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IMPACTO DAS CAVIDADES DE ACESSO MINIMAMENTE INVASIVAS NOS DESFECHOS DO TRATAMENTO ENDODÔNTICO

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O presente trabalho em nível de doutorado foi avaliado e aprovado por banca examinadora composta pelos seguintes membros:

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Florianópolis, 24 de março de 2020.

Dedico este trabalho e tudo o que sou
aos meus pais: Ivam e Márcia.

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RESUMO

Introdução: Os acessos endodônticos minimamente invasivos (AEMI) priorizam a máxima preservação de estrutura dental sadia, com o intuito de minimizar a perda de resistência do elemento dental tratado endodonticamente. A presente tese é composta por dois estudos. O primeiro deles objetivou revisar sistematicamente a literatura e responder a seguinte questão: o acesso endodôntico minimamente invasivo aumenta a resistência à fratura de dentes humanos extraídos quando comparados ao acesso endodôntico tradicional? O segundo estudo teve como objetivo, avaliar a influência da localização e design da cavidade de acesso endodôntico na eficácia da instrumentação, qualidade da obturação, limpeza da câmara pulpar e resistência à fratura de incisivos inferiores. **Metodologia:** No primeiro estudo, dois revisores independentes realizaram uma busca sem restrições, nas bases de dados PubMed, Science Direct, Scopus, Web of Science e Open Grey. Buscas manuais também foram realizadas nas referências dos artigos. Foram incluídos todos os estudos *in vitro* que avaliaram a influência dos AEMI na resistência à fratura de dentes humanos extraídos. Cada estudo teve suas características descritas e foi avaliado quanto a sua qualidade em alto, médio ou baixo risco de viés. No segundo estudo, quarenta incisivos inferiores foram escaneados em micro tomografia computadorizada (micro-CT), pareados de acordo com as similaridades anatômicas e distribuídos em quatro grupos experimentais de acordo com o tipo de acesso e instrumentos utilizados no preparo do canal (n=10): tradicional/TRUShape (T/TRU); tradicional/MTwo (T/MT); minimamente invasivo/TRUShape (MI/TRU); e minimamente invasivo/MTwo (MI/MT). O acesso nos grupos com AEMI foi realizado na borda incisal por lingual dos elementos dentais com broca esférica de pequeno diâmetro. A instrumentação foi realizada com os instrumentos TRUShape ou MTWO. Novos escaneamentos em micro-CT foram realizados após a instrumentação e obturação dos elementos dentais. Os parâmetros analisados foram: volume e área do canal radicular, áreas não instrumentadas, transporte e centralização do preparo, debris acumulados, espaços vazios nas obturações e quantidade de material obturador remanescente na câmara pulpar. Os espécimens foram então submetidos ao ensaio de resistência à fratura em uma máquina de testes universal. Os dados foram analisados pelos testes estatísticos Shapiro-Wilk, ANOVA e Bonferroni ($\alpha=0,05$). **Resultados:** No primeiro estudo, um total de 810 estudos foi obtido na busca eletrônica e seis foram incluídos na RS. Os estudos demonstraram grande variabilidade entre os valores de resistência à fratura e desvios padrão. No segundo estudo, *in vitro*, não foram observadas diferenças estatísticas entre os quatro grupos em todos os parâmetros avaliados antes e após a instrumentação dos canais radiculares (volume e área do canal radicular, áreas não instrumentadas, transporte e centralização do preparo, e debris acumulados) ($p>0,05$). Os grupos MI/TRU e MI/MT apresentaram significativamente mais espaços vazios nas obturações quando comparados aos grupos T/TRU e T/MT ($p<0,05$). A quantidade de material obturador remanescente na câmara pulpar e os valores médios de resistência à fratura não foram estatisticamente significante entre os quatro grupos experimentais ($p>0,05$). **Conclusões:** Não foram encontradas evidências científicas que suportem a premissa de que os AEMI são capazes de aumentar a resistência à fratura de elementos dentais tratados endodonticamente quando comparados aos AET. A localização e o design da cavidade de acesso endodôntico não interferiram no preparo do sistema de canais radiculares. No entando, o AEMI pode comprometer a obturação do sistema de canais radiculares. Além disso, o AEMI não foi associado a um aumento na resistência à fratura do incisivo inferior, o que evidenciou a ausência de benefícios em seu uso quando comparado ao AET.

Palavras-chave: Acesso endodôntico minimamente invasivo. Micro-CT. Resistência à fratura.

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ABSTRACT

Introduction: Contracted endodontic cavities (CEC) prioritize the maximum preservation of healthy dental structure, in order to minimize the loss of resistance of the endodontically treated teeth. This thesis was composed of two studies. The first one aims to systematically review the literature and answer the following question: do CEC increase resistance to fracture in extracted human teeth compared to traditional endodontic cavities TEC? The second study aimed to evaluate the influence of the location and design of the endodontic access cavity on shaping and filling ability, cleaning of the pulp chamber, and fracture resistance of mandibular incisors. **Methodology:** In the first study, a literature search without restrictions was carried out in PubMed, Science Direct, Scopus, Web of Science, and Open Grey databases. Articles were selected by two independente reviewers. In addition, a reference and hand search was also fulfilled. All included in vitro studies evaluated the influence of CECs on strength to fracture in extracted human teeth and compared to TECs. Each study had its characteristics described and was evaluated for its quality at high, medium or low risk of bias. In the second study, forty extracted intact mandibular incisors were scanned in a micro-computed tomographic device, matched based on similar anatomical features of the canals and assigned to four experimental groups (n=10) according to the endodontic access cavity and root canal preparation protocol: traditional/TRUShape (T/TRU); traditional/MTwo (T/MT); contracted/TRUShape (C/TRU); and contracted/MTwo (C/MT). The access cavity in the groups with CEC was performed at the incisal edge of the dental elements with a small diameter spherical drill. Root canal instrumentation was performed with TRUShape or MTwo instruments. Samples was scanned after root canal instrumentation, filling and restoration procedures. The analyzed parameters were: volume and area of the root canal, non-instrumented canal areas, canal transportation and centering ratio, accumulated hard tissue debris, voids in root fillings and root filling remnants in the pulp chamber. The specimens were then subjected to the fracture resistance test on a universal testing machine. Data were analysed statistically using Shapiro–Wilk, ANOVA and Bonferroni tests with a significance level of 5% (α=0.05). **Results:** In the first study, a total of 810 studies were obtained in the electronic search and six were included in the systematic review. Studies have shown great variability between fracture resistance values and standard deviations. In the second study, in vitro, there was no difference regarding all parameters evaluated before and after root canal preparation (volume and area of the root canal, non-instrumented canal areas, canal transportation and centering ratio, and accumulated hard tissue debris) among the groups ($P>0.05$). C/TRU and C/MT groups presented significantly more voids in root fillings when compared to the T/TRU and T/MT groups ($P<0.05$). Percentage of root filling remnants in the pulp chamber after cleaning procedures and mean fracture resistance values were not statistically significant among the four experimental groups ($P>0.05$). **Conclusions:** There is no evidence in literature that supports the use of CEC are able to increase fracture resistance of endodontically treated teeth when compared to traditional endodontic cavity. The location and design of the endodontic access cavity did not interfere in the root canal preparation. However, CEC can compromise the filling of the root canal system. In addition, CEC was not associated with an increase in fracture resistance of the mandibular incisor, which evidenced the absence of benefits in its use when compared to traditional endodontic cavity.

Keywords: Conservative Endodontic Cavity. Micro-CT. Fracture Resistance.

