD/CAM fusionado com dissilicato de lítio (n=30). Após um ano de acompanhamento, não houve fraturas catastróficas envolvendo a infraestrutura. Não houve diferença estatística entre os grupos em relação às complicações. A ocorrência de fratura da cerâmica de cobertura foi similar entre os grupos: 11% no grupo com cobertura por CAD/CAM e 10.3% no grupo por estratificação manual.

Seydler e Schmitter (2015) compararam clinicamente 60 coroas monolíticas de dissilicato de lítio (n=30) e confeccionadas pela técnica CAD/CAM fusionada com dissilicato de lítio (n=30), cimentadas em molares. Após 2 anos de acompanhamento, não ocorreram complicações técnicas (como *chipping* e fraturas) em nenhum grupo.

Belli et al. (2016) reuniram informações provenientes de um banco de dados de restaurações protéticas. Pontes fixas confeccionadas por CAD/CAM fusionado com dissilicato de lítio (535 restaurações com tempo médio de avaliação de 380 dias), por estratificação manual (364 restaurações com tempo médio de avaliação de 294 dias) e com zircônia monolítica (129 restaurações com tempo médio de avaliação de 263 dias) não apresentaram diferença estatística para a sobrevivência. Houve 21 falhas para o método CAD/CAM fusionado, 3 falhas para a estratificação manual e 0 falhas para a zircônia monolítica. Coroas confeccionadas com dissilicato de lítio monolítico (9053 restaurações com tempo médio de avaliação de 633 dias) apresentaram sobrevivência estatisticamente inferior à técnica CAD/CAM fusionada (3095 restaurações com tempo médio de avaliação de 643 dias) e zircônia monolítica (716 restaurações com tempo médio de avaliação de 102 dias). Houve 111 falhas para o dissilicato de lítio monolítico, 19 falhas para a técnica CAD/CAM fusionada e 0 falhas para a zircônia monolítica.

2.4 ANÁLISE DE ELEMENTOS FINITOS (FEA) AVALIANDO MÉTODOS DE COBERTURA DE Y-TZP

A análise de elementos finitos é um método matemático em que um objeto é subdividido em elementos com as mesmas propriedades originais. O método é usado para avaliar a distribuição de tensões em diversas áreas, inclusive em estudos em Odontologia (LOTTI et al., 2006). A combinação de FEA com testes experimentais permite melhor entendimento do comportamento mecânico e das falhas dos materiais (WANDSCHER et al., 2015).

No estudo de Schmitter, Mueller e Rues (2012), coroas em forma de molar cimentadas a núcleos de cromo-cobalto e dentina foram simuladas com cobertura pelo método CAD/CAM fusionado com dissilicato de lítio e foi aplicada carga com esfera de aço. Observou-se alta tensão principal de tração em torno do local de aplicação de carga e nas interfaces. A rigidez do núcleo (dentina ou cromo-cobalto) não influenciou na concentração de tensões na cerâmica de cobertura e de fusão, porém quanto mais rígido o núcleo, maior foi a tensão máxima de tração na superfície interna da zircônia.

Schmitter, Mueller e Rues (2013) simularam coroas com forma de molar e aplicação de carga com esfera de aço. Foram usados diferentes módulos de elasticidade para a interface entre Y-TZP e cerâmica feldspática: 3,5 GPa, 18,5 GPa (correspondentes a cimentos resinosos) e 70 GPa (correspondente à cerâmica feldspática, simulando a estratificação manual). O núcleo não foi incluído nos cálculos. A tensão máxima de tração na superfície interna da cerâmica de cobertura foi reduzida com o aumento do módulo de elasticidade.

Schmitter et al. (2014) avaliaram a distribuição de tensões em coroas com forma de molar ao carregamento com pistão de aço. A cobertura de dissilicato de lítio foi simulada com as técnicas de confecção CAD/CAM fusionado e cimentado. O núcleo não foi incluído nos cálculos. Observou-se concentração de tensões em torno da área de aplicação de carga. Houve menor tensão de tração e compressão na infraestrutura para o grupo cimentado. A maior tensão de tração para o grupo cimentado ocorreu na região interna da cerâmica de cobertura, enquanto para o grupo fusionado ocorreu na camada da cerâmica de fusão.

No estudo de Costa et al. (2014), foi simulado teste de flexão biaxial com configuração *ball-on-ring* de discos de Y-TZP com cobertura pela técnica convencional e cimentação de cerâmica feldspática. Foi aplicada carga de 350 N e calculada a Tensão Máxima Principal. A tensão de tração dentro da camada de Y-TZP permaneceu abaixo da resistência à flexão esperada do material, e a tensão na superfície inferior da cerâmica de cobertura, em contato com a YTZP ou cimento resinoso, foi maior para o grupo cimentado.

No estudo de Kanat et al. (2014), foram calculadas Tensões de von Misses em coroas com forma de molar cimentadas em núcleos de aço com carregamento oclusal por pistão esférico de aço. Os métodos de fabricação foram CAD/CAM fusionado com dissilicato de lítio, estratificação manual e prensagem com vitro-cerâmicas de fluorapatita. As tensões da cerâmica de cobertura se propagaram até a Y-TZP no grupo por CAD/CAM fusionado. Para o método de estratificação manual, as tensões se acumularam mais na cerâmica de cobertura e na interface que no grupo por prensagem.

Kanat-Ertürk et al. (2015) avaliaram a distribuição de tensões em coroas com forma de molar cimentadas em núcleos de aço. As coroas foram simuladas com infraestrutura de Y-TZP e cobertura de cerâmica feldspática confeccionadas pelos métodos de estratificação manual, prensagem e cimentação. Foi feita aplicação de carga por um pistão esférico de aço na superfície oclusal e foram calculadas Tensões de von Misses. Para a cobertura cimentada, as tensões se acumularam apenas na área de aplicação da carga na cerâmica de cobertura. Nos demais grupos, as tensões se propagaram para a zircônia e ocorreu concentração de tensões na interface, sendo em maior magnitude para a técnica de estratificação manual.

No estudo de Costa (2016), foram gerados modelos de próteses fixas de três elementos (segundo pré-molar e segundo molar inferiores como pilares e primeiro molar como pôntico) cimentados em pilares de G10. Os modelos de próteses fixas foram feitos com infraestrutura de Y-TZP e com três tipos de cerâmica de cobertura: uma estratificada e duas pelo método CAD/CAM, sendo uma delas pelo protocolo *Rapid Layer Technology* e a outra pelo protocolo *CAD-on*. Foi feita aplicação de carga no centro do pôntico e analisou-se a distribuição de tensão de tração (Tensão Máxima

Principal). Observou-se que a restauração confeccionada pelo método convencional apresentou maior concentração de tensão de tração na região inferior do conector. Para as restaurações confeccionadas pelo método CAD/CAM, houve menor concentração de tensão na região inferior do conector e na região interna da cerâmica de cobertura do pôntico para o método *CAD-on*. Para o método *Rapid Layer Technology*, houve maior concentração de tensões na região interna da cerâmica de cobertura do pôntico e inferior do conector.

3 ARTIGO 1 - *DOES VENEERING TECHNIQUE AFFECT FLEXURAL STRENGTH OR LOAD TO FAILURE OF BILAYER Y-TZP? A SYSTEMATIC REVIEW AND META-ANALYSIS*

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Does veneering technique affect the flexural strength or load to failure of bilayer Y-TZP? A systematic review and meta-analysis

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Does veneering technique affect the flexural strength or load to failure of bilayer Y-TZP? A systematic review and meta-analysis

ABSTRACT

Statement of problem. Causes of failures of bilayer yttria-stabilized tetragonal zirconia polycrystal (Y-TZP) restorations include the processing technique and the properties of the veneer ceramic. The effect of the veneering method on the mechanical behavior of veneered Y-TZP remains unclear.

Purpose. The purpose of this systematic review was to assess the effect of the veneering method on the flexural strength and failure load of bilayer Y-TZP.

Material and methods. This study followed the Preferred Reporting Items for the Systematic Reviews and Meta-Analyses (PRISMA) statement. Searches were performed through August 2017 on PubMed/MEDLINE, Web of Science (Core Collection), Scopus, and Embase with no year or language limit targeting in vitro studies evaluating the effect of the veneering technique on the flexural strength and load to failure of bilayer Y-TZP immediately or after aging. Statistical analyses were conducted using RevMan 5.3. Comparisons were drawn with random-effect models (α=.05).

Results. From 3242 identified studies, 241 were selected for full-text analysis; from these, 33 were included. Hand searching yielded no additional papers. The meta-analysis comprised 32 studies. Meta-analysis was performed separately for flexural strength and failure load data to compare the hand-layered method (control) with pressed, fused, and cemented veneering techniques. The cemented and fused methods were analyzed using subgroups depending on the veneering material being examined (predominantly glass-ceramics and particle-filled glass-ceramics), and the results were compared with the hand-layered method. The pressed group presented similar flexural strength (7 studies) (*P*=.150) and failure load (19 studies) (*P*=.140) values to those of the hand-layered group. Subgroup analysis revealed that the fused group with particle-filled glass-ceramics (7 studies) produced higher load to failure (*P*=.006) than the hand-layered group. Subgroup analyses showed a statistical difference that favors the hand-layered over the cemented group with predominantly glass-ceramic materials (5 studies) (*P*=.002).

Conclusions. The fused technique with particle-filled glass-ceramics seems appropriate for the veneering of Y-TZP, with improved failure load than the hand-layered method with predominantly glass-ceramic materials. The use of predominantly glass-ceramics for the cemented method is not recommended since failure load was lower than for the hand-layered group. Pressed veneers showed similar failure load and flexural strength to the hand-layered technique.

CLINICAL IMPLICATIONS

By understanding the impact of veneering techniques on the mechanical performance of Y-TZP bilayered restorations, clinicians can better select processing methods and materials. Fused veneers with particle-reinforced glass-ceramics should be considered as they increase load to failure.

INTRODUCTION

Yttria-stabilized tetragonal zirconia polycrystal (Y-TZP) ceramics have been widely used in dentistry because of their excellent mechanical properties and improved esthetics in relation to metal.[1-5] Despite the advantages, Y-TZP is less translucent than natural teeth due to its highly crystalline content.[6] Therefore, a veneering glass-ceramic is needed to obtain superior esthetics.[2,7]

The most common clinical failures of veneered Y-TZP restorations caused by mechanical complications are chipping and delamination.[8-10] Such failures have a multifactorial cause, including repetitive occlusal contact during mastication, residual stresses introduced during fabrication,[5,11-12] veneer thickness, restoration geometry,[6] processing technique,[13] and the mechanical properties of the veneer ceramics.[6] The veneering ceramic can be applied by manual layering, where ceramic powder and liquid are mixed, applied to the framework, and fired[12,14] or by pressing, where the veneer ceramic is heat-pressed on the sintered zirconia.[13-14] Recently a computer-aided design-computer-aided manufacturing (CAD-CAM) method, also known as file-splitting,[14] has been introduced. This consists of milling the veneer from a glass-filled ceramic block and combining it with the milled zirconia framework with either low-fusing ceramic or resin cement.[14-18] This technique decreases the laboratory stages and allows the use of relatively strong homogeneous blocks for the veneer.[14]

Which veneering method provides the best mechanical performance of veneered zirconia is currently unclear. Analysis of the combined available data could integrate results and support an evidence-based decision.[19,20] Therefore, the purpose of this systematic review was to evaluate the effect of the veneer application method on the flexural strength and failure load of bilayer Y-TZP. Two null hypotheses were tested: that no difference would be found in flexural strength regardless of the veneering method and that no difference would be found in load to failure regardless of the veneering method.

MATERIAL AND METHODS

This systematic review was registered at the international prospective register of systematic reviews (PROSPERO) database (CRD42016041264) and reported according to the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) statement.[21] The PICOs strategy was defined as follows: Population: specimens with any geometry that comprises Y-TZP framework; Intervention: pressed, cemented, or fused veneer on Y-TZP framework; Comparison: hand-layered veneer on Y-TZP framework; Outcomes: flexural strength or load to failure; Study design: in vitro studies.

MEDLINE via PubMed, Web of Science (Core Collection), Scopus, and Embase databases were searched to identify relevant articles through August 2017 with no limit on language or publication year. The articles were retrieved from PubMed/MEDLINE using the following search strategy: (((((((Zirconium[MeSH Terms]) OR zirconi*) OR yttria*) OR y-tzp) OR ytzp)) AND (((veneer*) OR bilayer*) OR chipping)) AND (((((((Compressive Strength[MeSH Terms]) OR strength) OR resistance) OR load*) OR fracture) OR flexural*) OR fatigue). A sensitive search strategy was adapted for Web of Science, Scopus, and Embase.

The inclusion criteria for study selection were as follows: in vitro studies; using Y-TZP framework specimens covered with a ceramic veneer; and evaluating flexural strength or load to failure regardless of the mechanical test configuration adopted (monotonic or cyclic loading) either immediately or after any type of aging. The final decision on the inclusion of a given study was made based on full-text analysis of potentially relevant studies. Those studies that did not contain the following items were excluded: at least 1 group with hand-layering; at least 1 group with pressed, fused or cemented veneer on the framework; and quantitative means, standard deviations (in MPa for flexural strength or in N for load to failure), and sample sizes of the groups. If means, standard deviations or sample size information was not available, the authors were contacted via e-mail for the information. Fatigue data described in terms of reliability or number of cycles were not considered because comparisons with MPa and N data were not possible.

The titles and abstracts were reviewed independently by 2 authors (A.M.E.M and I.L.A.). Studies were selected for full-text reading if the titles and abstracts met the inclusion criteria. The abstracts were selected with the consensus of both authors. The interexaminer agreement was calculated (Kappa = 0.95). The full-text articles were reviewed, and those that did not meet any exclusion criteria were included (Kappa = 0.97). The references of the selected papers were manually reviewed, and the studies that could potentially fulfill the inclusion criteria were examined. Data were extracted independently by the same reviewers (A.M.E.M and I.L.A.).

A methodological quality assessment was performed according to the following parameters: specimen randomization; specimens obtained in a standardized manner; specimens fabricated by a single operator; description of sample size calculation; blinding of the testing machine operator; and specimen dimensions and flexural test executed according to standard specifications (such as International Organization for Standardization - ISO, and American Society for Testing and Materials - ASTM standards) for studies that evaluated flexural strength, and fracture test performed in a standardized and reproducible manner (with details of speed, piston diameter, and inclination) for studies that evaluated load to failure. Each criterion was scored according to methods reporting on the paper.[22,23] The parameter received a score of 0 if it was clearly reported; 1 if it was reported but was inadequate or unclear; and 2 if it was not possible to find the information. Studies receiving scores 0 to 4 were classified as having a low risk of bias, 5 to 8 as medium-risk, and 9 to12 as high-risk.

Meta-analyses were performed separately for flexural strength and failure load data to compare the hand-layered (control) to pressed, cemented, and fused veneering techniques. The failure load data from cemented and fused methods were analyzed by subgroups determined by the type of veneering material being examined – predominantly glass-ceramics and particle-filled glass-ceramics (lithium disilicate and leucite-reinforced ceramics) –in comparison with the hand-layered method. When appropriate, specific formulas were applied to combine data from multiple groups of the same study into single sample sizes, mean, and standard deviation values.[24] Pooled effect estimates were obtained by comparing the means of each of the flexural strength and load to failure values, and these were expressed as the raw mean difference among the groups. A *P* value ≤.05 was considered statistically significant (Z test). The statistical heterogeneity among the studies was assessed using both the Cochran Q test, where a *P* value <.1 was considered statistically significant, and the inconsistency I^2 test, where values higher than 50% were considered indicative of substantial heterogeneity.[24] All analyses were performed using Review Manager Software 5.3 (Cochrane Collaboration). The results for data with 3 or fewer studies were not summarized statistically since a small number of studies may reduce the power of the meta-analysis estimate.[25] However, a graphical display of forest plots without statistical analysis were presented for visual representation of the results.

RESULTS

Figure 1 shows the flowchart of the article selection process according to the PRISMA statement.[21] From the 3242 studies identified, 1799 remained after removing duplicates. A total of 1558 studies were excluded because they did not meet the inclusion criteria. The 241 remaining studies were selected for full-text analysis, of which 208 papers were excluded. A total of 33 papers were included in the systematic review, of which 32 were included in the meta-analyses and 1 was used only in the descriptive analysis. Three studies were included both in the meta-analyses and descriptive analysis. Manual searching yielded no additional studies. The characteristics of the studies included in the review are listed in Supplemental Tables 1 and 2, including the test configurations and ceramic materials used. Feldspathic ceramic or fluorapatite glass-ceramics were used in all studies including hand-layered and pressed groups. A total of 24 studies presented medium risk of bias,[2,6,11-13,15-18,26-40] whereas 6 showed high risk,[1,41-45] and only 3 presented low risk,[14,46-47] (Table 1). The least clearly described parameter was blinding of the testing operator, followed by description of the sample size calculation.