SUMÁRIO

1 INTRODUÇÃO

O sucesso do tratamento endodôntico está associado à eficiente desinfecção e formatação do sistema de canais radiculares através do preparo químico-mecânico. O preparo do conduto deve manter o caminho original do canal, afunilando-se até o ápice radicular, mantendo o forame apical patente e em sua posição original (SCHILDER, 1974). Além disso, é muito importante que a obturação contemple todo o sistema de canais radiculares, evitando reinfecções no local que podem levar ao insucesso do tratamento endodôntico (SCHILDER, 1974; GOMES et al., 2015; CHUGAL et al., 2017).

A obtenção de uma cavidade de acesso apropriada é essencial para o sucesso do tratamento do sistema de canais radiculares e tem um impacto significante nos procedimentos subsequentes (YAHATA et al., 2017). Tradicionalmente, o acesso endodôntico preconiza a remoção de cárie e restaurações definitivas, preservando a estrutura sadia do dente (COHEN; HARGREAVES, 2011). A forma da cavidade de acesso é definida principalmente pela morfologia da câmara pulpar individual do dente a ser tratado. Com o intuito de localizar todos os orifícios dos canais radiculares e proporcionar acesso direto ao forame apical ou à curvatura inicial do canal, o teto da câmara pulpar é totalmente removido e a abertura complementada pela remoção de saliências de dentina cervical e ampliação do orifício do canal (PATEL; RHODES, 2007). O acesso endodôntico adequado é essencial para a eficiente localização, mensuração, preparo químico-mecânico e obturação do sistema de canais radiculares. Além disso, previne iatrogenias tais como desvio da anatomia original do canal durante a instrumentação e fratura de instrumentos endodônticos. A não localização de algum canal radicular, ou ainda, o preparo químico-mecânico ineficiente, pode levar à persistência da infecção após o tratamento endodôntico e, consequentemente, ao insucesso da terapia (PATEL; RHODES, 2007). Porém, segundo alguns autores, o acesso endodôntico tradicional remove grande quantidade de estrutura dentinária, podendo assim fragilizar o elemento dental e, supostamente, reduzir sua resistência à fratura (CLARK; KHADEMI, 2010; TANG et al., 2010).

Um novo modelo de acesso endodôntico, minimizando a remoção da estrutura dental, foi proposto para superar as limitações do acesso endodôntico tradicional (CLARK; KHADEMI, 2010). Para isso, divergindo dos princípios básicos gerais das aberturas coronárias tradicionais, esses acessos conservadores preservam parte do teto da câmara pulpar (CLARK; KHADEMI, 2010). Segundo esses autores, o modelo tradicional dos acessos endodônticos não conduz ao sucesso em longo prazo, uma vez que compromete estruturalmente o dente por remover uma quantidade excessiva de dentina, o que predispõe à fratura dentária (CLARK; KHADEMI, 2010). A partir disso, passaram a ser divulgados alguns conceitos, como por exemplo, a preservação da dentina pericervical na tentativa de aumentar a resistência do dente tratado endodonticamente (CLARK; KHADEMI, 2009; CLARK; KHADEMI, 2010).

A dentina pericervical pode ser definida como a área aproximadamente 4 mm acima da crista óssea, sendo responsável pela transmissão das forças oclusais para a raiz. Segundo Clark et al. (2013), a maneira mais segura de não danificar essa dentina é preservar parte do teto (0,5 a 3 mm) ao redor de toda câmara pulpar, o que diminuiria a flexão das cúspides e, consequentemente, o índice de fratura do dente. Seguindo essa linha de raciocínio, nessa modalidade mais conservadora de acesso, a manutenção da dentina pericingular também assume um papel importante, uma vez que existe uma concentração de forças de tensão no cíngulo quando os incisivos estão em função e sua remoção resultaria também em menor resistência à fratura (CLARK; KHADEMI, 2009).

1.1 FORMAS DE ACESSO ENDODÔNTICO MINIMAMENTE INVASIVO (AEMI)

Dentre as diferentes formas de AEMI podemos citar os acessos conservadores. Esta foi a primeira forma descrita na literatura endodôntica com o objetivo de minimizar a remoção da estrutura, preservando parte do teto da câmara pulpar e da dentina pericervical (CLARK; KHADEMI, 2010). Outra forma é o acesso ultraconservador. Nesta modalidade a abertura coronária é realizada de forma pontual com brocas esféricas de pequeno calibre e o acesso não é estendido (PLOTINO et al., 2017). Essa abordagem é extremamente conservadora e também conhecida popularmente como acesso endodôntico “ninja”, em consequência das possíveis dificuldades técnicas relacionadas ao tratamento endodôntico de elementos dentais que receberam este tipo de acesso (PLOTINO et al., 2017). Outra abordagem de AEMI é o acesso endodôntico direcionado, também conhecido como *truss-access* (NEELAKANTAN et al., 2018). Nesse tipo de abordagem, cavidades separadas são preparadas para abordar diferentes sistemas de canais (por ex. uma cavidade mesial e uma cavidade distal em molares inferiores, ou uma cavidade vestibular e uma cavidade palatina para os molares superiores), preservando uma ponte de dentina entre as duas cavidades (NEELAKANTAN et al., 2018).

1.2 INFLUÊNCIA DAS CAVIDADES DE ACESSO ENDODÔNTICO MINIMAMENTE INVASIVO NAS ETAPAS DO TRATAMENTO ENDODÔNTICO

1.2.1 Localização dos canais radiculares

Rover et al. (2017) analisaram a interferência dos acessos tradicionais e ultraconservadores na localização dos canais radiculares de molares superiores em 3 etapas distintas: etapa 1, sem a utilização de magnificação; etapa 2, sob ampliação de até 16x utilizando microscópio operatório e; etapa 3, sob ampliação de até 16x e com auxílio de insertos ultrassônicos. Os resultados demonstraram que no grupo de acessos endodônticos tradicionais, foi possível localizar todos os canais das amostras nas etapas 1-3 em 73,33%, 80% e 86,67% respectivamente. No grupo de AEMI, foi possível localizar todos os canais nas etapas 1-3 em 26,67%, 33,33% e 80% respectivamente. Este estudo demonstrou que a realização dos acessos ultraconservadores dificultou a localização do canal mésio-vestibular 2 (quarto canal) em molares superiores quando o microscópio operatório e o ultrassom não foram utilizados durante os procedimentos endodônticos.

Saygili et al. (2018) avaliaram o impacto de acessos tradicionais, conservadores e ultraconservadores na localização dos canais radiculares de molares superiores. Os procedimentos foram realizados com o uso de microscópio operatório e ultrasom em todos os casos. Os resultados mostraram que a localização dos canais radiculares foi significativamente menor nos elementos dentais acessados de forma ultracoservadora. Não houve diferença estatística entre os dentes acessados de forma tradicional ou conservadora.

1.2.2 Limpeza e modelagem do sistema de canais radiculares

Devido a não remoção de todo o teto da câmara pulpar nos dentes com AEMI, o instrumento endodôntico tende a trabalhar, durante o preparo químico-mecânico, com uma curvatura mais acentuada (CLARK; KHADEMI, 2010). Aumentando assim, as chances de desvios na anatomia original do canal radicular e de fratura dos instrumentos endodônticos, mesmo quando sistemas com maior flexibilidade são utilizados (LOPES et al., 2013; ÖZYÜREK; YILMAZ; USLU, 2017).

Alguns estudos demonstram maior desvio na anatomia original do sistema de canais radiculares (KRISHAN et al., 2014; EATON et al., 2015; ROVER et al., 2017; ALOVISI et al., 2018) e maior acúmulo de debris associado à realização de AEMI (SILVA et al., 2020). No entanto, outros estudos relataram não haver diferença na instrumentação do sistema de canais radiculares acessados de forma minimamente invasiva (MOORE et al., 2016; NEELAKANTAN et al., 2018). É importante ressaltar que existem diferenças metodológicas entre os estudos citados, como por exemplo, a utilização de diferentes instrumentos endodônticos, com diferentes ligas de Ni-Ti, tratamentos térmicos, diâmetro da ponta e conicidade, e diferenças na forma de análise da instrumentação do sistema de canais radiculares. Nos estudos de Moore et al. (2016) e Neelakantan et al. (2018) foram utilizados instrumentos com tratamento térmico, que apresentam propriedades mecânicas e desempenho superiores aos instrumentos de NiTi convencionais (SILVA et al., 2016a; SILVA et al., 2016b; DE-DEUS et al., 2017). Esses novos instrumentos podem beneficiar a instrumentação de dentes acessados de forma minimamente invasiva, uma vez que apresentam maior flexibilidade quando comparados a instrumentos que não passaram por esse tipo de tratamento (SILVA et al., 2016a, SILVA et al., 2016b).

Neelakantan et al. (2018) analisaram a capacidade de limpeza da cavidade pulpar em elementos dentais acessados de forma tradicional e minimamente invasiva (acesso truss) em molares inferiores. Os autores não encontraram diferenças estatísticas na quantidade de tecido pulpar remanescente nos canais radiculares e istmos após a instrumentação. No entanto, quando a câmara pulpar foi avaliada, houve um acúmulo significativamente maior de tecido pulpar remanescente no grupo com acesso truss. Os resultados apresentados nesse estudo mostram que a forma do acesso endodôntico não interferiu na limpeza do canal radicular e de istmos, porém impediu a correta limpeza da câmara pulpar devido a não remoção completa do teto.

A presença de restos pulpares e debris na cavidade endodôntica após o término do tratamento endodôntico pode servir como fonte de nutrição para bactérias remanescentes no tecido infectado, resultando em uma infecção persistente e, consequentemente, gerar um insucesso endodôntico (AHMED; NEELAKANTAN; DUMMER, 2018). No entanto, um recente estudo, *in vitro* (TÜFENKÇI; YILMAZ, 2020) verificou que a redução da contagem bacteriana de *Enterococcus Faecalis* foi similar em molares inferiores acessados de forma conservadora ou tradicional.

1.2.3 Obturação do sistema de canais radiculares

Uma das dificuldades nas novas modalidades de AEMI, principalmente nos casos de dentes multirradiculares, ocorre no momento da radiografia da prova dos cones de guta-percha, realizada durante a etapa da obturação. É necessária a realização de mais de uma incidência radiográfica, uma vez que o tamanho restrito do acesso impede que todos os cones de guta-percha sejam inseridos de uma só vez (CLARK; KHADEMI, 2010).

Um recente estudo, realizado por Silva et al. (2020), avaliou a qualidade da obturação e a capacidade de limpeza da câmara pulpar de pré-molares birradiculares acessados de forma tradicional e ultraconservadora. Os resultados não mostraram diferenças na quantidade de espaços vazios na obturação dos canais radiculares, porém os elementos dentais acessados de forma ultraconsevadora apresentaram uma quantidade significativamente maior de material obturador presente na câmara pulpar após a realização dos procedimentos de limpeza. Portanto, os AEMI dificultam a limpeza da câmara pulpar, não somente de matéria orgânica, como previamente demonstrado (NEELAKANTAN et al., 2018), como também de materiais obturadores (CLARK; KHADEMI, 2010; SILVA et al., 2020). Tal fato pode acarretar em problemas futuros, como alterações da coloração da coroa do elemento dental, impactando diretamente na estética dental (LENHERR et al., 2012; MARCHESAN et al., 2018).

1.3 INFLUÊNCIA DAS CAVIDADES DE ACESSO ENDODÔNTICO MINIMAMENTE INVASIVO NA RESISTÊNCIA À FRATURA DOS ELEMENTOS DENTAIS

A principal motivação que impulsionou a preconização dos AEMI foi baseada na premissa de que essas modalidades de acesso poderiam aumentar a resistência à fratura dos elementos dentais tratados endodonticamente (CLARK; KHADEMI, 2010). Uma série de estudos foram recentemente publicados comparando a resistência à fratura de elementos dentais com diferentes formas de acessos endodônticos (KRISHAN et al., 2014; MOORE et al., 2016; CHLUP et al., 2017; IVANOFF et al., 2017; PLOTINO et al., 2017; ROVER et al., 2017; ÖZYÜREK et al., 2018; CORSENTINO et al., 2018; SABETI et al., 2018; SILVA et al., 2020).

Krishan et al. (2014) avaliaram o impacto do acesso conservador na resistência à fratura de incisivos superiores, pré-molares e molares inferiores. Os resultados desse trabalho demostraram, em pré-molares e molares, que a força média necessária para a fratura foi significantemente maior para os dentes que receberam acessos conservadores quando comparadas com os que tiveram acessos tradicionais, e não diferiram dos dentes hígidos (controle negativo). Para os incisivos, a força média necessária para a fratura não diferiu entre os grupos de acessos conservadores, tradicionais e controle negativo. No entanto, é importante salientar que o ensaio de fratura neste estudo foi realizado sem que os elementos dentais fossem restaurados, o que pode influenciar diretamente nos resultados obtidos. A literatura mostra que a correta reabilitação das cavidades endodônticas é capaz de restaurar a resistência a fratura de elementos dentários em aproximadamente 80% (HAMOUDA; SHEHATA, 2011).

Moore et al. (2016) avaliaram as respostas biomecânicas dos acessos conservadores em molares superiores restaurados com resina composta. Nesse estudo, os elementos dentais, após instrumentados e restaurados, receberam ciclos simulando cerca de 4 anos de função mastigatória antes do ensaio de fadiga. As médias de força necessária para as fraturas não apresentaram diferenças estatisticamente significantes entre os elementos dentários que receberam acessos tradicionais e os que receberam acessos conservadores. Resultados similares foram encontrados por Rover et al. (2017), que também demonstraram não haver diferença na resistência à fratura de molares superiores acessados de forma tradicional ou conservadora.

Ivanoff et al. (2017) compararam a resistência à fratura de pré-molares inferiores restaurados com resina composta em cavidades mésio-oclusal após acessos com cavidades tradicionais e conservadoras. Os resultados desse estudo não demonstraram haver diferenças na resistência à fratura quando as duas cavidades de acesso foram comparadas.

Resultados similares também foram encontrados por Chlup et al. (2017), ao compararem acessos tradicionais e conservadores em pré-molares superiores e inferiores.

Plotino et al. (2017) investigaram a resistência à fratura de pré-molares e molares superiores e inferiores tratados endodonticamente com diferentes tipos da cavidade de acesso: acessos tradicionais, acessos conservadores e acessos ultraconservadores. Os resultados mostraram que a média da força necessária para a fratura foi significativamente menor para o grupo com acessos tradicionais, quando comparado com os acessos conservadores e ultraconservadores. Porém não foi encontrada diferença entre os grupos com acessos conservadores e ultraconservadores. No entanto, é importante enfatizar que os acessos endodônticos tradicionais executados nesse estudo são exageradamente expulsivos. Embora a literatura recomende a remoção completa do teto da câmara pulpar, não indica a expulsividade das paredes axiais do elemento dentário (PATEL; RHODES, 2007; COHEN; HARGREAVES, 2011). Diferindo do que foi encontrado nesse estudo, Silva et al. (2020) demonstraram não haver diferença na resistência à fratura de pré-molares superiores birradiculares acessados de forma tradicional ou ultraconservadora.

Özyürek et al. (2018) compararam a resistência à fratura de molares inferiores acessados de forma tradicional e conservadora. Os autores concluíram que o acesso conservador não aumentou a resistência à fratura de dentes com cavidades classe II restauradas com resina composta. Da mesma forma, Corsentino et al. (2018) avaliaram diferentes formas de AEMI, associados ou não à perda das paredes proximais, quanto a resistência à fratura. Não foi observada diferença significante na resistência nos diferentes acessos testados. Além disso, a perda das paredes mesial e distal (classe II) diminuiu significativamente a resistência do elemento dental, independentemente do tipo da cavidade de acesso endodôntica realizada.