To assess flexural strength, pressed × hand-layered meta-analysis was performed. Meta-analysis was not performed for fused × hand-layered veneering, because only 1 study evaluated the considered experimental group.[26] Three meta-analyses were conducted for failure load: a global one that compared pressed × hand-layered groups and the other 2 by subgroups that compared hand-layered × fused and hand-layered × cemented veneering, considering the effect of the veneering ceramic used in the experimental groups. One study was included in both flexural strength and load to failure meta-analyses (pressed × hand-layered).[26] As heterogeneity was present, all meta-analyses were performed using a random-effect model (α=.05).

For flexural strength, the meta-analysis comprised 7 studies that compared the pressed and hand-layered groups. The results exhibited no statistical difference between the control and experimental veneering techniques (P=.150). The I^2 test showed high heterogeneity (95%), as seen in Figure 2. Control and cemented veneering were not compared statistically since only 2 studies were available. Visual representation is shown in Figure 3.

With regard to failure load, 19 studies were evaluated for pressed × hand-layered methods, and the analysis did not show a statistical difference (P=.140; I^2=94%) (Fig. 4). Ten studies were considered in the fused veneering analysis (Fig. 5). Overall results showed that fused veneering produced higher load to failure than the control (P=.010; I^2=84%). Subgroup results showed that fused veneering with particle-filled glass-ceramics (7 studies) produced higher load to failure than the control (P=.006; I^2=88%). Due to the low number of studies (3), the statistical meta-analysis was not completed for fused veneering with predominantly glass-ceramics, but the results varied among the studies. Seven studies were considered for cemented veneers comparison. Global results exhibited no statistical difference between hand-layered and cemented groups (P=.160; I^2=99%) (Fig. 6). The subgroup analyses showed a statistical difference favoring the hand-layered over the cemented veneering with predominantly glass-ceramic (5 studies) (P=.002; I^2=98%). For the cemented method with particle-filled glass-ceramics, the statistical meta-analysis was not completed because only 2 studies were available; however, the results of individual studies indicated a statistical difference favoring the cemented group.

Data from 4 studies were descriptively analyzed. Regarding flexural strength, the study by Kanat et al[26] was not included in the meta-analysis since it was the only one comparing fused and hand-layered veneering. This study showed that the experimental group had statistically higher flexural strength (583 ±63 N) than the control (428 ±41 N). For hand-layered × cemented groups, flexural strength was not compared statistically since only 2 studies were available for the analysis. Figure 3 shows that the study by Costa et al[9] favored the cemented group and the study by Pharr et al[17] favored the control. Considering load to failure, the study by Baldassarri et al[33]was not included in the meta-analysis because it was the only study reporting mean and standard deviation (N) for a fatigue test, whereas all other studies performed monotonic tests (or fatigue tests without complete data of mean, standard deviation, and sample size, as determined in the eligibility criteria). Using step-stress accelerated life testing, Baldassarri et al[33] found that for mild stress profile, failures occurred at statistically higher loads for the hand-layered (882 ±61 N) than for the pressed group (696 ±149 N). A monotonic test was also performed, but the standard deviations were unavailable.

DISCUSSION

This systematic review and meta-analyses analyzed the effect of the veneering method on the flexural strength and load to failure of bilayer Y-TZP. The first null hypothesis was accepted because no statistical difference was found between the hand-layered and pressed groups in flexural strength. Because the fused group had higher load to failure than the control, the second null hypothesis was rejected.

To compare pressed and hand-layered techniques, all studies used exclusively fluorapatite glass-ceramic or feldspathic ceramic, which have similar mechanical properties due to the high glass content, for both groups.[3] In the study by Baldassarri et al,[33] failure occurred at lower loads for the pressed method under fatigue testing; the authors associated the findings with the thermal coefficient and residual stresses between the veneer and zirconia. The results of the meta-analyses indicated no difference in the methods for both flexural strength and failure load tests. The manual layering method of veneering ceramic is more technique-sensitive because of the building variability and firing steps and thus is susceptible to the incorporation of flaws and bubbles. Therefore, pressing would be expected to generate higher mechanical resistance because a more controlled method should be less prone to defects and should improve material density.[6,27,44] The absence of a statistical difference can be explained by the similar microstructural characteristics of the pressing and layering veneering materials and also because for both techniques zirconia was the supporting framework material.[13,44] The more homogeneous structure provided by the pressing method[13] seems insufficient for improving mechanical resistance when studies are analyzed together. The absence of statistical difference could also be related to the variability of methodologies among the studies: divergence in specimen aspects (specimen configuration and number), aging (presence/type of aging or storage), and outcome measurement (failure definition, testing configuration) may produce variation in the interstudy results, which makes the variables that influenced the combined results of the studies difficult to identify.

The CAD-CAM technique was introduced to combine a milled veneering material with a zirconia framework, thus resulting in components with reduced processing defects because the ceramic blocks are produced industrially.[26,32] Failure load global meta-analysis comparing the hand-layered and fused veneering subgroup favored the fused group. Interfacial fusion glass-ceramic bonding allows the ceramic system to behave as a homogeneous structure because both bilayer components are fused together.[7,26] Subgroup analyses favored the fused veneering with particle-filled glass-ceramics, which is corroborated by the qualitative analysis of Kanat et al,[26] which found a statistically higher flexural strength for the fused veneering (using lithium disilicate). Lithium disilicate and leucite-reinforced ceramics have a higher elastic modulus and mechanical strength than the glass-ceramics used for hand-layering.

For the cemented method, only 2 studies using predominantly glass-ceramics evaluated flexural strength and showed opposite findings. Failure load global meta-analysis showed no statistical difference from the control. However, subgroup results for predominantly glass-ceramics showed higher failure load for the hand-layered method. The assembly formed by veneers cemented on Y-TZP behaves differently from hand-layered when loaded. Resin cements have a lower elastic modulus than the ceramic system; hence, its presence on the framework/veneer interface can reduce the supporting effect of Y-TZP on the brittle veneer layer, leading to stress distribution only in the veneer loading area and not in the entire zirconia/veneer surface.[14] In addition, proper bonding of resin cements to zirconia is difficult because the highly crystalline composition does not allow acid etching,[4] resulting in lower interfacial bonding for cemented than for hand-layered veneering. [14] The 2 individual studies using particle-filled glass-ceramics showed a statistical difference favoring the cemented group. Although resin cement was also used, this result was probably due to the stronger materials (lithium disilicate and leucite-reinforced ceramics) used in the cemented subgroup.[38]

The meta-analyses presented high heterogeneity.[24] Heterogeneity across studies refers to the degree of differences between the results of individual studies.[19] Although heterogeneity can be prevented to some extent by strict eligibility criteria, it cannot be completely avoided because random and systematic heterogeneities exist between studies.[20] The high heterogeneity could be explained by the differences among methodologies (materials composition, sample preparation, aging, and mechanical testing), the wide range of flexural strength and failure load values, and the high standard deviations among the studies. All the factors favoring heterogeneity may have affected the results of this review. One aspect varied across the studies: failure was defined either as fracture, crack, or chipping of the veneer or framework and was detected visually, acoustically, or by load curve drop. The different definitions may explain in part the wide range of results, since each definition implies different load/stress at failure.

Most studies comprised load to failure tests, and only a few used flexural strength tests. Some studies, particularly those evaluating failure load, deviated from the others.[14,26,28,30,38] Load to failure tests are claimed to have reproducibility and validity issues.[48,49] Unlike flexural strength tests, which are ordinarily performed according to standard specifications and in which failure stress is easily calculated, specimen dimensioning, test designs, and load to failure calculations are not standardized among studies using failure load testing. Also, failure load tends to generate higher values than those of the maximum occlusal force.[48]

Most studies had a medium or high risk of bias. This highlights the likelihood that these studies did not control all the variables that could influence the results, explaining to some extent the heterogeneity. Therefore, this review was limited by the high heterogeneity obtained by the studies and the degree of scientific evidence. Poor methodological reporting is a common problem,[22] although it does not necessarily reflect poor design/execution (high quality studies may not score well because of poor reporting); however it does prevent assessment and confidence in the methodological quality.[23] Also, in 2 studies, the ceramic was not milled,[17,18] and in another study sintered powder/fluid veneer was used.[12] Thus, the results should be interpreted cautiously, since for the file-splitting method, the framework and veneers are machined.

Favorable results that encourage the use of particle-reinforced veneers should be analyzed carefully, since in vitro studies have limitations and the mechanical behavior of bilayer Y-TZP also depends on laboratory and clinical variables. Although many studies aged specimens before testing, meta-analyses could only be performed for those investigating monotonic loading. Ceramics are susceptible to subcritical crack growth under water and cyclic loading, both of which are present in the oral environment.[5] Therefore, more studies using fatigue tests are required.

CONCLUSIONS

Based on the findings of this systematic review, the following conclusions were drawn:

1. Fused veneering appears to be an appropriate alternative to Y-TZP bilayers since it improved failure load more than the hand-layered method, particularly with particle-filled ceramics.
2. The results do not encourage the use of predominantly glass-ceramics for the cemented technique.
3. Pressed veneers on Y-TZP had a similar failure load and flexural strength to those of the hand-layered veneers.

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Supplemental Table 1. Characteristics of included studies evaluating flexural strength

Author/ Year	**Y-TZP Brand/ Manufacturer**	**Control Group (Hand Layered) Brand/ Manufacturer**	**Control Group Ceramic Type**	**Experimental Group**	**Experimental Group Brand/Manufacturer**	**Experimental Group Ceramic Type**	**Type of Aging**	**Flexural Strength Testing/Load Application**	**Side Under Tension**	**Failure Definition**
Longhini et al[45] (2016)	Vita In-Ceram YZ/ Vita Zahnfabrik	Vita VM9/ Vita Zahnfabrik	Feldspathic ceramic	Pressed	Vita PM9/ Vita Zahnfabrik	Feldspathic ceramic	None	Piston-on-3-ball/ Monotonic	Veneer	Not detailed
Pharr et al[17] (2016)	Cercon/ DeguDent Dentsply	Vita VM9/ Vita Zahnfabrik	Feldspathic ceramic	Pressed Cemented	Vita PM9/ Vita Zahnfabrik VITABLOCS Triluxe Forte/ Vita Zahnfabrik	Feldspathic ceramic Feldspathic ceramic	None	3-point bending/ Monotonic	Not informed	Not detailed
Oh et al[2] (2015)	IPS e.max ZirCAD/ Ivoclar Vivadent	IPS e.max Ceram/ Ivoclar Vivadent	Nano-fluorapatite glass-ceramic	Pressed	IPS e.max ZirPress/ Ivoclar Vivadent	Fluorapatite glass-ceramic	6000 thermal cycles	Piston-on-3-ball/ Monotonic	Veneer	Fracture
Costa et al[12] (2014)	Vita In-Ceram YZ/ Vita Zahnfabrik	Vita VM9/ Vita Zahnfabrik	Feldspathic ceramic	Cemented	Vita VM9/ Vita Zahnfabrik	Feldspathic ceramic	None	Ball-on-ring/ Monotonic	Y-TZP	Not detailed
Kanat et al[26] (2014)	IPS e.max ZirCAD/ Ivoclar Vivadent	IPS e.max Ceram/ Ivoclar Vivadent	Nano-fluorapatite glass-ceramic	Pressed Fused	IPS e.max ZirPress/ Ivoclar Vivadent IPS e.max CAD/ Ivoclar Vivadent	Fluorapatite glass-ceramic Lithium disilicate glass-ceramic	Water storage (48h)	3-point bending/ Monotonic	Not informed	Fracture

Author/ Year	Y-TZP Brand/ Manufacturer	Control Group (Hand Layered) Brand/ Manufacturer	Control Group Ceramic Type	Experimental Group	Experimental Group Brand/Manufacturer	Experimental Group Ceramic Type	Type of Aging	Flexural Strength Testing/Load Application	Side Under Tension	Failure Definition
Lima et al[13] (2013)	Vita In-Ceram YZ/ Vita Zahnfabrik	Vita VM9/ Vita Zahnfabrik	Feldspathic ceramic	Pressed	Vita PM9/ Vita Zahnfabrik	Feldspathic ceramic	2 million mechanical cycles	4-point bending/ Monotonic	Veneer	First sign of fracture verified by noise and changes in the load-deflection curve
Lin et al[31] (2012)	IPS e.max ZirCAD/ Ivoclar Vivadent	IPS e. max max Ceram/ Ivoclar Vivadent	Nano-fluorapatite glass-ceramic	Pressed	IPS e.max ZirPress/ Ivoclar Vivadent	Fluorapatite glass-ceramic	None	Piston-on-3-ball/ Monotonic	Not informed	Fracture
Deng et al[34] (2011)	Kavo	IPS e.max Ceram/ Ivoclar Vivadent	Nano-fluorapatite glass-ceramic	Pressed	IPS e.max ZirPress/ Ivoclar Vivadent	Fluorapatite glass-ceramic	None	3-point bending/ Monotonic	Not informed	Sudden drop in load

Supplemental Table 2. Characteristics of included studies evaluating load to failure

Author/ Year	Y-TZP Brand/ Manufacturer	Control Group (Hand Layered) Brand/ Manufacturer	Control Group Ceramic Type	Experimental Group	Experimental Group Brand/ Manufacturer	Experimental Group Ceramic Type	Type of Storage/ Aging	Specimens configuration/ Load application	Failure Definition
Alessandretti et al[18] (2017)	IPS e.max ZirCAD/ Ivoclar Vivadent	IPS e.max Ceram/ Ivoclar Vivadent	Nano-fluorapatite glass-ceramic	Fused	IPS e.max CAD/ Ivoclar Vivadent	Lithium disilicate glass-ceramic	None	Ceramic disks cemented on fiber-reinforced epoxy resin-based disks	First sound correspondent to the critical crack and drop in loading curve
Obermeier et al[40] (2017)	IPS e.max ZirCAD/ Ivoclar Vivadent	IPS e.max Ceram/ Ivoclar Vivadent	Nano-fluorapatite glass-ceramic	Fused	IPS e.max CAD/ Ivoclar Vivadent	Lithium disilicate glass-ceramic	1.2 million thermo-mechanical cycles	Mandibular left first molar crowns screw-retained to titanium implants/ Monotonic	Optically or audibly perceptible chipping/ fracture or abrupt decrease of force of at least 10%
Al-Wahadni et al[41] (2016)	Ceramill ZI/ Amann Girrbach	Vita VM9/ Vita Zahnfabrik	Feldspathic ceramic	Pressed	Vita PM9/ Vita Zahnfabrik	Feldspathic ceramic	3000 thermal cycles + water storage (24h)	Maxillary first premolar crowns cemented cobalt-chromium dies/ Monotonic	Occurrence of visible cracks in combination with load drops and acoustic events
				Cemented	Vita Triluxe Forte/ Vita Zahnfabrik	Feldspathic ceramic			

Author/ Year	Y-TZP Brand/ Manufacturer	Control Group (Hand Layered) Brand/ Manufacturer	Control Group Ceramic Type	Experimental Group	Experimental Group Brand/ Manufacturer	Experimental Group Ceramic Type	Type of Storage/ Aging	Specimens configuration/ Load application	Failure Definition
Mahmood et al[16] (2016)	Vita In-Ceram YZ/ Vita Zahnfabrik IPS e.max ZirCAD/ Ivoclar Vivadent	Vita VM9/ Vita Zahnfabrik IPS e.max Ceram/ Ivoclar Vivadent	Feldspathic ceramic Nano-fluorapatite glass-ceramic	Pressed Fused Cemented	IPS e.max ZirPress/ Ivoclar Vivadent IPS e.max CAD/ Ivoclar Vivadent VITABLOCS Mark II, Vita Zahnfabrik	Fluorapatite glass-ceramic Lithium disilicate glass-ceramic Feldspathic ceramic	5000 thermal cycles + 10000 mechanical cycles	Anterior three-unit fixed dental prostheses (FDP) cemented on a polymer material)/ Monotonic	A visible crack in the veneer or through the entire construction
Baladhandayutham et al[46] (2015)	Lava/ 3M ESPE	Lava Ceram/ 3M ESPE	Feldspathic ceramic	Fused	Lava DVS/ 3M ESPE	Glass-ceramic	Water storage (24h) + 200000 mechanical cycles	Mandibular first molar crowns cemented on composite resin preparations/ Monotonic	A sudden reduction to 40% of the applied load
Kanat-Ertürk et al[14] (2015)	Vita In-Ceram YZ/ Vita Zahnfabrik	Vita VM9/ Vita Zahnfabrik	Feldspathic ceramic	Pressed Cemented	Vita PM9/ Vita Zahnfabrik VITABLOCS Mark II/ Vita Zahnfabrik	Feldspathic ceramic Feldspathic ceramic	Water storage (48h)	Mandibular left first molar crowns cemented on stainless steel dies/ Monotonic	Fracture
Nossair et al[15] (2015)	inCorisZi/ Sirona	IPS e.max Ceram/ Ivoclar Vivadent	Nano-fluorapatite glass-ceramic	Fused Cemented	IPS Empress CAD	Leucite-based ceramic	3.2 million mechanical cycles	Implant abutments seated on titanium short abutments/ Monotonic	A sudden drop in applied load or a cracking sound