Sabeti et al. (2018) avaliaram o efeito de diferentes designs da cavidade de acesso endodôntica e diferentes conicidades do preparo do canal radicular na resistência à fratura de molares superiores tratados endodonticamente. Foi possível observar que o aumento da conicidade dos instrumentos endodônticos diminuiu a resistência dos elementos dentais. Quanto às diferentes formas de aberturas endodônticas, os resultados de Sabeti et al. (2018) corroboram com outros estudos recentes que demonstraram não haver diferenças na resistência de molares superiores com acessos tradicionais ou conservadores (MOORE et al., 2016; ROVER et al., 2017).

Ao se realizar esta revisão bibliográfica, pode-se constatar que o papel dos AEMI no aumento da resistência à fratura e nos demais desfechos do tratamento endodôntico permanece controverso. Enquanto somente dois estudos apontam melhoras na resistência à fratura (KRISHAN et al., 2014; PLOTINO et al., 2017), a grande maioria demonstra não haver um real impacto na mesma (MOORE et al., 2016; CHLUP et al., 2017; IVANOFF et al., 2017; ROVER et al., 2017; ÖZYÜREK et al., 2018; CORSENTINO et al., 2018; SABETI et al., 2018; SILVA et al., 2020). Soma-se a esses fatores outras dúvidas relacionadas à real capacidade de proporcionar um adequado preparo químico-mecânico e obturação do sistema de canais radiculares em uma cavidade de acesso muito constrita (KRISHAN et al., 2014; EATON et al., 2015; ROVER et al., 2017; ALOVISI et al., 2018; NEELAKANTAN et al., 2018), o que poderia comprometer o prognóstico do elemento dentário em longo prazo (PATEL; RHODES, 2007).

Diante da escassez e das limitações dos estudos atuais, surge à necessidade de um maior número de estudos relacionados aos principais desfechos dos tratamentos endodônticos obtidos após a realização dos AEMI.

2 PROPOSIÇÃO

2.1 OBJETIVO GERAL

Substanciar cientificamente as teorias estabelecidas a respeito da efetividade dos diferentes tipos de acessos endodônticos minimamente invasivos.

2.2 OBJETIVOS ESPECÍFICOS

2.2.1 Revisar sistematicamente a literatura e responder a seguinte questão: o acesso endodôntico minimamente invasivo aumenta a resistência à fratura de dentes humanos extraídos quando comparados ao acesso endodôntico tradicional?

2.2.2 Avaliar a influência da localização e design da cavidade de acesso endodôntico na eficácia da instrumentação, qualidade da obturação, limpeza da câmara pulpar e resistência à fratura de incisivos inferiores.

2.3 HIPÓTESE

A hipótese nula testada foi de que não há diferença entre as cavidades de acesso endodônticas (minimamente invasivas e tradicionais) em todos os desfechos investigados.

3 ARTIGO 1

Impact of contracted endodontic cavities on fracture resistance of endodontically treated teeth: a systematic review of in vitro studies

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Abstract

Objective This systematic review was performed to answer the following question: do contracted endodontic cavities (CECs) increase resistance to fracture in extracted human teeth compared to traditional endodontic cavities (TECs)?

Methods A literature search without restrictions was carried out in PubMed, Science Direct, Scopus, Web of Science, and Open Grey databases. Articles were selected by two independente reviewers. In addition, a reference and hand search was also fulfilled. All included in vitro studies evaluated the influence of CECs on strength to fracture in extracted human teeth and compared to TECs. The quality of the selected studies was evaluated and they were classified as having a low, moderate or high risk of bias.

Results A total of 810 articles were obtained in the electronic search. After the application of the eligibility criteria, reference and hand search, and duplicate removal, six studies were included in this systematic review. All included studies evaluated the influence of CECs on strength to fracture in extracted human teeth and compared to TECs. Characteristics investigated in the selected articles included the sample size and tooth type, access cavity design, filling and restoration procedures, load at fracture test characteristics, and results. The studies demonstrated large variability among the fracture resistance values and standard deviations and low power. Three of the reviewed studies presented low risk of bias and the other three showed medium risk of bias.

Conclusion Overall, this systematic review of in vitro studies showed that there is no evidence that supports the use of CECs over TECs for the increase of fracture resistance in human teeth.

Clinical relevance Recently, CECs have gained attention in endodontics due to maximum tooth structure preservation including the pericervical dentin, which could improve the strength to fracture of endodontically treated teeth. However, the influence of access cavity design on fracture resistance remains limited and controversial.

Keywords Dental pulp cavity. Fracture strength. Minimally invasive. Systematic review

Introduction

Obtaining an appropriate access cavity is essential for a successful treatment of the root canal system and has a significant impact on subsequent procedures [1]. Traditionally, endodontic access advocates the removal of caries and definitive restorations, preserving the healthy structure of the tooth. The shape of the access cavity is defined primarily by the morphology of the individual pulp chamber of the tooth to be treated. The roof of the pulp chamber is completely removed in order to locate all orifices of the root canals and provide direct access to the apical foramen or to the initial curvature of the canal by removing cervical dentin protrusions and enlarging the canal orifice [2]. Adequate endodontic access is essential for the efficient localization, measurement, chemomechanical preparation, and root canal filling. In addition, adequate root canal access can prevent iatrogenic complications such as the deviation of the original anatomy of the root canal during instrumentation and fracture of endodontic instruments [2, 3]. The non-location of a root canal or ineficiente chemical-mechanical preparation can lead to the persistence of infection after treatment and, consequently, to failure [2]. However, according to some authors, traditional endodontic access removes a large amount of dentin structure, which may weaken the dental structure, and supposedly reduces its fracture resistance [4, 5].

Following the trend of minimally invasive dentistry, Clark and Khademi [4] introduced a new model of endodontic access, focusing on the minimal removal of the tooth structure. Diverging from the general basic principles of traditional coronary openings, these conservative accesses preserve part of the roof of the pulp chamber, and the pericervical and pericingular dentin. According to these authors, the current model of endodontic accesses does not lead to long-term success, since they structurally compromise the tooth by removing an excessive amount of dentin, which predisposes to tooth fracture [4]. From this, some concepts have been disclosed in an attempt to improve the resistance of endodontically treated teeth. One of these concepts would be the preservation of the pericervical dentin, which can be defined as the area approximately 4 mm above and 6 mm below the bone crest. This structure is responsible for the transmission of occlusal forces to the root. According to Clark et al. [6], the safest way to avoid damaging this dentin is preserving part of the ceiling (0.5 to 3 mm) around the entire pulp chamber, which would reduce the flexion of the cusps and, consequently, the fracture index of the tooth. Following this rationale, in this new modality of access called conservative or contracted endodontic access, the maintenance of the pericingular dentin plays an importante role, since there is a concentration of tension forces in the cingulum when the incisors are in function and their removal would result in lower fracture resistance [7].

Previous studies showed conflicting results regarding the influence of access cavity on fracture resistance of endodontic treated teeth [8–13]. Thus, the influence of contracted endodontic cavities (CECs) on fracture resistance outcomes remains controversial. This systematic review was performed to answer the following question: do CECs increase resistance to fracture in extracted human teeth compared to traditional endodontic cavities (TECs)?

Methods

Study design

A systematic review of all studies that assessed the influence of access cavity design on fracture resistance in extracted human teeth was undertaken. TECs were used as a reference for comparison. This systematic review was registered in the PROSPERO database (PROSPERO registry number CRD 42017071644) and followed the recommendations of the PRISMA statement for the report of this systematic review [14].

Literature search strategy

A systematic search without restrictions was performed by two independent reviewers in the electronic databases PubMed, Science Direct, Scopus, Web of Science, and Open Grey from their inception through July 22, 2017. Detailed individual search strategies for each database were performed using the following terms from Medical Subject Heading terms (MeSH) or text word (tw) and their combinations: “dental pulp cavity” (MeSH), “dental pulp necrosis” (MeSH), “endodontic cavity” (tw), “traditional endodontic cavity” (tw), “contracted endodontic cavity” (tw), “conservative endodontic cavity” (tw), “minimally invasive endodontics” (tw), “stress fracture” (MeSH), “fatigue” (MeSH), “strength to fracture” (tw), “resistance to fracture” (tw) “fracture strength” (tw), “biomechanical responses” (tw), and “fracture resistance” (tw). The “AND” and “OR” Boolean operators were applied to combine keywords (Supplementary material B). In addition, a reference search was made in the reference lists of all selected articles and a hand search was performed in the Journal of Endodontics and the International Endodontic Journal. Experts were also contacted to identify unpublished and ongoing studies.

Eligibility criteria

It included studies which the primary objective was to evaluate the influence of CECs on fracture resistance compared to TECs in human teeth. The following eligibility criteria were based on the PICOS strategy [14]: extracted fully formed (mature) human teeth (P - participants), contracted endodontic cavities technique (I - intervention), studies that compare traditional endodontic cavities technique (C - comparison), fracture resistance values as an outcome (O - outcome), and in vitro transversal studies (S - study design). Although the PICO strategy is generally used for clinical trials, all of the included in vitro studies presented an intervention. Thus, PICO strategy was adapted for this purpose. No language or time restrictions were applied.

It excluded reviews, letters, opinion articles, conference abstracts, case reports, serial case, studies performed in animals, studies that included immature or artificial teeth.

Selection study process

Two independent reviewers (G. R. and F. G. B.) selected all references in two stages. In stage 1, both reviewers evaluated the titles and abstracts of the published studies and then applied the eligibility criteria. Full articles were retrieved and examined when their title and abstract did not provide enough information for a final decision. In stage 2, the selected full articles were independently reviewed and screened by the same two reviewers (G. R. and F. G. B.). Disagreements on eligibility criteria of a study were discussed between the reviewers until a decision was obtained by consensus. If there was no consensus, a third reviewer (E. J. S.) resolved any discrepancies. After the full-text analyses of the potentially relevant studies, the selected studies were included in this systematic review. Articles appearing in more than one database search were considered only once.

Data collection process

Two reviewers (G. R. and F. G. B.) performed data extraction in all the included studies independently. Any potential conflict was resolved by discussion with a third reviewer (E. J. S.). The following information was extracted from each study and recorded: study characteristics (authors, year, and country), sample characteristics (tooth type and sample size), endodontic procedures (access cavity design, filling, and restoration), strength to fracture (load at fracture test characteristics and results), and other findings (root canal detection, instrumentation efficacy, and fracture patterns, when present).

Study quality assessment

The quality of the selected studies was evaluated using a adaptation of the methods used in previous systematic reviews performed with in vitro studies [15, 16]. Two reviewers (G. R. and F. G. B.) independently assessed the methodological quality of each included study using the following parameters: (1) sample size calculation, (2) samples with similar dimensions, (3) presence of a control group (intact teeth), (4) execution of filling procedures, (5) presence of coronal restoration, and (6) correct statistical analysis carried out. The blinding of the operator was not considered since the shapes of the access cavities are very different and allow the operator to identify the performed treatment. The parameters reported in original studies were assigned as “yes” and missing information was assigned as “No”. The articles were classified as having a low risk of bias if five or six items were reported, a moderate risk of bias if three or four items were reported, and a high risk of bias if one or two parameters were reported. The third reviewer (E. J. S.), when needed, resolved any disagreement into the reviewers.

The power of studies was calculated based on the fracture resistance means, standard deviations, and sample size for each group of teeth. The power analysis is able to measure the effect size that can be detected using a given sample size. For this purpose, a confidence interval of 95% and a two-tailed test using OpenEpi 3.04.04 software were adopted.

Results

Study selection

The identification process and the eligibility criteria of the studies are shown in Fig. 1. A total of 810 articles were obtained in the electronic search: 57 from Science Direct, 133 from PubMed, 461 from Scopus, 159 from Web of Science, and 0 from Open Grey. After the application of the eligibility criteria, the discarding of duplicates, and the inclusion of one study identified from reference lists, 21 articles were selected for full-text assessment. After reading the complete articles, 15 of them were excluded [1, 4, 6, 7, 17–27]; the reasons are explained in Table 1. As a result, six studies fulfilled the eligibility criteria and were included in this systematic review [8–13].

Fig. 1 Flow diagram outlining the study identification and screening process adapted from PRISMA recommendation [14]