Author/ Year	Y-TZP Brand/ Manufacturer	Control Group (Hand Layered) Brand/ Manufacturer	Control Group Ceramic Type	Experimental Group	Experimental Group Brand/ Manufacturer	Experimental Group Ceramic Type	Type of Storage/ Aging	Specimens configuration/ Load application	Failure Definition
Turk et al[47] (2015)	IPS e.max ZirCAD/ Ivoclar Vivadent	IPS e.max Ceram/ Ivoclar Vivadent	Nano-fluorapatite glass-ceramic	Pressed	IPS e.max ZirPress/ Ivoclar Vivadent	Fluorapatite glass-ceramic	10000 thermal cycles	Mandibular molar crowns cemented on metal dies/ Monotonic	First discontinuity in the load, whether it was an early crack or a catastrophic failure
Costa et al[12] (2014)	Vita In-Ceram YZ/ Vita Zahnfabrik	Vita VM9/ Vita Zahnfabrik	Feldspathic ceramic	Cemented	Vita VM9/ Vita Zahnfabrik	Feldspathic ceramic	None	Disks/ Monotonic	Not detailed
Kanat et al[26] (2014)	IPS e.max ZirCAD/ Ivoclar Vivadent	IPS e.max Ceram/ Ivoclar Vivadent	Nano-fluorapatite glass-ceramic	Pressed	IPS e.max ZirPress/ Ivoclar Vivadent	Fluorapatite glass-ceramic	Water storage (48h)	Mandibular left first molar crowns cemented on stainless steel dies/ Monotonic	Fracture
				Fused	IPS e.max CAD/ Ivoclar Vivadent	Lithium disilicate glass-ceramic			
Chaar et al[27] (2013)	ZenotecZr Bridge/ Wieland Dental	Vintage ZR/ Shofu Dental GmbH	Leucite-strengthened feldspathic ceramic	Pressed	PressXZr/ Wieland Dental	Leucite-free high-density feldspathic ceramic	None	Posterior three-unit FDP cemented on prepared teeth/ Monotonic	Fracture
		Zirox/ Wieland Dental	Leucite-free high-density feldspathic ceramic				1.2 million thermo-mechanical cycles		

Author/ Year	Y-TZP Brand/ Manufacturer	Control Group (Hand Layered) Brand/ Manufacturer	Control Group Ceramic Type	Experimental Group	Experimental Group Brand/ Manufacturer	Experimental Group Ceramic Type	Type of Storage/ Aging	Specimens configuration/ Load application	Failure Definition
Guess et al[11] (2013)	Vita In-Ceram YZ/ Vita Zahnfabrik	Vita VM9/ Vita Zahnfabrik	Feldspathic ceramic	Pressed	Vita PM9/ Vita Zahnfabrik	Feldspathic ceramic	Water storage of the crowns (7 days)	Molar crowns cemented on aged composite resin dies/ Monotonic	Chip-off fractures of the veneering ceramic and core fractures
Kim et al[28] (2013)	Rainbow Zirconia/ Dentium	IPS e.max Ceram/ Ivoclar Vivadent	Nano-fluorapatite glass-ceramic	Pressed	IPS e.max ZirPress/ Ivoclar Vivadent	Fluorapatite glass-ceramic	Saline storage (24 h)	Mandibular first molar crowns cemented on metal dies/ Monotonic	Fracture
Preis et al[1] (2013)	Lava/ 3M ESPE	Lava Ceram/ 3M ESPE	Feldspathic ceramic	Pressed Fused	IPS e.max ZirPress/ Ivoclar Vivadent Experimental ceramic/ 3M ESPE	Fluorapatite glass-ceramic Glass-ceramic	6000 thermal cycles + 1.2 million mechanical cycles	Mandibular left first molar crowns cemented on polymethylmethacrylate prepared teeth/ Monotonic	Chipping of the veneer or combined fracture of the veneer and core
Schmitter et al[29] (2013)	inCorisZi/ Sirona	Not informed	Feldspathic ceramic	Cemented	CEREC Bloc/ Sirona	Feldspathic ceramic	None	Molar crowns cemented on cobalt-chromium dies/ Monotonic	Fracture
Agustín-Panadero et al[42] (2012)	IPS e.max ZirCAD/ Ivoclar Vivadent	IPS e.max Ceram/ Ivoclar Vivadent	Nano-fluorapatite glass-ceramic	Pressed	IPS e.max ZirPress/ Ivoclar Vivadent	Fluorapatite glass-ceramic	None	Maxillary first molar crowns cemented on epoxy resin dies/ Monotonic	Fracture

Author/ Year	Y-TZP Brand/ Manufacturer	Control Group (Hand Layered) Brand/ Manufacturer	Control Group Ceramic Type	Experimental Group	Experimental Group Brand/ Manufacturer	Experimental Group Ceramic Type	Type of Storage/ Aging	Specimens configuration/ Load application	Failure Definition
Choi et al[30] (2012)	Lava/ 3M ESPE	Vita VM9/ Vita Zahnfabrik	Feldspathic ceramic	Pressed Fused	PS e.max ZirPress/ Ivoclar Vivadent Lava DVS/ 3M ESPE	Fluorapatite glass-ceramic Glass-ceramic	Water storage (48h)	Mandibular right first molar crowns cemented on titanium dies/ Monotonic	Visible cracks in combination with load drops and acoustic events or chipping that would make the crown clinically unusable
Schmitter et al[32] (2012)	inCorisZi/ Sirona	Not informed	Feldspathic ceramic	Fused	IPS e.max CAD/ Ivoclar Vivadent	Lithium disilicate glass-ceramic	None	Molar crowns cemented on cobalt-chromium dies/ Monotonic	First damage of the veneer
Albrecht et al[43] (2011)	Straumann Anatomical IPS e.max Abutments/ Straumann	IPS e.max Ceram/ Ivoclar Vivadent	Nano-fluorapatite glass-ceramic	Pressed Cemented	IPS e.max ZirPress/ Ivoclar Vivadent IPS e.max CAD/ Ivoclar Vivadent	Fluorapatite glass-ceramic Lithium disilicate glass-ceramic	None 1.2 million mechanical cycles with simultaneous thermocycling	Abutments attached to premolar implants/ Monotonic	Fracture
Baldassarri et al[33] (2011)	Procera/ Nobel Biocare	NobelRondo Porcelain/ Nobel Biocare	Feldspathic ceramic	Pressed	NobelRondo Press/ Nobel Biocare	Feldspathic ceramic	Water storage (14 days)	Posterior three-unit implant-supported FDP screw-retained to titanium implants/ Fatigue (step-stress)	Fracture

Author/ Year	Y-TZP Brand/ Manufacturer	Control Group (Hand Layered) Brand/ Manufacturer	Control Group Ceramic Type	Experimental Group	Experimental Group Brand/ Manufacturer	Experimental Group Ceramic Type	Type of Storage/ Aging	Specimens configuration/ Load application	Failure Definition
Eisenburger et al[35] (2011)	IPS e.max ZirCAD/ Ivoclar Vivadent	IPS e.max Ceram/ Ivoclar Vivadent	Nano-fluorapatite glass-ceramic	Pressed	IPS e.max ZirPress/ Ivoclar Vivadent	Fluorapatite glass-ceramic	None	Maxillary central incisor crowns cemented on cobalt-chromium-molybdenum dies/ Monotonic	A decrease in load of at least 50 N, regardless of whether failure was chipping or a catastrophic failure of the core
Stawarczyk et al[36] (2011)	ZENO TEC/ Wieland Dental	Zirox/ Wieland Dental GC Initial ZR/ GC Europe Vita VM 9/ Vita Zahnfabrik IPS e.max Ceram/ Ivoclar Vivadent	Leucite-free high-density feldspathic ceramic Feldspathic ceramic Feldspathic ceramic Nano-fluorapatite glass-ceramic	Pressed	PressXZr/ Wieland Dental GC Initial IQ LF/ GC Europe VITA PM9/ Vita Zahnfabrik IPS e.max ZirPress/ Ivoclar Vivadent	Leucite-free high-density feldspathic ceramic Feldspathic ceramic Feldspathic ceramic Fluorapatite glass-ceramic	1.2 million mechanical cycles with simultaneous thermocycling	Maxillary lateral incisor crowns cemented on metal abutments/ Monotonic	When fracture load decreased by 10% of the maximum load

Author/ Year	Y-TZP Brand/ Manufacturer	Control Group (Hand Layered) Brand/ Manufacturer	Control Group Ceramic Type	Experimental Group	Experimental Group Brand/ Manufacturer	Experimental Group Ceramic Type	Type of Storage/ Aging	Specimens configuration/ Load application	Failure Definition
Stawarczyk et al[37] (2011)	ZENO TEC/ Wieland Dental	Zirox/ Wieland Dental GC Initial ZR/ GC Europe Vita VM 9/ Vita Zahnfabrik IPS e.max Ceram/ Ivoclar Vivadent	Leucite-free high-density feldspathic ceramic Feldspathic ceramic Feldspathic ceramic Nano-fluorapatite glass-ceramic	Pressed	PressXZr/ Wieland Dental GC Initial IQ LF/ GC Europe VITA PM9/ Vita Zahnfabrik IPS e.max ZirPress/ Ivoclar Vivadent	Leucite-free high-density feldspathic ceramic Feldspathic ceramic Feldspathic ceramic Fluorapatite glass-ceramic	None	Maxillary canine crowns cemented on cobalt-chromium abutments/ Monotonic	When fracture load decreased by 10% of the maximum load
Beuer et al[38] (2009)	IPS e.max ZirCAD/ Ivoclar Vivadent	IPS e.max Ceram/ Ivoclar Vivadent	Nano-fluorapatite glass-ceramic	Pressed Fused	IPS e.max ZirPress/ Ivoclar Vivadent IPS e.max CAD/ Ivoclar Vivadent	Fluorapatite glass-ceramic Lithium disilicate glass-ceramic	Water storage (48 h)	Maxillary right second molar crowns cemented on cobalt-chromium dies/ Monotonic	Visible cracks in combination with load drops and acoustic events or chipping that would make the crown clinically unusable
Guess et al[6] (2009)	IPS e.max ZirCAD/ Ivoclar Vivadent	IPS e.max Ceram/ Ivoclar Vivadent	Nano-fluorapatite glass-ceramic	Pressed	IPS e.max ZirPress/ Ivoclar Vivadent	Fluorapatite glass-ceramic	Water storage (7 days)	Square bilayer ceramic cemented on square aged composite resin/ Monotonic	Fracture of the veneering ceramic

Author/ Year	Y-TZP Brand/ Manufacturer	Control Group (Hand Layered) Brand/ Manufacturer	Control Group Ceramic Type	Experimental Group	Experimental Group Brand/ Manufacturer	Experimental Group Ceramic Type	Type of Storage/ Aging	Specimens configuration/ Load application	Failure Definition
Aboushelib et al[39] (2008)	Tosoh	IPS e.max Ceram/ Ivoclar Vivadent	Nano-fluorapatite glass-ceramic	Pressed	IPS e.max ZirPress/ Ivoclar Vivadent	Fluorapatite glass-ceramic	None	Mandibular right molar crowns cemented on composite resin dies/ Monotonic	Fracture
Tsalouchouet al[44] (2008)	KaVo Everest ZS-blank/ KaVo Dental	IPS e.max Ceram/ Ivoclar Vivadent	Nano-fluorapatite glass-ceramic	Pressed	IPS e.max ZirPress/ Ivoclar Vivadent	Fluorapatite glass-ceramic	Water storage (24 h) + 50000 mechanical cycles	Cylindrical crowns cemented on brass dies/ Monotonic	Fracture

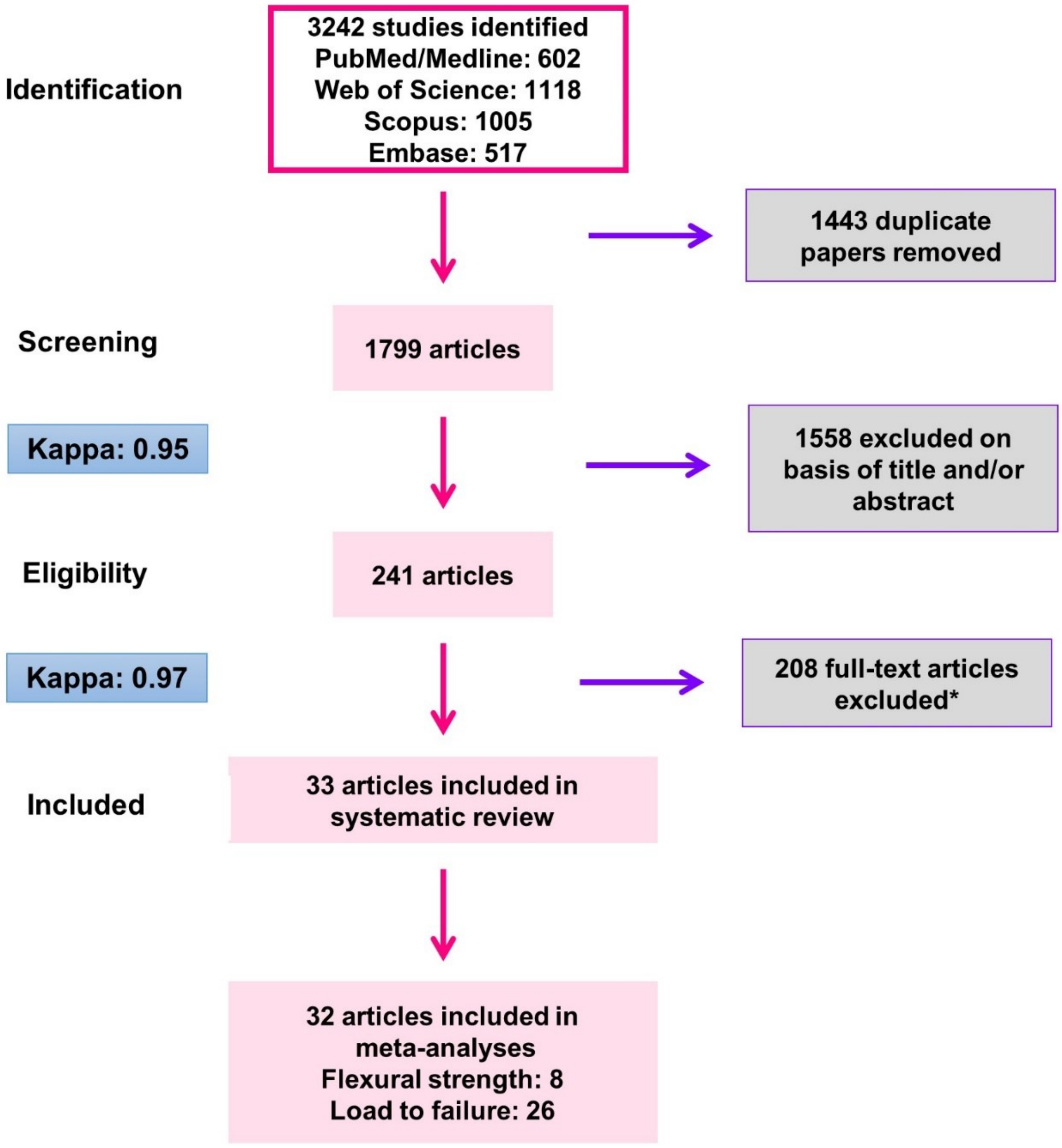
Table 1. Risk of bias of included studies