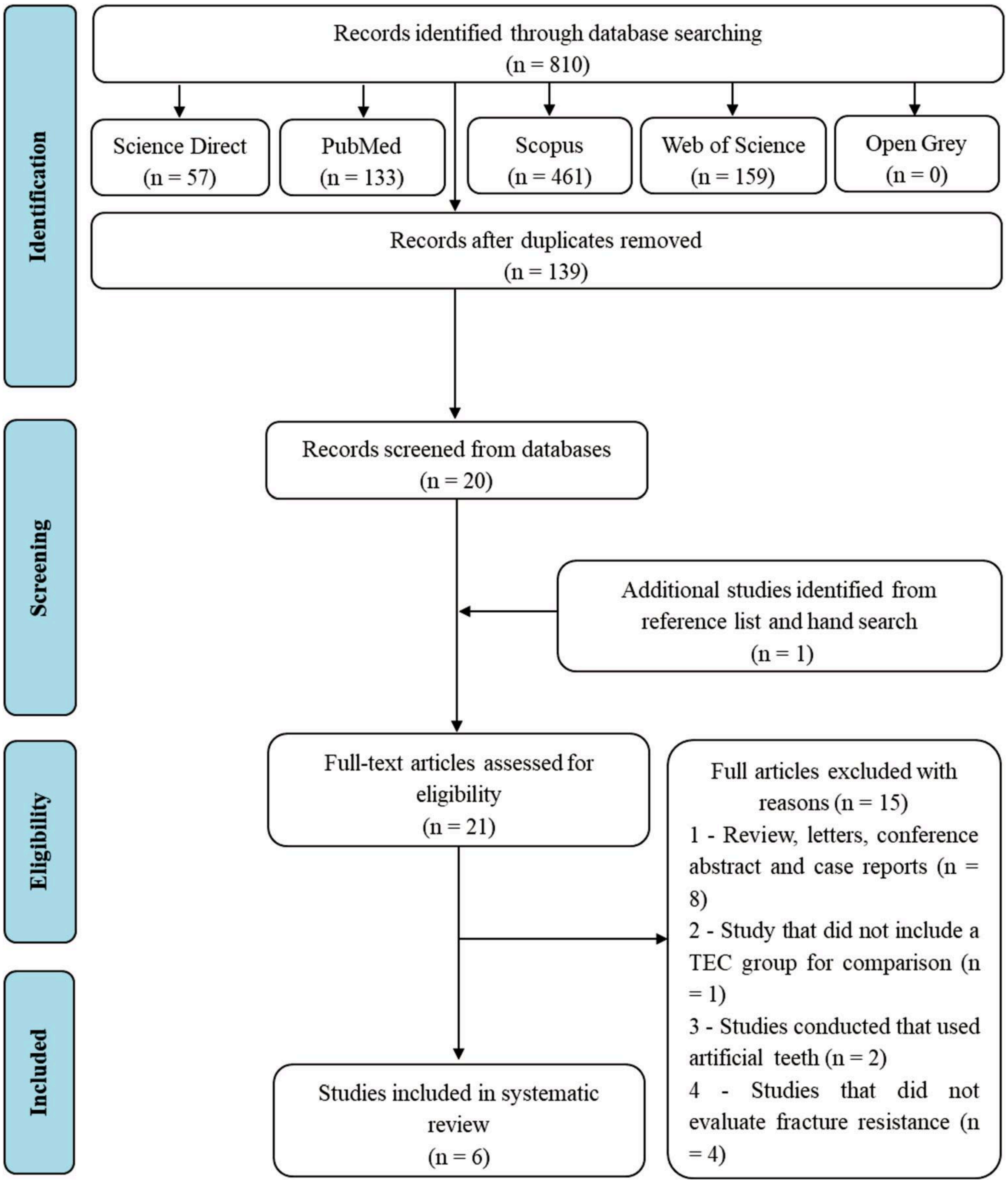

Table 1 Excluded studies and the respective reasons for each exclusion

Studies	**Exclusion Reason**
Ahmed & Gutmann 2015 [17] Boveda & Kishen 2015 [18] Bürklein & Shäfer 2015 [19] Clark & Khademi 2009 [7] Clark & Khademi 2010 [4] Clark et al 2013 [6] Gluskin et al 2014 [20] Khademi et al 2016 [21]	1 - Review, letters, abstract conference and case reports
Al Amri et al 2016 [22]	2 – Study that dit not include a TECs group for comparison
Bonessio et al 2017 [23] Yuan et al 2016 [24]	3 - Studies conducted that used artificial teeth
Eaton et al 2015 [25] Niemi et al 2016 [26] Varghese et al 2016 [27] Yahata et al 2017 [1]	4 - Studies that did not evaluate fracture resistance

Study characteristics

All included studies evaluated the influence of CECs on strength to fracture in extracted human teeth and compared to TECs. The studies analyzed different teeth: maxillary incisors [8], premolars [10, 12] and molars [9, 12, 13], and mandibular premolars [8, 10–12] and molars [8, 12]. Sample sizes also presented discrepancies ranging from 30 [13] to 160 [12]. Before the resistance test, some studies did not perform filling [8, 9, 11], restoration procedures [8], and periodontal ligament simulation [8, 10–12]. It was observed that there are diferences in the methodology in fracture resistance tests: some authors [8–13] applied a continuous compressive force at the central fossa at a 30° angle, while one author [11] at a 45° angle and other [8] at a 135° angle. The crosshead diameter varied among the studies and also its speed: some authors [10–12] used a crosshead of 0.05 mm/min and others [8, 9, 13] used 0.10 mm/min. The studies also demonstrated large variability among the fracture resistance values and standard deviations. Characteristic details of all selected studies [8–13] are summarized in Table 2.

Strength to fracture results of individual studies

Table 2 summarizes the characteristics of the included studies and the main statistical findings. Chlup et al. [10] did not observe statistically significant differences between TEC and CEC groups in maxillary and mandibular premolars. Ivanoff et al. [11] did not find statistically significant differences between CEC, TEC, and control groups in mandibular premolars restored with mesial-occlusal composites. Krishan et al. [8] found mean load at fracture for CECs significantly higher than for TECs, and it did not differ significantly from control group in mandibular premolars and molars. In the TEC group, the load at fracture in mandibular premolars and molars was significantly lower than in control group. For maxillary incisors, the mean load at fracture did not differ significantly among the three groups. Moore et al. [9] and Rover et al. [13] showed that load at failure for CECs did not differ significantly from TEC group, and it was lower for both groups when compared to intact teeth [9] in maxillary molars. Plotino et al. [12] evaluated maxillary and mandibular molars and premolars. No difference was observed between CECs, "ninja" endodontic cavities (NECs), and intact teeth in all types of teeth. TEC showed lower strength than other groups.

Table 2 Summary of descriptive characteristics of included studies

Authors, year, country	**Study design**	**Sample size (n)**	**Tooth type**	**Groups size** **Number of samples (n) and *Power analysis assessment (PA)**	**Load at fracture test**	**Mean load at failure values (N) ± Standard deviation**	**Analysis of resistance test results**	**Others outcomes**
Chlup et al 2017 [10] Czechia	In vitro	60	Maxillary and mandibular premolars	CEC (n = 10/ tooth type) TEC (n = 10/ tooth type) Control (intact teeth/n = 10/ tooth type) PA - Maxillary premolars: 34.84% PA - Mandibular premolars: 11.69%	After the simulation of the alveolar bone, a continuous compressive force was applied at the central fossa at a 30° angle from the long axis of the tooth with a diameter of 3/16” crosshead at 0.5 mm/min until failure occurred.	Maxillary premolars: CEC (860.0 ± 206.8 N) TEC (687.4 ± 279.4 N) Control (745.0 ± 418.6 N) Mandibular premolars: CEC (1079.0 ± 383.2 N) TEC (946.6 ± 384.1 N) Control (1171.8 ± 568.0 N)	No statistically significant difference was observed between TEC and CEC in maxillary and mandibular premolars.	
Ivanoff et al 2017 [11] USA	In vitro	45	Mandibular premolars	CEC (n = 15) TEC (n = 15) Control (intact teeth/n = 15) PA - Mandibular premolars: 1.14%	After the simulation of the alveolar bone, a continuous compressive force was applied at the central fossa at a 45° angle from the long axis of the tooth with a 3.6-mm spherical crosshead at 0.5 mm/min until failure occurred.	CEC (600.9 ± 360.3 N) TEC (601.7 ± 307.9 N) Control (609.7 ± 279.1 N)	There was no statistically significant difference in resistance to failure between any of the groups. Modifying access outline to a contracted design did not improve fracture resistance of mandibular premolars restored with mesial-occlusal composites.	All three groups had an equal number of “favourable” (repairable) and “unfavourable” failures, defined as irreparable failures or root fractures below the level of simulated bone.

Krishan et al 2014 [8] Canada	In vitro	90	Maxillary incisors, mandibular premolars, and molars	CEC (n = 10/ tooth type) TEC (n = 10/ tooth type) Control (intact teeth/n = 10/ tooth type) PA - Maxillary incisors: 95.76% PA - Mandibular premolars: 100% PA - Mandibular molars: 100%	After the simulation of the alveolar bone, a continuous compressive force was applied at the central fossa at a 30° angle in premolars and molars, and at a 135° angle in incisors from the long axis of the tooth. With a spherical crosshead at 1 mm/min until failure occurred.	Maxillary incisors: CEC (1134.6 ± 109.2 N) TEC (1305.2 ± 97.6 N) Control (1276.6 ± 93.8 N) Mandibular premolars: CEC (586.8 ± 116.9 N) TEC (328.4 ± 56.7 N) Control (634. ± 4 58.6 N) Mandibular molars: CEC (1586.9 ± 196.8 N) TEC (641.7 ± 62.0 N) Control (2029.1 ± 259.7 N)	In premolars and molars, the mean load at fracture for CEC was significantly higher than for TEC, and it did not differ significantly from control group. In the TEC group, the load at fracture in premolars and molars was significantly lower than in control group. For incisors, the mean load at fracture did not differ significantly among the 3 groups.	- CEC afforded conservation of coronal dentin in incisors, premolars, and molars. - CEC was associated with the risk of compromised canal instrumentation only in the distal canals of molars.
Moore et al 2016 [9] Canada	In vitro	39	Maxillary molars	CEC (n = 14) TEC (n = 14) Control (intact teeth/n = 11) PA - Maxillary molars: 42.57%	After the simulation of the periodontal ligament and alveolar bone, cyclically fatigued (1 million cycles, 5-50 N, 15 Hz) directed at 30º angle from the tooth's long axis and, subsequently, continuous compressive force was applied with a 5-mm spherical crosshead at 1 mm/min until failure occurred.	CEC (1703 ± 558 N) TEC (1384 ± 377 N) Control (2457 ± 941 N)	Load at failure for CEC did not differ significantly from TEC and was lower for both groups when compared to control group.	Instrumentation efficacy was not significantly impacted by endodontic cavity design.
Plotino et al 2017 [12] Italy	In vitro	160	Maxillary molars and premolars Mandibular molars and premolars	NEC (n = 10/ tooth type) CEC (n = 10/ tooth type) TEC (n = 10/ tooth type)	After the simulation of the alveolar bone, a continuous compressive force was applied at the central fossa at a 30° angle from the long axis of the tooth with a 6-mm spherical crosshead at 0.5 mm/min until failure	Maxillary molars: NEC (1170 ± 432 N) CEC (1143 ± 506 N) TEC (810 ± 425 N) Control (1172 ± 598 N) Maxillary premolars: NEC (805 ± 204 N) CEC (821 ± 324 N)	No difference was observed between CEC, NEC ("ninja") access cavity designs and intact teeth. Teeth with TEC showed lower strength than other groups.	- Intact teeth showed more restorable fractures than all the prepared ones.