Author/Year	Randomization of specimens	Specimens obtained from standardized process	Specimens fabrication by single operator	Sample size calculation	Blinded operator of testing machine	Standardized test	Sum	Estimated risk of bias
Alessandretti et al[18] (2017)	2	0	2	2	2	0	8	Medium
Obermeier et al[40] (2017)	2	0	0	2	2	0	6	Medium
Al-Wahadni et al[41] (2016)	2	0	2	2	2	1	9	High
Longhini et al[45] (2016)	2	0	2	2	2	1	9	High
Mahmood et al[16] (2016)	2	0	0	1	2	0	5	Medium
Pharr et al[17] (2016)	0	0	2	2	2	1	7	Medium
Baladhandayutham et al[46] (2015)	2	0	0	0	2	0	4	Low
Kanat-Ertürk et al[14] (2015)	2	0	0	2	0	0	4	Low
Nossair et al[15] (2015)	0	0	2	2	2	0	6	Medium
Oh et al[2] (2015)	2	0	2	2	2	0	8	Medium
Turk et al[47] (2015)	0	0	0	2	2	0	4	Low
Costa et al[12] (2014)	0	0	2	2	2	1	7	Medium
Kanat et al[26] (2014)	2	0	1	2	2	1	8	Medium
Chaar et al[27] (2013)	0	0	1	2	2	0	5	Medium
Guess et al[11] (2013)	2	0	0	2	2	1	7	Medium
Kim et al[28] (2013)	2	0	2	2	2	0	8	Medium
Lima et al[13] (2013)	0	0	2	2	2	1	7	Medium
Preis et al[1] (2013)	2	0	2	2	2	1	9	High
Schmitter et al[29] (2013)	2	0	0	2	2	1	7	Medium
Agustín-Panadero et al[42] (2012)	2	1	2	2	2	0	9	High
Choi et al[30] (2012)	2	0	1	2	2	0	7	Medium
Lin et al[31] (2012)	2	0	2	1	2	0	7	Medium

Author/Year	Randomization of specimens	Specimens obtained from standardized process	Specimens fabrication by single operator	Sample size calculation	Blinded operator of testing machine	Standardized test	Sum	Estimated risk of bias
Schmitter et al[32] (2012)	2	0	0	2	2	1	7	Medium
Albrecht et al[43] (2011)	2	0	2	2	2	1	9	High
Baldassarri et al[33] (2011)	2	0	1	2	2	0	7	Medium
Deng et al[34] (2011)	0	0	2	2	2	1	7	Medium
Eisenburger et al[35] (2011)	2	0	2	0	2	0	6	Medium
Stawarczyk et al[36] (2011)	0	0	2	2	2	1	7	Medium
Stawarczyk et al[37] (2011)	0	0	2	2	2	1	7	Medium
Beuer et al[38] (2009)	2	0	1	2	2	0	7	Medium
Guess et al[6] (2009)	0	0	2	2	2	1	7	Medium
Aboushelib et al[39] (2008)	2	0	2	2	2	0	8	Medium
Tsalouchou et al[44] (2008)	2	0	2	2	2	1	9	High

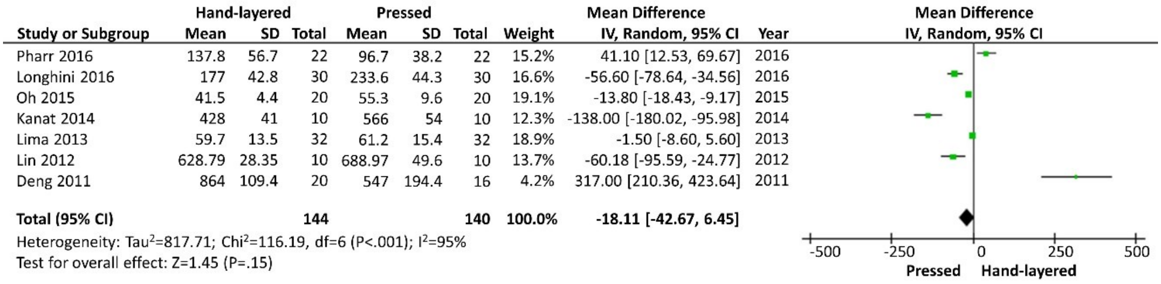
FIGURES

Figure 1. Flowchart of study selection procedures according to PRISMA Statement.



***Exclusions:** Absence of proper experimental or control group (n=206); Absence of standard deviation (n=2).

Figure 2. Forest plot for flexural strength analysis (pressed × hand-layered).

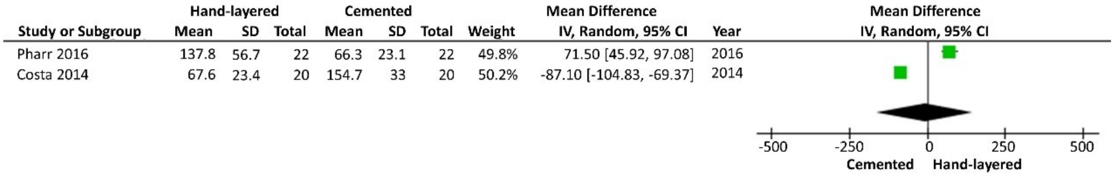


	Hand-layered			Pressed				Mean Difference		Mean Difference
Study or Subgroup	**Mean**	**SD**	**Total**	**Mean**	**SD**	**Total**	**Weight**	**IV, Random, 95% CI**	**Year**	**IV, Random, 95% CI**
Pharr 2016	137.8	56.7	22	96.7	38.2	22	15.2%	41.10 [12.53, 69.67]	2016	
Longhini 2016	177	42.8	30	233.6	44.3	30	16.6%	-56.60 [-78.64, -34.56]	2016	
Oh 2015	41.5	4.4	20	55.3	9.6	20	19.1%	-13.80 [-18.43, -9.17]	2015	
Kanat 2014	428	41	10	566	54	10	12.3%	-138.00 [-180.02, -95.98]	2014	
Lima 2013	59.7	13.5	32	61.2	15.4	32	18.9%	-1.50 [-8.60, 5.60]	2013	
Lin 2012	628.79	28.35	10	688.97	49.6	10	13.7%	-60.18 [-95.59, -24.77]	2012	
Deng 2011	864	109.4	20	547	194.4	16	4.2%	317.00 [210.36, 423.64]	2011	
Total (95% CI)			**144**			**140**	**100.0%**	**-18.11 [-42.67, 6.45]**		

Heterogeneity: Tau²=817.71; Chi²=116.19, df=6 (P<.001); I²=95%

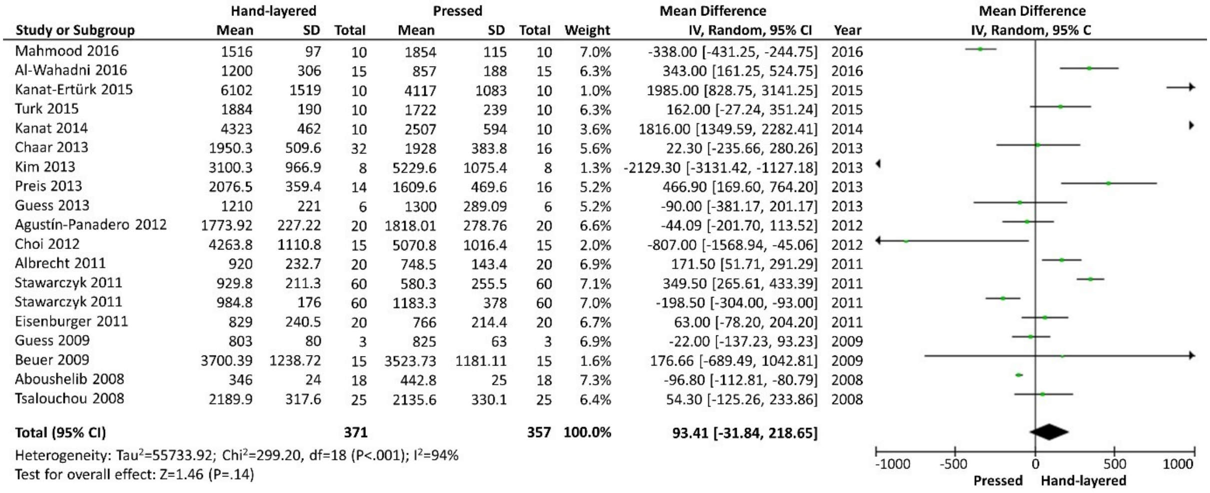
Test for overall effect: Z=1.45 (P=.15)

Figure 3. Forest plot for flexural strength analysis (cemented × hand-layered).



	Hand-layered			Cemented				Mean Difference	
Study or Subgroup	Mean	SD	Total	Mean	SD	Total	Weight	IV, Random, 95% CI	Year
Pharr 2016	137.8	56.7	22	66.3	23.1	22	49.8%	71.50 [45.92, 97.08]	2016
Costa 2014	67.6	23.4	20	154.7	33	20	50.2%	-87.10 [-104.83, -69.37]	2014

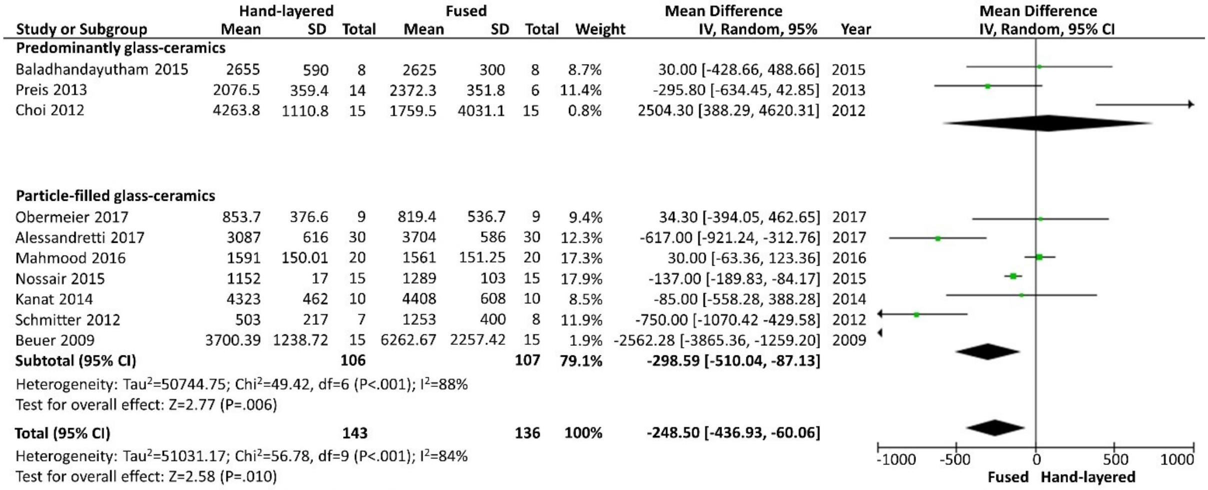
Figure 4. Forest plot for load to failure analysis (pressed × hand-layered).



Study or Subgroup	Hand-layered Mean	Hand-layered SD	Hand-layered Total	Pressed Mean	Pressed SD	Pressed Total	Weight	Mean Difference IV, Random, 95% CI	Year
Mahmood 2016	1516	97	10	1854	115	10	7.0%	-338.00 [-431.25, -244.75]	2016
Al-Wahadni 2016	1200	306	15	857	188	15	6.3%	343.00 [161.25, 524.75]	2016
Kanat-Ertürk 2015	6102	1519	10	4117	1083	10	1.0%	1985.00 [828.75, 3141.25]	2015
Turk 2015	1884	190	10	1722	239	10	6.3%	162.00 [-27.24, 351.24]	2015
Kanat 2014	4323	462	10	2507	594	10	3.6%	1816.00 [1349.59, 2282.41]	2014
Chaar 2013	1950.3	509.6	32	1928	383.8	16	5.6%	22.30 [-235.66, 280.26]	2013
Kim 2013	3100.3	966.9	8	5229.6	1075.4	8	1.3%	-2129.30 [-3131.42, -1127.18]	2013
Preis 2013	2076.5	359.4	14	1609.6	469.6	16	5.2%	466.90 [169.60, 764.20]	2013
Guess 2013	1210	221	6	1300	289.09	6	5.2%	-90.00 [-381.17, 201.17]	2013
Agustín-Panadero 2012	1773.92	227.22	20	1818.01	278.76	20	6.6%	-44.09 [-201.70, 113.52]	2012
Choi 2012	4263.8	1110.8	15	5070.8	1016.4	15	2.0%	-807.00 [-1568.94, -45.06]	2012
Albrecht 2011	920	232.7	20	748.5	143.4	20	6.9%	171.50 [51.71, 291.29]	2011
Stawarczyk 2011	929.8	211.3	60	580.3	255.5	60	7.1%	349.50 [265.61, 433.39]	2011
Stawarczyk 2011	984.8	176	60	1183.3	378	60	7.0%	-198.50 [-304.00, -93.00]	2011
Eisenburger 2011	829	240.5	20	766	214.4	20	6.7%	63.00 [-78.20, 204.20]	2011
Guess 2009	803	80	3	825	63	3	6.9%	-22.00 [-137.23, 93.23]	2009
Beuer 2009	3700.39	1238.72	15	3523.73	1181.11	15	1.6%	176.66 [-689.49, 1042.81]	2009
Aboushelib 2008	346	24	18	442.8	25	18	7.3%	-96.80 [-112.81, -80.79]	2008
Tsalouchou 2008	2189.9	317.6	25	2135.6	330.1	25	6.4%	54.30 [-125.26, 233.86]	2008
Total (95% CI)			**371**			**357**	**100.0%**	**93.41 [-31.84, 218.65]**	

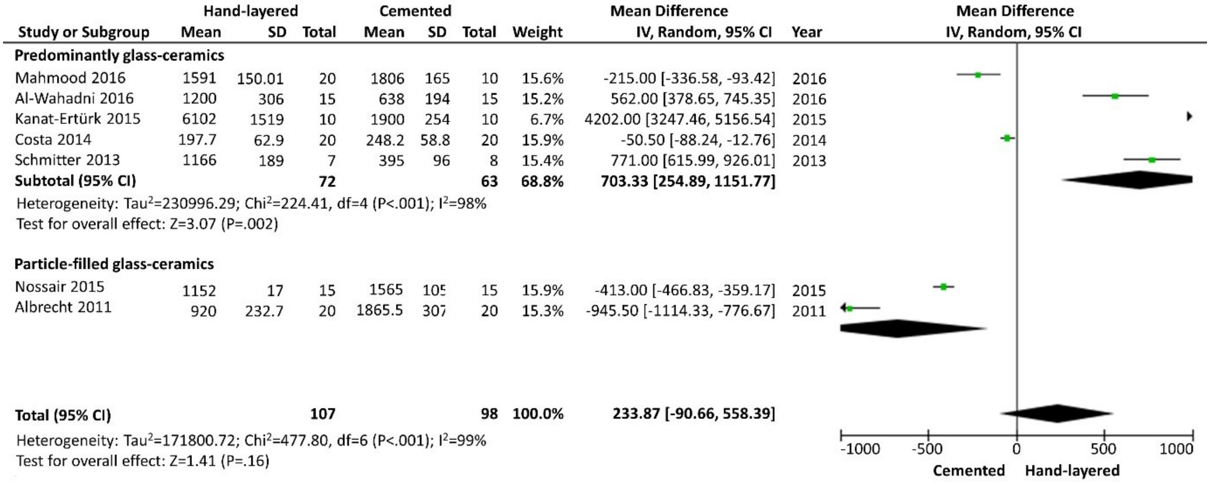
Heterogeneity: Tau^2=55733.92; Chi^2=299.20, df=18 (P<.001); I^2=94%
Test for overall effect: Z=1.46 (P=.14)

Figure 5. Forest plot for load to failure subgroup analyses (fused × hand-layered) regarding to the ceramic material.



	Hand-layered			Fused				Mean Difference	
Study or Subgroup	**Mean**	**SD**	**Total**	**Mean**	**SD**	**Total**	**Weight**	**IV, Random, 95%**	**Year**
Predominantly glass-ceramics									
Baladhandayutham 2015	2655	590	8	2625	300	8	8.7%	30.00 [-428.66, 488.66]	2015
Preis 2013	2076.5	359.4	14	2372.3	351.8	6	11.4%	-295.80 [-634.45, 42.85]	2013
Choi 2012	4263.8	1110.8	15	1759.5	4031.1	15	0.8%	2504.30 [388.29, 4620.31]	2012
Particle-filled glass-ceramics									
Obermeier 2017	853.7	376.6	9	819.4	536.7	9	9.4%	34.30 [-394.05, 462.65]	2017
Alessandretti 2017	3087	616	30	3704	586	30	12.3%	-617.00 [-921.24, -312.76]	2017
Mahmood 2016	1591	150.01	20	1561	151.25	20	17.3%	30.00 [-63.36, 123.36]	2016
Nossair 2015	1152	17	15	1289	103	15	17.9%	-137.00 [-189.83, -84.17]	2015
Kanat 2014	4323	462	10	4408	608	10	8.5%	-85.00 [-558.28, 388.28]	2014
Schmitter 2012	503	217	7	1253	400	8	11.9%	-750.00 [-1070.42 -429.58]	2012
Beuer 2009	3700.39	1238.72	15	6262.67	2257.42	15	1.9%	-2562.28 [-3865.36, -1259.20]	2009
Subtotal (95% CI)			**106**			**107**	**79.1%**	**-298.59 [-510.04, -87.13]**	
Heterogeneity: Tau²=50744.75; Chi²=49.42, df=6 (P<.001); I²=88%									
Test for overall effect: Z=2.77 (P=.006)									
Total (95% CI)			**143**			**136**	**100%**	**-248.50 [-436.93, -60.06]**	
Heterogeneity: Tau²=51031.17; Chi²=56.78, df=9 (P<.001); I²=84%									
Test for overall effect: Z=2.58 (P=.010)									

Figure 6. Forest plot for load to failure subgroup analyses (cemented × hand-layered) regarding to ceramic material.



	Hand-layered			Cemented				Mean Difference	
Study or Subgroup	Mean	SD	Total	Mean	SD	Total	Weight	IV, Random, 95% CI	Year
Predominantly glass-ceramics									
Mahmood 2016	1591	150.01	20	1806	165	10	15.6%	-215.00 [-336.58, -93.42]	2016
Al-Wahadni 2016	1200	306	15	638	194	15	15.2%	562.00 [378.65, 745.35]	2016
Kanat-Ertürk 2015	6102	1519	10	1900	254	10	6.7%	4202.00 [3247.46, 5156.54]	2015
Costa 2014	197.7	62.9	20	248.2	58.8	20	15.9%	-50.50 [-88.24, -12.76]	2014
Schmitter 2013	1166	189	7	395	96	8	15.4%	771.00 [615.99, 926.01]	2013
Subtotal (95% CI)			**72**			**63**	**68.8%**	**703.33 [254.89, 1151.77]**	
Heterogeneity: Tau^2=230996.29; Chi^2=224.41, df=4 (P<.001); I^2=98%									
Test for overall effect: Z=3.07 (P=.002)									
Particle-filled glass-ceramics									
Nossair 2015	1152	17	15	1565	105	15	15.9%	-413.00 [-466.83, -359.17]	2015
Albrecht 2011	920	232.7	20	1865.5	307	20	15.3%	-945.50 [-1114.33, -776.67]	2011
Total (95% CI)			**107**			**98**	**100.0%**	**233.87 [-90.66, 558.39]**	
Heterogeneity: Tau^2=171800.72; Chi^2=477.80, df=6 (P<.001); I^2=99%									
Test for overall effect: Z=1.41 (P=.16)									

4 ARTIGO 2 - *FILE-SPLITTING MULTILAYER VS MONOLITHIC Y-TZP: FATIGUE FLEXURAL STRENGTH AND LOADING STRESSES BY FINITE ELEMENT ANALYSIS*

Este artigo será submetido ao periódico Dental Materials, ISSN 0109-5641, fator de impacto, 4.070, Qualis A1. As normas para publicação estão descritas no Anexo B.

File-splitting multilayer vs monolithic Y-TZP: fatigue flexural strength and loading stresses by finite element analysis

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ABSTRACT

Objectives. To compare file-splitting multilayer (fused and cemented) with monolithic Y-TZP on the fatigue flexural strength and finite element analysis (FEA) stresses. Additionally, to verify the effect of the material under tension in multilayer Y-TZP.

Methods. Disc-shaped (diameter: 14.4 mm; thickness: 1.4 mm) monolithic Y-TZP (IPS e.max ZirCAD – Ivoclar Vivadent) and trilayer specimens with Y-TZP framework (IPS e.max ZirCAD), intermediate layer of fusion ceramic (IPS e.max CAD Crystall./Connect) or resin cement (Multilink Automix) and lithium disilicate veneer (IPS e.max CAD) were divided into five groups (n=20): monolithic Y-TZP (M), fused file-splitting with framework under tension (F-FT), cemented file-splitting with framework under tension (C-FT), fused file-splitting with veneer under tension (F-VT) and cemented file-splitting with veneer under tension (C-VT). Fatigue flexural strength was determined (piston-on-three ball) by the staircase approach (750,000 cycles; 20 Hz). Mean and confidence intervals (CI) were calculated. FEA was evaluated under the application of the experimental mean fatigue load.

Results. The fatigue strength was statistically different for all groups. Means and CI (MPa) were: M - 405.92 (CI 397.58-414.26), F-FT - 377.73 (CI 374.59-380.88), C-FT - 346.54 (CI 340.62-352.46), F-VT - 154.79 (CI 151.86-157.72) and C-VT - 100.34 (CI 97.42-103.26). FEA tensile stresses were similar to the mean experimental values (up to ≅10 MPa of variation), with the most discrepant calculated stresses for C-FT (≅20 MPa higher than experimental result).

Significance. Monolithic specimens showed the highest flexural fatigue strength and fused file-splitting resulted in higher fatigue strength than cemented file-splitting. The material under tension affected the fatigue strength of multilayer ceramic discs.

KEYWORDS: Fatigue; Biaxial flexural strength; Zirconia; Lithium disilicate; Multilayer structures; Dental ceramics; CAD/CAM; Finite element analysis; Fractography.

1. INTRODUCTION

Yttria-stabilized tetragonal zirconia polycrystal (Y-TZP) ceramics have been extensively used in Dentistry owing to the superior esthetic characteristics in comparison with metal frameworks [1]. Their popularity is due to their excellent mechanical properties compared to other dental ceramics, such as high strength and toughness, and the introduction of the CAD/CAM (Computer Aided Design/Computer Aided Manufacturing) technology [2]. However, the main disadvantage of Y-TZP is the low translucency resulting from its highly crystalline structure, which causes a mismatch with adjacent teeth [3-4]. In spite of the continuous development of more translucent materials, for higher esthetic requirements, a veneering ceramic with inferior mechanical properties to those of the frameworks is applied on a Y-TZP high-strength core to provide improved natural appearance [1,3,5].

Although high survival rates have been reported for restorations of veneered Y-TZP, clinical evaluations show that chipping (fracture of the veneer ceramic) and delamination (fracture on the interface between framework and veneer) are common complications for single crowns and multi-unit fixed prosthodontics [6-10] because the glass ceramic is the weakest part of the ceramic system [1]. Fracture of the veneer may be influenced by patient-related variables, such as moisture exposure and chewing [1], and material-related variables such as residual stresses introduced as a consequence of the thermal behavior of different materials [11], elastic modulus [12], thickness [13], restoration design [1,4] and manufacturing method [1,4]. Thus, considerable attention has been focused on the development of materials and processing techniques in order to reduce fatigue related fracture events [11].

A veneering ceramic is commonly applied with the hand-layered technique (in which ceramic powder and liquid are mixed, applied over the framework and sintered) and the pressed technique (in which the final contour of the veneer is waxed-up on the framework and a pressable ceramic is injected after investment) [13-14]. The hand-layered method is susceptible to pore incorporation and affected by the successive application of ceramic layers and sintering cycles [13]. The probability of porosity in the pressed technique is reduced [13], but it is still time consuming and likely to be influenced by the many laboratorial steps (i.e. the cleanliness of the modelling wax and air-abrasion for investment removal) [12]. The new “file-splitting” method was developed to improve Y-TZP/veneer mechanical behavior: it consists of producing the Y-TZP framework and the veneer using CAD-CAM and combining them with resin cement or fusion glass ceramic [12,14]. Less fabrication stages are needed due to the automated character of this technique, thereby decreasing the chance of incorporating defects mainly during the veneering step. Also, the high-strength homogeneous pre-fabricated ceramic blocks available for veneer fabrication tend to be mechanically superior when compared with the existing glass ceramic veneers for pressed and hand-layered methods [12,14].

Recent studies have shown similar uniaxial flexural strength, characteristic strength and Weibull modulus [5], as well as similar failure load and reliability [15] for monolithic Y-TZP and veneered Y-TZP with one of the fused file-splitting technique systems (“CAD-on” method by Ivoclar Vivadent, in which the fusion glass ceramic connects the frameworks to lithium disilicate veneers) [16]. Other studies found high fracture strength for fused and cemented file-splitting [17-18]. Although file-splitting seems to be a promising approach, the long-term behavior of ceramics is not only determined by the initial strength, but also by the material resistance to crack propagation at subcritical stress levels (subcritical crack growth), which decreases the ceramic strength over time [19]. Clinically, it is more likely that failures result from repeated loads below the nominal strength during increased service time than after a single intense load [20]. Thus, fatigue tests could more accurately predict the long-term behavior of ceramic structures fabricated by the fused and cemented file-splitting method. Basso et al. [21] showed that cyclic fatigue decreased the reliability of three-unit fixed prosthesis fabricated by the CAD-on technique in comparison to monotonic testing.

Multilayer ceramic structures are very complex as the interaction between the different materials affects the ceramic strength and fracture mode [22]. Stress at the interface is not continuous because of the difference in elastic moduli of the ceramic layers. Also, different stresses are developed if the framework is either under tension or under compression [23]. When the framework material is under tension, the strength is similar to that of the monolithic framework material, but when veneer is under tension, the strength is similar as if it was monolithic veneering ceramic [22].

Therefore, the objective of this study was to evaluate the flexural fatigue strength of ceramic structures obtained by both the cemented and fused file-splitting techniques in comparison with monolithic Y-TZP, testing the hypothesis that the fabrication technique and the material under tension influences the fatigue strength. In addition, finite element analysis (FEA) of the ceramic systems was performed to evaluate the stress distribution profiles under the simulated loading conditions, and to compare the model predictions with the flexural fatigue strength values found experimentally.

2. MATERIAL AND METHODS

2.1 Specimen preparation

Monolithic and trilayer discs were prepared according to ISO 6872:2008 standard [24]. Experimental groups were determined according to the specimen design (monolithic and trilayer), the method used to bond the Y-TZP framework and the lithium disilicate veneer (cementation or fusion glass ceramic) and material under tension during testing (framework or veneer) (Table 1). The monolithic and trilayer specimens final dimensions were 14.4 mm in diameter and 1.4 mm in thickness. Trilayer specimens had a 0.6 mm thick layer of Y-TZP, about 0.1 mm of fusion ceramic (F-FT and F-VT) or resin cement (C-FT and C-VT), and 0.7 mm thick layer of lithium disilicate.

For monolithic specimens, Y-TZP (IPS e.max ZirCAD, Ivoclar Vivadent, Liechtenstein) blocks were ground into cylinders in a polishing machine (EcoMet/AutoMet 250, Buehler, United States) using 400, 600 and 1200 grit silicon carbide paper consecutively under water cooling. The cylinders were cut with a diamond saw (Isomet 1000, Buehler) under water cooling to obtain discs. Then the discs were manually polished under water cooling, with 400, 600 and 1200 grit silicon carbide paper. The specimens were cleaned with isopropyl alcohol in ultrasonic bath for 10 min, and then sintered (VITA ZYRCOMAT 6000 MS, Vita Zahnfabrik, Germany) according to the manufacturer’s instructions (heating rate 10°C/min; sintering temperature 1500°C; holding time 120 min; cooling rate 5°C/min). Final thickness mean and standard-deviation (SD) were 1.35 and 0.01, respectively.

For trilayer specimens, both Y-TZP (IPS e.max ZirCAD, Ivoclar Vivadent) and lithium disilicate (IPS e.max CAD, Ivoclar Vivadent) discs were fabricated as described for monolithic specimens, except for their final thickness: approximately 0.6 mm for Y-TZP (mean: 0.58; SD: 0.009) and 0.7 mm for lithium disilicate (mean: 0.69; SD: 0.008) (IPS e.max CAD, Ivoclar Vivadent). Y-TZP and lithium disilicate discs were then randomized in F-FT, C-FT, F-VT and C-VT groups.

For F-FT and F-VT, Y-TZP and lithium disilicate discs were bonded using a fusion ceramic. The capsule containing the powder and liquid of the fusion ceramic IPS e.max CAD Crystall./Connect (Ivoclar Vivadent) was placed in the vibration plate of Ivomix (Ivoclar Vivadent) for 10s. The capsule was opened, the material was applied to the lithium disilicate surface and united with Y-TZP under vibration. Excess fusion glass was removed with a microbrush. The fusion of IPS e.max CAD Crystall./Connect and crystallization of lithium disilicate were performed simultaneously following the manufacturer's instructions (initial temperature 403°C, closing time 6 min, heating rate t_1 90°C/min, firing temperature T_1 820°C, holding time H_1 0:10 s, heating rate t_2 30°C/min, firing temperature T_2 840°C, holding time H_2 7 min, vacuum 1 from 550°C to 820°C, vacuum 2 from 820°C to 840°C, cooling 700°C) in a VITA VACUMAT 6000 MP furnace (VITA ZYRCOMAT 6000 MS). Final fusion ceramic thickness mean and SD were 0.07 and 0.03, respectively.

For C-FT and C-VT, lithium disilicate discs were sintered according to the abovementioned manufacturer's instructions. Y-TZP cementation surface was sandblasted with 50 µm aluminum oxide particles for 15 seconds at 2.8 bar from 5 mm distance and then Monobond Plus (Ivoclar Vivadent) was applied for 60 seconds. The lithium disilicate cementation surface was etched with 5% hydrofluoric acid IPS Ceramic Etching Gel (Ivoclar Vivadent) for 20 seconds, rinsed for 20 seconds and air-dried. Monobond Plus (Ivoclar Vivadent) was applied for 60 seconds. Y-TZP and lithium disilicate were bonded using Multilink Automix (Ivoclar Vivadent) resin cement and then each specimen was placed under a load of 100 g for 60 s. Final cement thickness mean and SD were 0.08 and 0.02, respectively.

After fatigue testing, the fusion ceramic and cement layer thickness was checked in three specimens in each group in scanning electron microscopy (SEM).

The mean (SD) values (µm) found were: F-FT- 85.21 (31.78), F-VT- 87.94 (19.00), C-FT 69.95.37 (2.00) and C-VT- 69.06 (0.75).

2.2 Monotonic flexural strength test

Prior to the fatigue test, the monotonic biaxial flexural strength was determined for 3 specimens from each group according to ISO 6872:2008 [24] using a piston-on-three-ball configuration in a universal testing machine (DL-1000 Emic, Brazil). The discs were positioned on the top of three steel spheres (2.5 mm in diameter, positioned 120° apart on a 10 mm diameter circle). The load was applied at 1 mm/min, perpendicular to the center of the top surface of the disc by a circular cylinder steel piston with a 1.6 mm diameter flat tip. An adhesive tape of 25 µm was placed between the piston and the disc before loading in order to avoid spreading the fragments and to provide more homogeneous contact between the piston tip and the specimen. In addition, a polyethylene sheet was placed between the supporting balls and the disc to evenly distribute contact pressures [24].

Flexural strength (σ) in MPa was calculated using Eqs. (1)-(5) [25]. The stress-moment relation is described by:

$$\sigma_i = \frac{E_i(z-z^*)M}{(1-v_i)(1+v_{ave})D^*} \quad \text{(for i = 1 to n)} \tag{1}$$

where E_i is Young's modulus of the i^{th} layer, M is the biaxial bending moment per unit length, and z*, D*, and v_{ave} are the neutral plane position, the flexural rigidity, and the average Poisson's ratio of the multilayered disc, respectively, such that:

$$z^* = \frac{\sum_{i=1}^{n}[E_i t_i/(1-v_i^2)](h_{i-1}+\frac{t_1}{2})}{\sum_{i=1}^{n}(E_i t_i)/(1-v_i^2)} \tag{2}$$

$$D^* = \sum_{i=1}^{n} \frac{E_i t_i}{1-v_i^2}\left[h_{i-1}^2 + h_{i-1}t_i + \frac{t_i^2}{3} - (h_{i-1} + \frac{t_i}{2}z^*\right] \tag{3}$$

$$v_{ave} = \frac{1}{h_n}\sum_{i=1}^{n} v_i t_i \tag{4}$$

The relationship between h_i and t_i is:

$$h_i = \sum_{j=1}^{i} t_j$$

The biaxial moment is related to the load by:

$$M = \frac{-P}{8\pi}\{(1+v_{ave})\left[1+2\ln\left(\frac{a}{c}\right)\right] + (1-v)\left[\left(1-\frac{c^2}{2a^2}\right)\frac{a^2}{R^2}\right] \quad \text{(for } r \leq c\text{)} \tag{5}$$

where P is the load at fracture (N), t is the disc thickness (mm), v is Poisson's ratio, *a* is the support ball radius (5.77 mm), c is the radius of the tip of the piston (0.8 mm), and R is the specimen radius (7.2 mm). The Poisson’s ratios for Y-TZP, fusion ceramic, resin cement and lithium disilicate were 0.33 [26], 0.21 [17], 0.35 [27] and 0.26 [28], respectively. The elastic moduli of Y-TZP, fusion ceramic, resin cement and lithium disilicate used were 210 GPa [29], 70 GPa [29], 6.3 GPa [27] and 95 GPa [29], respectively.

2.3 Flexural fatigue strength test

The biaxial flexural fatigue strength test of the groups (n=20) was conducted in an electric machine (Instron ElectroPuls E3000, Instron Corporation, United States) using the same piston-on-three-ball configuration [24] in water. An adhesive tape was placed between the piston and the disc, and a polyethylene sheet was placed between the supporting balls and the disc [24].