				Control (intact teeth/n = 10/ tooth type) PA - Maxillary molars: 35.71% PA - Maxillary premolars: 70.40% PA - Mandibular molars: 66.70% PA - Mandibular premolars: 30.22%	occurred.	TEC (498 ± 250 N) Control (913 ± 188 N) Mandibular molars: NEC (1459 ± 278 N) CEC (1401 ± 495 N) TEC (923 ± 393 N) Control (1572 ± 639 N) Mandibular premolars: NEC (945 ± 267 N) CEC (929 ± 384 N) TEC (704 ± 310 N) Control (1006 ± 313 N)		
Rover et al 2017 [13] Brazil	In vitro	30	Maxillary molars	CEC (n = 15) TEC (n = 15) PA - Maxillary molars: 5.33%	After the simulation of the periodontal ligament and alveolar bone, a continuous compressive force was applied at the central fossa at a 30° angle from the long axis of the tooth with a 4-mm spherical crosshead at 1 mm/min until failure occurred.	CEC (996.30 ± 490.78 N) TEC (937.55 ± 347.25 N)	Load at failure for CEC did not differ significantly from TEC.	- The ultrasonic troughing associated with an operating microscope was essential to the location of the root canals with CEC. - Instrumentation efficacy was not significantly impacted by endodontic cavity design.

Study quality assessment

Of the six studies included, three of them presented low risk of bias [9, 12, 13] and the other three showed medium risk of bias [8, 10, 11]. The results are described in Table 3 according to the parameters considered in the analysis. The power analysis demonstrated low power of the studies varying from 1.14% [11] to 70.40% [12]. The higher power was found in the Krishan et al. [8] study that obtained 100% of power. The power analysis of all selected studies [8–13] was showed in Table 2.

Table 3 Quality assessment and risk of bias

Study	Sample size calculation	Samples with similar dimensions	Control group (intact teeth)	Performance of filling procedures	Performance of restoration procedures	Statistical analysis carried out	Risk of bias
Chlup et al. 2017 [10]	No	No	Yes	Yes	Yes	Yes	Moderate
Ivanoff et al. 2017 [11]	No	Yes	Yes	No	Yes	Yes	Moderate
Krishan et al. 2014 [8]	Yes	Yes	Yes	No	No	Yes	Moderate
Moore et al. 2016 [9]	Yes	Yes	Yes	No	Yes	Yes	Low
Plotino et al. 2017 [12]	No	Yes	Yes	Yes	Yes	Yes	Low
Rover et al. 2017 [13]	Yes	Yes	No	Yes	Yes	Yes	Low

Discussion

The reduction of tooth structure is suggested to be one relevant reason of fractures in root canal filled teeth. Traditional endodontic cavity design is considered the second main cause of tooth structure loss [28]. Therefore, CECs were recently proposed to reduce the fracture risk of endodontically treated teeth [4].Within this background and all the attention that this access design approach has gained in endodontics, this systematic review of in vitro studies focused on accessing the impact of CECs on fracture resistance of endodontically treated teeth.

A total of 810 studies were obtained from the electronic search. However, after the eligibility criteria and the discard of duplicates, only six of them [8–13] were included. It is important to emphasize that the six studies included were classified as low/moderate risk of bias. Even though it was not comparable due to the important discrepancies in the methodology of the included studies, in these cases, the meta-analysis is not recommended. Only two of the studies included in this review presented an improved fracture resistance of CECs compared to TECs [8, 12]. Krishan et al. [8] showed that mandibular premolars and molars had a higher mean load at fracture for CECs, while no diferences were observed for maxillary incisors. However, the authors in this study performed the fracture test without filling and restoration of the teeth, which made it present a moderate risk of bias. Moreover, it is well established that restoration of endodontic cavities restore the fracture strength of teeth up to 72% of that of intact teeth [9, 29]. In the other study, Plotino et al. [12] evaluated, besides CECs and TECs, the fracture resistance of NECs and found that TECs presented lower fracture strength than CECs and NECs in maxillary and mandibular premolars and molars. No statistical significance was found in the fracture resistance mean values of CECs and NECs.

CECs were found not to improve fracture resistance of teeth according to the four other studies included in this review [9–11, 13]. Ivanoff et al. [11] showed that modifying access outline to a contracted design did not improve fracture resistance of mandibular premolars restored with mesialocclusal composites. In addition, Chlup et al. [10] did not observe statistically significant difference between TEC and CEC groups in maxillary and mandibular premolars. Moreover, Moore et al. [9] and Rover et al. [13], the two studies that presented low risk of bias and similar methodology, demonstrated no statistical difference between TEC and CEC in maxillary molars ($p > 0.05$).

Additionally, the power analysis of the studies demonstrated that only Krishan et al. [8] were adequately powered to find significant results since the power of this study was higher than 80%. The large variability among the fracture resistance values, as demonstrated through the high standard deviation, and the limited sample size are two importante reasons for the low power of the studies. The findings presented here reinforce the need of the conduction of powdered in vitro studies prior to clinical trial conduction. However, it is important to consider that the extrapolation of the in vitro results for in vivo repercussion must be done with caution since is hard to determine which fracture resistance difference would clinically impact.

It is consensus that CECs affect tooth structure preservation including pericervical dentin [4, 20]. However, this type of access design does not reflect the clinical daily routine once it can mainly be performed on sound teeth, which does not occur frequently. It is paramount that an ideal endodontic access cavity should permit the location of all canals, an eficiente preparation (with a complete removal of pulp tissue, debris, and necrotic materials) and filling of root canals without procedural errors [2, 3]. Nonetheless, CECs might enhance the possibility of missing some root canal orifices [13] and impact negatively on the instrumentation efficacy [8, 13]. Moreover, to date, no study has evaluated the ability of root canal disinfection after performing CECs; it is possible that this cavity modality hinders an adequate cleaning and disinfection of the root canal system, compromising the long-term prognosis of endodontically treated teeth. Therefore, clinicians should be cautious and focus on performing a "necessary invasive endodontics", aiming to preserve the maximumof tooth structure during root canal therapy but without compromising the treatment outcomes.