The flexural fatigue strength was determined for 750000 cycles, using the staircase approach [30] at 20 Hz. Sinusoidal loading was applied with amplitude ranging from 10 MPa to the maximum tensile stress. The first specimen of each group was tested at approximately 60% of the flexural strength determined in the monotonic test and stress increment. The test was conducted sequentially, increasing or decreasing the maximum applied stress by a fixed load increment (approximately 10%

of the initial strength) according to whether the previous tested specimen survived or failed. If the specimen failed before reaching the 750000 cycles, the stress level was decreased by one step size for the next specimen testing, but if the specimen survived, the stress level was increased by one step size for the next specimen testing.

Loads required to achieve the stress levels were calculated from Eqs. (1)–(5) [25]. Thus, all fatigue tests were controlled by tension.

2.4 Fractographic analysis

After the mechanical tests, the broken parts of the discs were analyzed in an optical microscope (Stereo Discovery V20, Carl Zeiss, Germany) in order to choose a representative specimen from each group to be examined in SEM at different magnifications. SEM analysis at lower power allowed for identifying fractographic features that led to the surface where the fracture initiated [31,32].

Only fragments in which the framework and veneer remained bonded to each other were chosen for F-FT, F-VT and C-FT failed specimens for SEM analysis. In C-VT group, all failures resulted in radial cracking on the veneer side, but no specimen fragmentation occurred. Thus, sectioning the C-VT specimens into two parts perpendicularly to the radial crack at the center was necessary in order to perform the fractographic analysis.

2.5 Statistical analysis

Mean fatigue flexural strength (σ_f) and the standard deviations were calculated based on the data of the least frequent event (survival or failure), using the method described by Collins, 1993 (Eqs. (6) and (7)) [30]:

$$\sigma_f = \sigma_{f0} + d[\sum in_i / \sum n_i \pm 1/2] \tag{6}$$

$$s = 1{,}62d\{[(\sum in_i \sum i^2 n_i - (\sum in_i)^2)/(\sum n_i)^2] + 0{,}029\}$$

if: $[(\sum in_i \sum i^2 n_i - (\sum in_i)^2)/(\sum n_i)^2] \geq 0.3$ (7)

where σ_{f0} is the lowest stress level considered in the analysis and *d* is the fixed step size. In Eq. (7), the negative sign is used if the less frequent event is failure; otherwise the positive sign is used. The lowest stress level considered is designated as i=0, the next level as i=1, and so on; while n_i is the number of failures or survivals at the given stress level. The confidence intervals (CI) (95%) were calculated [33] and the statistical difference was given by the non-overlapping of the CI.

2.6 Finite Element Analysis

Five three-dimensional models were obtained using a design software program (Rhinoceros 4.0, Robert McNeel & Associates, Spain), identically reproducing the specimen dimensions submitted to laboratorial tests (metallic base, lithium disilicate disc, zirconia disc, fusion ceramic, resin cement and metallic piston). Fusion ceramic and resin cement thickness was 0.1 mm and the thickness for the other layers were designed following the dimensions described for biaxial flexural strength tests. After modeling, geometric surfaces were imported to a post-processing software (ANSYS 13.0, ANSYS, United States) using the *stp* format.

After convergence tests, the size of the elements were defined in 0.2 mm for metallic base, 0.15 mm for zirconia and lithium disilicate discs, 0.05 mm for resin cement and fusion ceramic and 0.15 mm for metallic piston. The elements of the metallic base were tetrahedral, while the elements of other materials were hexagonal. The average number of elements for each model was 520000. The metallic base was considered fixed at axes x, y and z. The disc surfaces were considered perfectly bonded and the metallic piston applied a specifically vertical force (top to bottom direction) in the center of the superior disc. This force was in accordance with the mean value obtained for each groups after fatigue tests. All materials were considered isotropic, homogeneous and linear and the properties were the same as those already cited for the flexural strength calculations. The maximum principal stresses distribution was evaluated at Y-TZP, lithium disilicate, resin cement and fusion ceramic materials.

3. RESULTS

The monotonic flexural strength, stress levels for the first specimen of each group, step sizes, fatigue strength means and CI (MPa) are shown in Table 1. Significant differences were found for biaxial fatigue strength among all groups in the following order: M > F-FT > C-FT > F-VT > C-VT. The pattern of runouts and failures for each group is described in Fig. 1.

Representative SEM images of fractured surfaces for each specimen configuration are presented in Fig. 2. At low power, fractographic markings such as the mirror region and the compression curl led to the identification of the failure origin on the tensile side of the specimens and the direction of crack propagation running to the opposite (compression) side in M (Fig. 2a), F-FT (Fig. 2c), C-FT (Fig. 2e) and F-VT (Fig. 2g) groups. In Figs. 2b, d, f and h, the origins were analyzed at high magnification. In the C-VT group, the radial crack originates from the bottom surface of lithium disilicate (tensile side) and propagates through the cement interface (Fig. 2i), which can also be seen at higher power (400x and 2000x, Fig. 2j). Fractographic analysis revealed a separation between Y-TZP and the fusion ceramic in F-VT (Fig. 2g), and between Y-TZP and the cement layer in C-VT (Figs. 2i and j).

Fig. 3 shows a FEA mesh generation. The veneering technique and material under tension affected FEA maximum principal stresses in the modeled specimens.

FEA tensile predicted stresses (MPa) values in the center of the bottom surface of the disc under tension were similar to the mean values obtained in the fatigue strength test, with up to ≅10 MPa of variation. C-FT had the most discrepant FEA value, which was ≅20 MPa higher than mean fatigue strength (Table 1). Fig. 4 shows FEA stress distribution on the ceramic layer subjected to tension and on the intermediate (fusion ceramic or resin cement) layer of trilayer specimens. For M, stress is more homogeneously distributed on the ceramic than in the other groups, in which stress distribution in the fusion ceramic/cement layer is evidently different than in the ceramic under tension. By comparing cemented and fused trilayer groups, stress concentrates in a larger area around the center of the loading point in the cement layers than in fusion ceramic layers.

4. DISCUSSION

New methods and materials have been developed to reduce clinical veneer fractures of bilayer Y-TZP restorations. One advantage of the file-splitting method is the use of ceramic blocks produced under rigorous industrial conditions to fabricate the veneer, with fewer defects than hand-layered veneers [12,14,34]. The CAD-on technique involves milling lithium disilicate veneers, which have superior mechanical properties than feldspathic ceramics conventionally used for veneering Y-TZP frameworks [35]. Although the CAD-on method consists of bonding both ceramics with a fusion ceramic, lithium disilicate veneers were also used for the cemented groups in order to allow comparability with the fused groups. As there was statistical difference found among all groups, the experimental hypothesis was accepted.

Interfaces represent an essential part in the mechanical behavior and durability of veneered ceramics [23] because large stresses are developed in the framework/veneer interfaces, resulting in a focal area for fracture [23,36]. With the file-splitting method, restorations have two interfaces: Y-TZP/fusion ceramic or resin cement and lithium disilicate/fusion ceramic or resin cement, making such multilayer ceramic structures even more complex. Biaxial flexural strength tests represent standardized methodologies suitable for understanding the interfaces and their influence on multilayer ceramics performance [23].

Clinically, ceramics fail under fatigue after growth of preexisting cracks at cyclic stresses below the critical value, especially in the presence of water, temperature and pH variations [20,37]. To the authors' knowledge, non-aged [5,12,15,38] and aged [1,17,18,34,39-42] fused file-splitting specimens, as well as non-aged [11,14,43-44] and aged cemented file-splitting specimens [17-18,40,42,44-46] were only compared with other veneering methods under monotonic testing. Therefore, it is difficult to confront the current results with existing literature.

Monolithic Y-TZP had the highest fatigue strength in comparison to all the other groups. Previous studies found no difference in the monotonic failure load [15] and uniaxial flexural strength [5] between monolithic Y-TZP and Y-TZP veneered with the CAD-on method. However, in the present study, comprising the effect of fatigue mechanisms on the failure of ceramic structures [19], both F-FT and C-FT groups had statistically lower fatigue strength than M. Although the material under tension has an important impact on flexural strength, the mechanical behavior of multilayer structures is also affected by other factors, such as thickness, Poisson's ratio and elastic modulus of each layer [25], as well as the interfacial bond [23]. After aging, monotonic failure load of monolithic Y-TZP was also superior to fused and cemented lithium-disilicate veneered Y-TZP molar crowns [18]. According to Lin et al. (2012) [29], the presence of a veneering ceramic reduces the strength and reliability of layered specimens in comparison with monolithic cores. The different compositions of the involved materials, the compatibility of the core and veneer, and the interfaces’ behavior may explain such difference between monolithic and layered specimens with framework under tension [47]. In addition to fatigue strength, FEA also predicted higher values for M than for F-FT and C-FT groups. In contrast to monolithic Y-TZP, which is composed by a single homogeneous material, in the FEA images it is possible to observe that veneered specimens have different stress distribution in each layer because the elastic properties are not continuous at the interfaces, which is in agreement with previous FEA results [48].

Cementation of the veneer instead of fusion would be desirable because it decreases thermal residual stresses from sinterization, as the fusion ceramic is not present [35]. However, cemented groups showed lower flexural strength than fused groups, regardless of the framework or veneer being under tension. This finding is in accordance with previous studies that found statistically higher fracture load after aging for fused in comparison to cemented veneers [17-18]. The resin cement used to bond the veneer to the framework has inferior mechanical properties than the fusion ceramic, which negatively impacts the fracture load of such restorations [17]. FEA showed that maximum tensile stresses concentrate in a larger area around the center of the cement loading area than in the fusion ceramic. Considering the situation in which the framework is under tension, the weaker cement layer at the Y-TZP/lithium disilicate interface might decrease the supportive effect of Y-TZP on the veneering ceramic, leading to stress accumulation in the veneer loading area and not in the entire zirconia/veneer surface [14]. In addition, the group in which the FEA value varied the most from the fatigue strength test was C-FT. However, the interfaces in the virtual models represent a perfectly bonded condition, but adequate resin cement bond to Y-TZP is clinically difficult because highly-crystalline ceramics are not responsive to acid etching [49].

Groups with the framework subjected to tension exhibited higher flexural fatigue strength and FEA calculated stress than those tested with the veneer under tension. It has been reported that the mechanical behavior of layered structures is controlled by the ceramic under tension [22,50-52]. Since Y-TZP is stronger than lithium disilicate, an improvement in the flexural strength is expected when it is subjected to tension. However, when the framework material, with superior mechanical properties, is not on the bottom surface, it fails to improve flexural strength of the assembly [22,51]. The fractographic analysis corroborates these findings since there was a separation between fusion ceramic and Y-TZP (F-VT), and between cement and Y-TZP (C-VT). When the veneer is on the bottom, lateral crack deflection when the zirconia interface is reached indicates the superior ability of Y-TZP to resist crack propagation [52]. FEA showed that the maximum tensile stress was located in the surface submitted to tension, where the failure originates for all groups, which is in agreement with the literature [48,53].

In the clinical situation, tensile stresses for single crowns are observed on the core and veneer below loading and on the core at the cementation surface [54-56]. For fixed partial dental prosthesis, the connector gingival area is subjected to high tensile stresses during occlusal loading and represents a potential location for failure [57]. Consequently, special attention should be given to the veneering of high tensile-subjected areas in layered prostheses. Some authors recommend that the connector and pontic cervical surfaces should not be veneered with weaker ceramics [52,58]. It is also important to highlight the presence of voids in the fusion ceramic observed in the SEM images (Fig. 2 c and g). In the study by Basso et al. (2016) [21], voids were identified in the fusion ceramic near the Y-TZP connector fracture origin. This may be a processing problem due to poor wettability of the Y-TZP by the fusion ceramic [59]. Clinically, such defects could be a region for stress concentration at the interfaces, resulting in a susceptible point for fracture [22,36].

The use of fractography is important to identify if the origin of the failure occurred from the assumed location [60]. The failures seemed to initiate on the surface subjected to tensile stress during the test in all specimens, and not due to stress concentration at the contact surface between loading piston and disc. The only group that did not allow failure origin identification was C-VT because no specimen was catastrophically broken, resulting in no fragments. Therefore, the failed discs were cut perpendicularly to the radial crack to enable microscope observation. Although it was not possible to identify the critical flaw origin in this group, the crack was located at the resin cement and lithium disilicate, which was subjected to tension during the fatigue test. Also, FEA images show that maximum tensile stress was located at the bottom of lithium disilicate layer, which seems to indicate that failure initiated at this surface.

One of the limitations of the present study was that the framework and veneer were not milled, thus the defects generated by the machining process were not reproduced. In addition, fatigue degradation is clinically associated with progressive surface wear produced by abrasion and attrition over time [60]. Future studies aiming to simulate the clinical conditions should be performed. Furthermore, the results of the current study should be cautiously analyzed since the behavior of veneered restorations also depends on laboratorial, clinical and patient-related variables.

5. CONCLUSIONS

Monolithic Y-TZP showed superior flexural fatigue strength than the fused and cemented file-splitting methods. Fused file-splitting could be an alternative for layered Y-TZP, since it had higher fatigue strength than the cemented file-splitting technique. The ceramic placed under tension during testing influenced the flexural fatigue strength result.

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FIGURES AND TABLES:

Figures

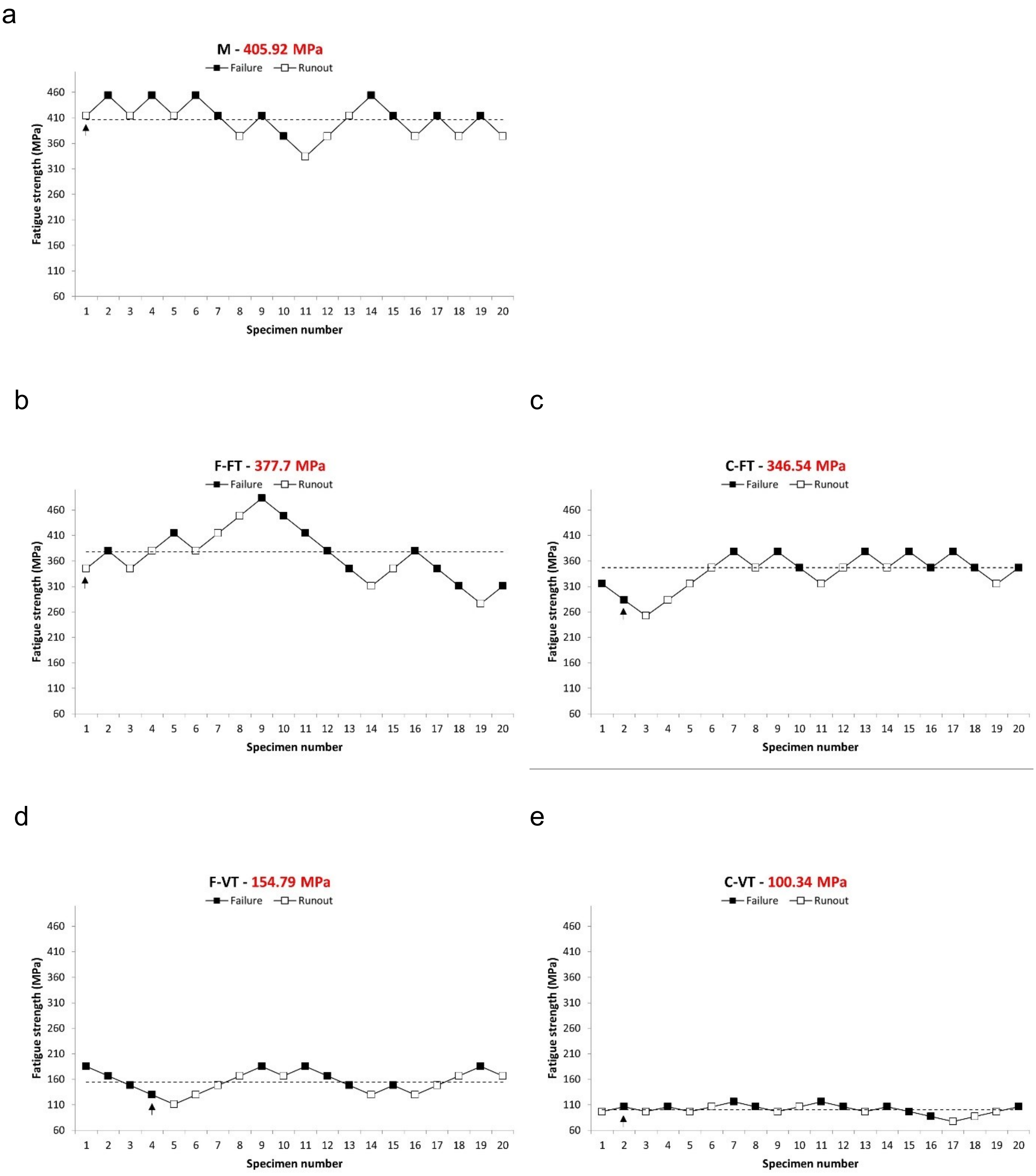
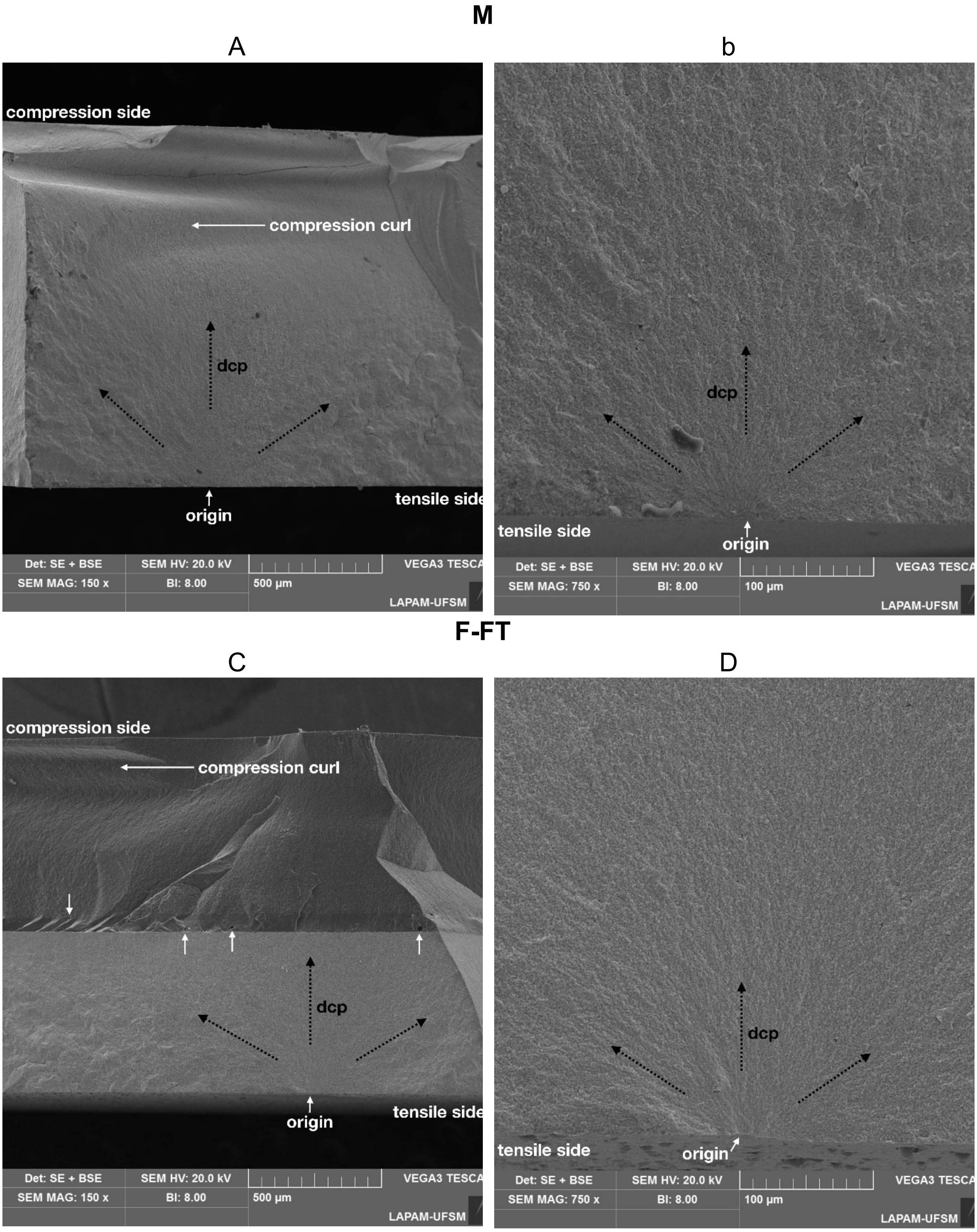


Fig. 1 - Staircase test results during mechanical cycling (750000 cycles) for M (a), F-FT (b), C-FT (c), F-VT (d), and C-VT (e). The arrows indicate the stress level at which the up-and-down behavior started. The dashed lines indicate the fatigue strength mean.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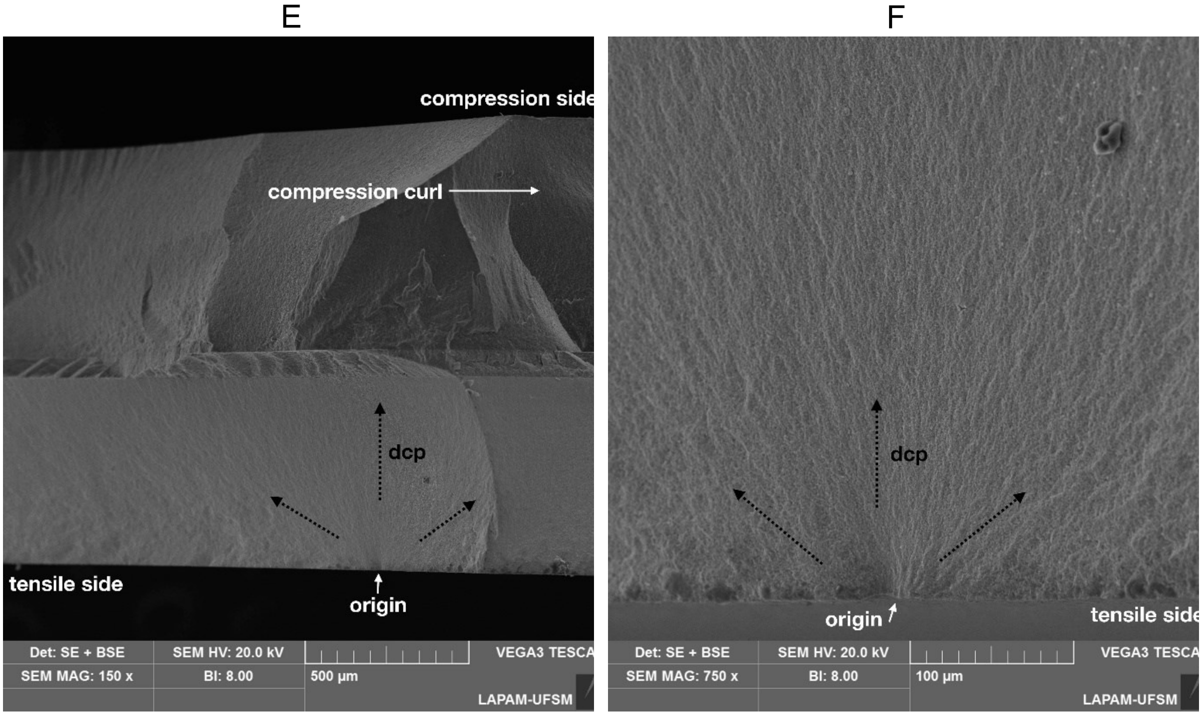
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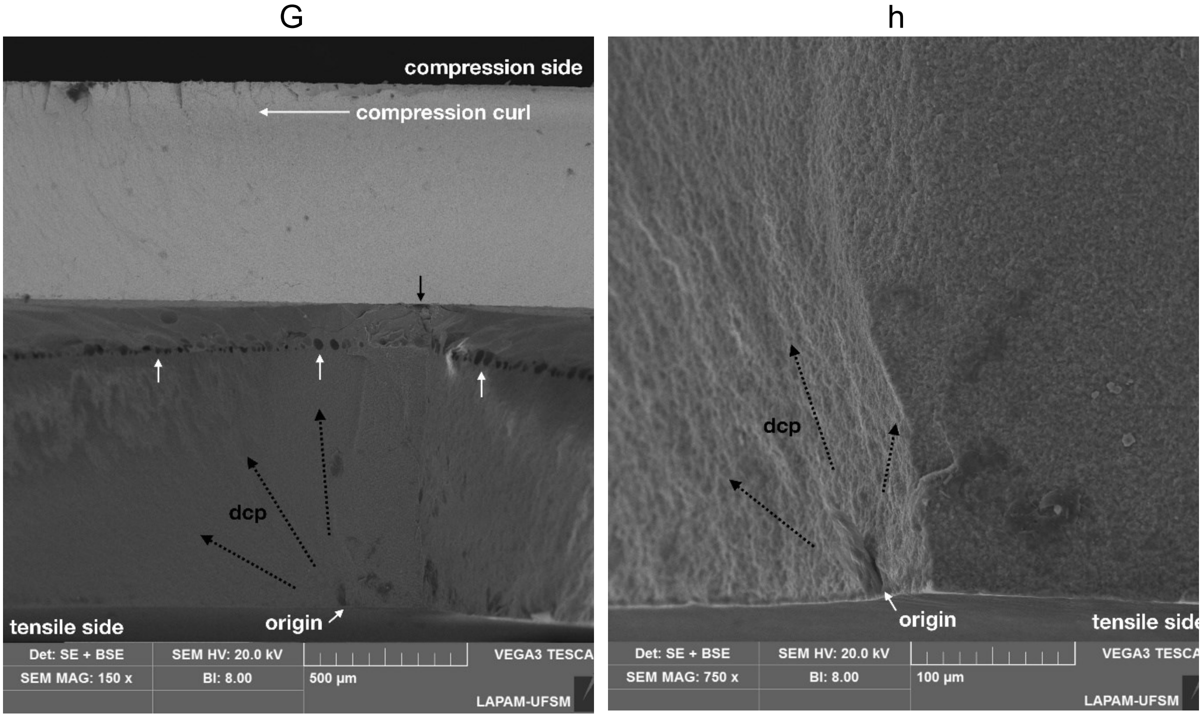
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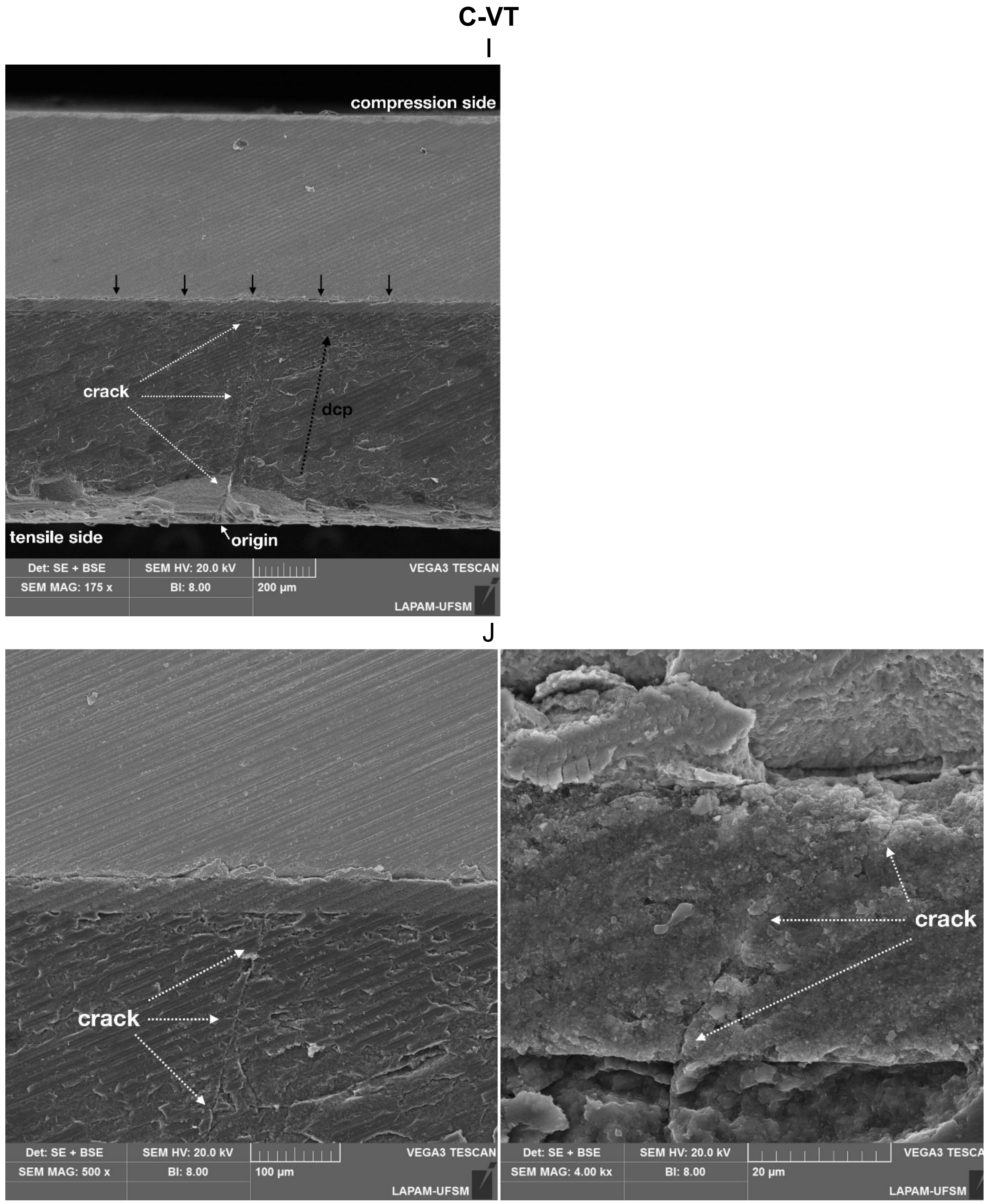

Fig. 2- Representative SEM images from the fracture surfaces of M (a,b), F-FT (c,d), C-FT (e,f), F-VT (g,h), and C-VT (i,j) groups. The failure origin (mirror region) [31] at the tensile side of the specimens and the direction of crack propagation (dcp, dashed black arrows) to the opposite side (signaled by a compression curl) can be detected in low magnification images for M (a), F-FT (c), C-FT (e) and F-VT (g) groups [32]. The

origins were also photographed at high magnification (b, d, f and h). In the C-VT group (i), the crack originates from the tensile side and propagates (dcp, dashed black arrows) through the cement layer. Crack propagation is displayed at higher magnifications (500x and 4000x) (j). Voids in the fusion ceramic in F-FT (d) and F-VT (g) (white arrows) can be visualized, as well as separation between the fusion ceramic and Y-TZP in F-VT (g) and between cement and Y-TZP in C-VT (j) (black arrows).

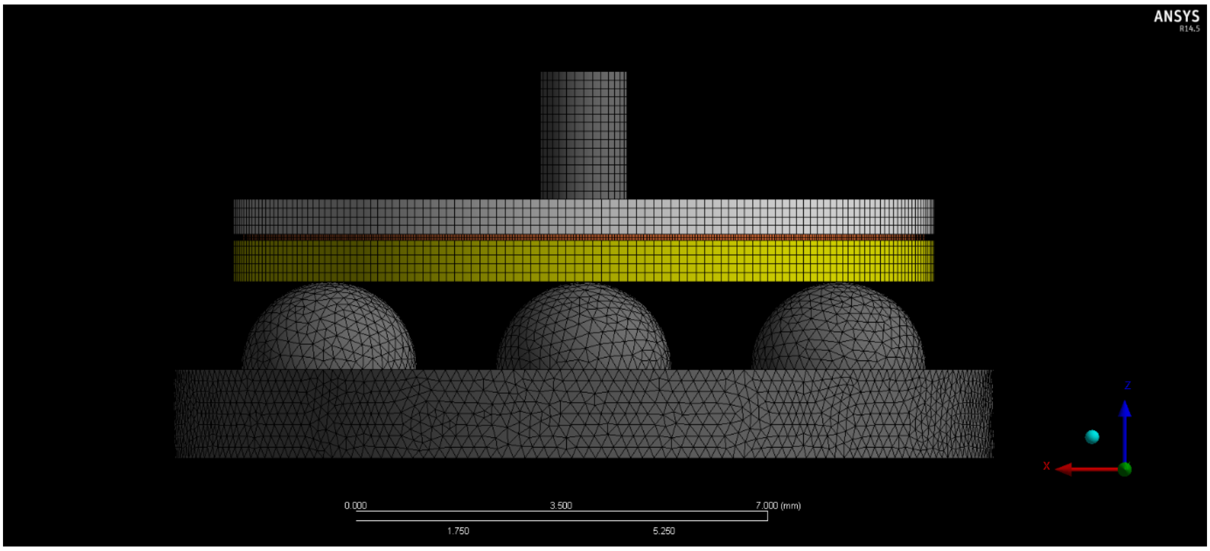

Fig. 3- Example of generated mesh pattern (trilayer with Y-TZP under tension).

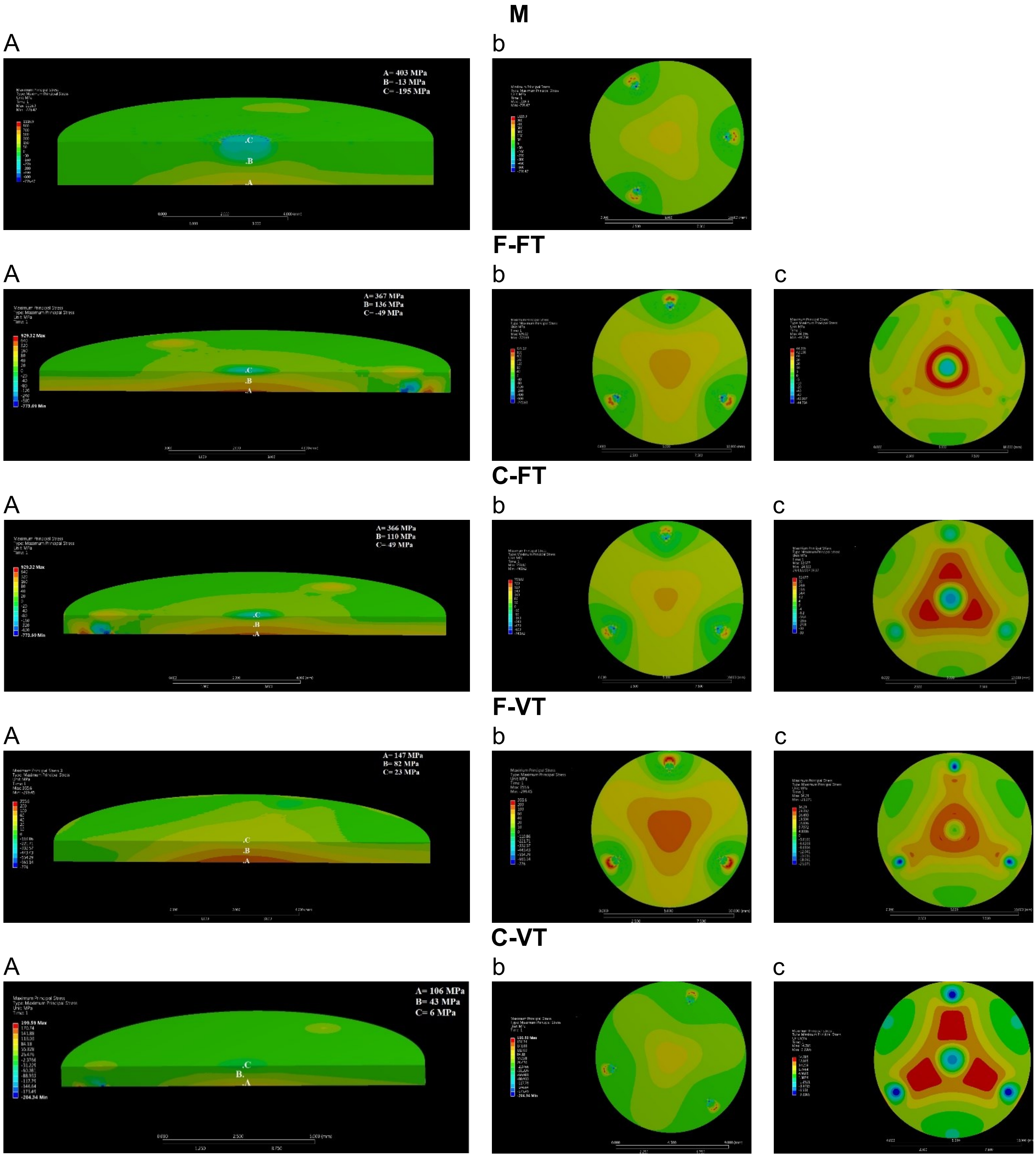

Fig. 4- FEA images for the maximum principal stresses (MPa) distribution on the sectioned (a) and bottom view (b) of the layer under tension and on the bottom view of the intermediate (fusion ceramic or cement) layer (c).

Table 1- Experimental groups, mean (SD) of the monotonic flexural strength, fatigue initial stress level, step size, fatigue flexural strength and FEA calculated stresses (MPa).

Group	Description	Material under tension	Monotonic strength (SD)	Fatigue initial stress	Step	Fatigue strength (CI)	FEA
M	Monolithic Y-TZP	-	689.86 (18.94)	413.92	40	405.92 (CI 397.58-414.26)	403
F-FT	Fused trilayer	Y-TZP framework	575.26 (11.03)	345.15	34.5	377.73 (CI 374.59-380.88)	367
C-FT	Cemented trilayer	Y-TZP framework	525.06 (0.53)	315.04	31.5	346.54 (CI 340.62-352.46)	366
F-VT	Fused trilayer	Lithium disilicate veneer	308.64 (22.11)	185.18	18.5	154.79 (CI 151.86-157.72)	147
C-VT	Cemented trilayer	Lithium disilicate veneer	160.83 (19.42)	96.5	9.6	100.34 (CI 97.42-103.26)	106

5 DISCUSSÃO

Devido à alta porcentagem de lascamento e delaminação de restaurações de Y-TZP com cobertura cerâmica (NÄPÄNKANGAS; PIHLAJA; RAUSTIA, 2015; PJETURSSON et al., 2015), há constante preocupação com o desenvolvimento de novos materiais e técnicas para melhorar o desempenho clínico dessas restaurações (COSTA et al., 2014). Assim, surgiu uma nova técnica de cobertura cerâmica por CAD/CAM, também conhecida por "*file-splitting*", em que a infraestrutura de Y-TZP e a cobertura de cerâmica feldspática ou reforçada por partículas são usinadas e unidas por uma cerâmica de fusão ou por um cimento resinoso (KANAT-ERTÜRK et al., 2015; KANAT et al., 2014; SCHMITTER et al., 2014).

Os resultados da revisão sistemática intitulada "***Does veneering technique affect the flexural strength or load to failure of bilayer Y-TZP? A systematic review and meta-analysis***" mostraram ausência de diferença estatística para as meta-análises de resistência flexural e carga à fratura entre os métodos de prensagem e estratificação manual. O achado está provavelmente relacionado à composição e propriedades similares das cerâmicas usadas para ambas as técnicas (LIMA et al., 2013; TSALOUCHOU et al., 2008), já que os estudos incluídos usaram cerâmicas feldspáticas ou de fluorapatita para as duas técnicas. O estudo de Güngör e Nemli (2017) (que não foi incluído na revisão sistemática por não apresentar valores quantitativos de desvio-padrão) não mostrou diferença estatística entre as médias de carga à fratura e resistência característica, assim como encontrou módulo de Weibull similar na comparação de coroas de Y-TZP com estratificação manual e com prensagem com dissilicato de lítio. Os autores justificaram tais resultados em função das sucessivas etapas necessárias para o processamento, que tornam os dois métodos delicados: a estratificação manual é sensível à experiência do técnico, homogeneidade da mistura cerâmica, ciclo de sinterização, resfriamento e contração de sinterização, enquanto a prensagem é influenciada pelo correto preenchimento do anel de revestimento, limpeza da cera, qualidade do material de prensagem, temperatura do forno e abrasão para remover resíduos de refratário (KANAT et al., 2014). Portanto, além das propriedades mecânicas do material de cobertura, outras variáveis afetam o comportamento mecânico de restaurações *bilayer*.

Em relação ao método CAD/CAM, a meta-análise geral avaliando carga à fratura da técnica fusionada mostrou diferença estatística, favorecendo tal método em comparação com estratificação manual, assim como a análise por subgrupos dos estudos que usaram cerâmica de cobertura reforçada por partículas para a técnica de fusão favoreceu a fusão em relação à estratificação manual. Porém, ao considerar a técnica cimentada, a meta-análise para carga à fratura não mostrou diferença estatisticamente significante entre os grupos. A análise de subgrupos favoreceu a estratificação manual em comparação com cimentação com cerâmicas predominantemente vítreas e não pôde ser realizada para cerâmicas reforçadas por partículas pelo número limitado de estudos.

Assim, o primeiro artigo desta tese indicou a necessidade de mais estudos avaliando a técnica CAD/CAM cimentada, especialmente com cerâmicas reforçadas por partículas. Sabe-se que as cerâmicas são suscetíveis à falha por fadiga quando submetidas a tensões cíclicas abaixo da sua resistência nominal, sendo que a água desempenha papel importante no crescimento lento de trincas (GONZAGA et al., 2011; ZHANG; SAILER; LAWN, 2013). A fadiga mecânica ocorre exclusivamente com carregamento cíclico e não pode ser inferida por testes monotônicos (ZHANG; SAILER; LAWN, 2013). A revisão sistemática também levantou a necessidade de estudos com testes de fadiga para avaliar o método CAD/CAM fusionado e cimentado, pois a maior parte dos estudos disponíveis usaram testes monotônicos.

O segundo artigo, de título “***File-splitting multilayer vs monolithic Y-TZP: fatigue flexural strength and loading stresses by finite element analysis***” objetivou trazer mais informações em relação aos tópicos levantados no primeiro artigo. O principal achado do segundo estudo foi que independentemente de a infraestrutura ou cobertura estar voltada para o lado de tração, a técnica de fusão apresentou maior resistência à fadiga. Tal achado se conecta aos resultados da revisão sistemática, em que a técnica CAD/CAM fusionada apresentou melhor desempenho mecânico que a estratificação manual, da mesma forma que a técnica cimentada foi similar à estratificação manual ou inferior na análise de subgrupos.

Outro achado importante foi que o material posicionado no lado de tração influenciou a resistência à fadiga do conjunto: quando o dissilicato de lítio foi testado para baixo a resistência à fadiga foi inferior que quando a Y-TZP foi testada sob tração. As propriedades mecânicas do material submetido à tração são mandatórias no comportamento do conjunto, o que explica a maior resistência à fadiga com a Y-TZP voltada para baixo (BORBA et al., 2011; BORBA et al., 2016; ZENG, ODÉN e HOWCLIFFE et al., 1998). Os resultados da análise de elementos finitos também mostraram que a máxima tensão de tração ocorre na superfície do espécime posicionada para baixo, corroborando com a influência do material sob tração na resistência da estrutura. Na revisão sistemática, o material voltado para o lado de tração variou entre os estudos primários, avaliando resistência flexural e, em alguns casos, não foi especificado.

A Y-TZP monolítica mostrou resistência superior aos demais grupos, inclusive aos grupos em que a camada de zircônia estava voltada para baixo. Apesar de as propriedades do material sob tração terem importante efeito no comportamento do conjunto, estruturas cerâmicas com múltiplas camadas são influenciadas também por outros fatores. Huang e Hsueh (2011) converteram a equação da ISO 6872 usada para cálculo resistência flexural biaxial de espécimes monolíticos para uso em estruturas multicamadas. É possível observar na equação que a espessura, coeficiente de Poisson e módulo de elasticidade de cada camada apresentam influência na resistência à flexão do conjunto. Além disso, a análise de elementos finitos do segundo artigo mostrou distribuição de tensões descontínua entre as camadas dos grupos com a zircônia, diferentemente da Y-TZP monolítica, em que o espécime é uniformemente constituído por um único material. No estudo de Borba et al. (2011), espécimes *bilayer* com infraestrutura de óxido de alumínio e zircônio infiltrados por vidro ou alumina policristalina com cobertura de cerâmica feldspática apresentaram resistência flexural estatisticamente similar aos correspondentes espécimes monolíticos com mesmo material da infraestrutura. No entanto, quando a infraestrutura foi confeccionada de Y-TZP, não foi possível comparar estatisticamente os grupos monolítico e bilayer, pois no último a cobertura falhou por compressão antes de a infraestrutura falhar por tração.

Novas investigações com ensaios de fadiga e simulação mais próxima das condições clínicas devem ser conduzidos, como espécimes que reproduzam a anatomia coronária cimentados a troqueis que simulem a dentina. Além disso, ensaios clínicos randomizados são necessários para confirmar os achados do presente estudo clinicamente.

6 CONCLUSÃO

A partir dos dois artigos apresentados nesta tese, pode-se concluir que a técnica CAD/CAM fusionada representa uma alternativa com melhor desempenho mecânico entre as técnicas de cobertura cerâmica em infraestruturas de Y-TZP, principalmente com cerâmicas reforçadas por partículas como o dissilicato de lítio. A utilização de restaurações monolíticas, quando indicada, parece ser mais favorável à longevidade estrutural das restaurações.

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ANEXO A - NORMAS PARA PUBLICAÇÃO NO PERIÓDICO *THE JOURNAL OF PROSTHETIC DENTISTRY*

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Articles are classified as one of the following: research/clinical science article, clinical report, technique article, systematic review, or tip from our readers. Required sections for each type of article are listed in the order in which they should be presented.

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The research report should be no longer than 10-12 double-spaced, typed pages and be accompanied by no more than 12 high-quality illustrations. Avoid the use of outline form (numbered and/or bulleted sentences or paragraphs). The text should be written in complete sentences and paragraph form.

Abstract (approximately 400 words): Create a structured abstract with the following subsections: Statement of Problem, Purpose, Material and Methods, Results, and Conclusions. The abstract should contain enough detail to describe the experimental design and variables. Sample size, controls, method of measurement, standardization, examiner reliability, and statistical method used with associated level of significance should be described in the Material and Methods section. Actual values should be provided in the Results section.

Clinical Implications: In 2-4 sentences, describe the impact of the study results on clinical practice.

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Material and Methods: In the initial paragraph, provide an overview of the experiment. Provide complete manufacturing information for all products and instruments used, either in parentheses or in a table. Describe what was measured, how it was measured, and the units of measure. List criteria for quantitative judgment. Describe the experimental design and variables, including defined criteria to control variables, standardization of testing, allocation of specimens/subjects to groups (specify method of randomization), total sample size, controls, calibration of examiners, and reliability of instruments and examiners. State how sample sizes were determined (such as with power analysis). Avoid the use of group numbers to indicate groups. Instead, use codes or abbreviations that will more clearly indicate the characteristics of the groups and will therefore be more meaningful for the reader. Statistical tests and associated significance levels should be described at the end of this section.

Results: Report the results accurately and briefly, in the same order as the testing was described in the Material and Methods section. For extensive listings, present data in tabular or graphic form to help the reader. For a 1-way ANOVA report of, F and *P* values in the appropriate location in the text. For all other ANOVAs, per guidelines, provide the ANOVA table(s). Describe the most significant findings and trends. Text, tables, and figures should not repeat each other. Results noted as significant must be validated by actual data and P values.

Discussion: Discuss the results of the study in relation to the hypothesis and to relevant literature. The Discussion section should begin by stating whether or not the data support rejecting the stated null hypothesis. If the results do not agree with other studies and/or with accepted opinions, state how and why the results differ. Agreement with other studies should also be stated. Identify the limitations of the present study and suggest areas for future research.

Conclusions: Concisely list conclusions that may be drawn from the research; do not simply restate the results. The conclusions must be pertinent to the objectives and justified by the data. In most situations, the conclusions are true for only the population of the experiment. All statements reported as conclusions should be accompanied by statistical analyses.

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Illustrations: See Figure Submission and Sample Figures page.

Clinical Report
The clinical report describes the author's methods for meeting a patient treatment challenge. It should be no longer than 4 to 5 double-spaced, pages and be accompanied by no more than 8 high-quality illustrations. In some situations, the Editor may approve the publication of additional figures if they contribute significantly to the manuscript.

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Clinical Report: Describe the patient, the problem with which he/she presented, and any relevant medical or dental background. Describe the various treatment options and the reasons for selection of the chosen treatment. Fully describe the treatment rendered, the length of the follow-up period, and any improvements noted as a result of treatment. This section should be written in past tense and in paragraph form.

Discussion: Comment on the advantages and disadvantages of the chosen treatment and describe any contraindications for it. If the text will only be repetitive of previous sections, omit the Discussion.

Summary: Briefly summarize the patient treatment.

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[1] J. van der Geer, J.A.J. Hanraads, R.A. Lupton, The art of writing a scientific article, J. Sci. Commun. 163 (2010) 51–59.

Reference to a book:

[2] W. Strunk Jr., E.B. White, The Elements of Style, fourth ed., Longman, New York, 2000.

Reference to a chapter in an edited book:

[3] G.R. Mettam, L.B. Adams, How to prepare an electronic version of your article, in: B.S. Jones, R.Z. Smith (Eds.), Introduction to the Electronic Age, E-Publishing Inc., New York, 2009, pp. 281–304.

Journal abbreviations source

Journal names should be abbreviated according to the List of Title Word Abbreviations:
http://www.issn.org/services/online-services/access-to-the-ltwa/.

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