The electronic search retrieved in vitro studies. Since it consists in an actual theme, there were no randomized clinical trials available yet. The clinical trials present higher strength of evidence, and for this reason, its findings can directly impact institutional policies, such as to guide federal government healthy policies, provide new teaching concepts among academic institutions, and to finally establish the most eficiente procedure for the patients [30]. It is well known that in vitro studies do not simulate clinical oral condition. In the included studies, the applied methodology did not include the reproduction cary progression and the challenges of teeth restoration under clinical conditions, irreproducible oral hygiene status, cariogenic and erosive challenges, masticatory forces, and other variables found in clinical conditions. Although clinical trials present higher strength of evidence compared to the in vitro studies, the in vitro studies provide preliminary important responses that are importante to design further clinical trials.

Other important highlight is the high clinical research workforce and costs, and for this reason, the assessment of the cost–benefit is important before being conducted [31]. In this sense, this systematic revision was conducted preliminarily demonstrating no in vitro benefit of CECs. Additionally, it is suggested that prior to conducting clinical trials, it is necessary to perform in vitro studies that evaluate other relevant outcomes, such as canal location, instrumentation efficacy, and root canal disinfection to avoid treatment failure and consequently clinical damage to the patients.

Conclusion

Although in vitro studies present limitations, the included studies have a satisfactory methodological quality contributing with a preliminary important information regarding this subject. Additionally, more in vitro studies are necessary to evaluate the quality of root canal preparation and disinfection before planning clinical studies. Finally, randomized controlled trials and retrospective and prospective studies are warranted before indicating this new access modality. In the overall analysis, this systematic review demonstrated that there is no scientific evidence that supports the use of CECs over TECs for the increase of fracture resistance in human teeth.

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4 ARTIGO 2

Influence of contracted endodontic cavities on shaping and filling ability, pulp chamber cleaning and fracture resistance of mandibular incisors

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Abstract

Aim To evaluate the influence of the location and design of contracted endodontic cavities (CEC) on shaping and filling ability, pulp chamber cleaning and fracture resistance of mandibular incisors.

Methodology After pre-selection using periapical radiographs, forty extracted intact mandibular incisors were scanned in a micro-computed tomographic device, matched based on similar anatomical features of the canals and assigned to four experimental groups (n=10) according to the endodontic access cavity and root canal preparation protocol: traditional/TRUShape (T/TRU); traditional/MTwo (T/MT); contracted/TRUShape (C/TRU); and contracted/MTwo (C/MT). The sample was scanned after root canal instrumentation andfilling procedures. The parameters evaluated were: volume and area of the root canal, non-instrumented canal areas, canal transportation and centering ratio, accumulated hard tissue debris, voids in root canal fillings and root canal filling materials remnants in the pulp chamber. After root canal filling and cavity restoration procedures, the specimes were submitted to the fracture resistance test. Data were statistically analysed using Shapiro–Wilk, ANOVA and Bonferroni tests with a significance level of 5% ($\alpha=0.05$).

Results There was no difference regarding all parameters evaluated before and after root canal preparation (volume and area of the root canal, non-instrumented canal areas, canal transportation and centering ratio, and accumulated hard tissue debris) among the groups ($P>0.05$). C/TRU and C/MT groups presented significantly more voids in root canal fillings when compared to the T/TRU and T/MT groups ($P<0.05$). Percentage of root canal filling materials remnants in the pulp chamber after cleaning procedures and mean fracture resistance values were not statistically significant among the four experimental groups ($P>0.05$).

Conclusions The location and design of the endodontic access cavity did not interfere in the root canal preparation and resistance to fracture of mandibular incisors, regardless of the instrument used. CEC may compromise root canal filling.

Keywords: Endodontic cavity, root canal treatment, fracture resistance, micro-CT.

Introduction

The preparation of the endodontic access cavity is one of the most important stages of root canal treatment (Yahata *et al.* 2017, Rover *et al.* 2017). Proper access should provide the complete pulp chamber roof removal in order to prevent pulp tissue remains, which may serve as a substrate for microorganisms (Neelakantan *et al.* 2018, Siqueira & Rôças 2008). In addition, the elimination of coronary interferences facilitates the detection of the root canal entrance (Rover *et al.* 2017). It serves as a gateway for disinfecting irrigants, improving the instrumentation effectiveness and avoiding accidents (Alovisi *et al.* 2018, Neelakantan *et al.* 2018, Silva *et al.* 2020). Traditional endodontic cavity (TEC) in anterior teeth is usually located in the cingulum region, not only for aesthetic reasons, but also because this region represents the shortest distance to reach the pulp chamber (Mannan *et al.* 2001). With additional wear in the pericervical dentin, it is possible to obtain a straight-line access to the apical foramen or initial canal curvature (Mannan *et al.* 2001, Nissan *et al.* 2007, Özkurt-Kayahan *et al.* 2016, Yahata *et al.* 2017). However, this design of endodontic cavity is responsible for removing a large amount of healthy dentin structure, which may weaken the tooth and supposedly to reduce its fracture resistance (Clark & Khademi 2009, Clark & Khademi 2010, Tang *et al.* 2010; Clark *et al.* 2013). Given this concern and diverging from general basic principles of TEC, contracted endodontic cavities (CEC) have been suggested to maximize the preservation of dental structures (Clark & Khademi 2009, Clark & Khademi 2010, Tang *et al.* 2010; Clark *et al.* 2013). In the anterior teeth, performing endodontic access cavity at the incisal location facilitates visibility throughout the treatment, provides straight-line access to the root canal, and still it preserves the pericervical dentin (Mannan *et al.* 2001, Nissan *et al.* 2007, Özkurt-Kayahan *et al.* 2016, Yahata *et al.* 2017). Although several studies have demonstrated that CEC performed in endodontically treated molars and pre-molars are not able to increase their fracture resistance after coronal restoration (Moore *et al.* 2016, Rover *et al.* 2017, Chlup *et al.* 2017, Ivanoff *et al.* 2017, Silva *et al.* 2020), little is know regarding anterior teeth (Krishan *et al.* 2014).

Cleaning, shaping, and disinfection of oval-shaped root canals pose a significant clinical challenge (Versiani *et al.* 2013, Zuolo *et al.* 2018). In fact, root canal instrumentation systems are mechanically able to act only in the central body of the canal lumen, leaving several areas of the root canal merely untouched (Zuolo *et al.*

2018, Versiani *et al.* 2013, De-Deus *et al.* 2015). Instruments with innovative designs have been developed and introduced in the market aiming to uniformly plane the perimeter of the root canals with complex anatomy (Metzger *et al.* 2010). The TRUShape 3D Conforming Files system (Dentsply Tulsa Dental Specialties, Tulsa, OK, USA) is a novel heat-treated NiTi rotary system with a characteristic longitudinal S-curve, noncutting tip (sizes 20 to 40) and a 0.06 taper in the apical 2 mm that regresses along the overall length. According to the manufacturer, this system promotes greater preservation of dentin during canal shaping, maintaining the integrity of the root structure. In fact, it has been demonstrated that this system promotes greater preservation of dentine and bacterial removal from the root canal walls in comparison with conventional NiTi rotary systems (Bortoluzzi *et al.* 2015). However, the results related to the shaping ability of this new system are scarce and controversial (Peters *et al.* 2015, Guimarães *et al.* 2017, Zuolo *et al.* 2018, Jensen *et al.* 2019, Oliveira *et al.* 2019). While some studies reported favorable results to TRUShape when compared to conventional NiTi instruments (Guimarães *et al.* 2017, Jensen *et al.* 2019, Oliveira *et al.* 2019), others showed similar shaping and cleaning ability (Peters *et al.* 2015, Zuolo *et al.* 2018).

Therefore, the purpose of the present study was to evaluate the influence of CEC located at the incisal region of mandibular incisors on the shaping and filling ability, pulp chamber cleaning, and fracture resistance after root canal preparation with TRUShape 3D or the conventional NiTi rotary system MTwo (VDW, Munich, Germany). TEC was used as a reference technique for comparison. The null hypothesis tested was that the type of endodontic cavity would not influence any of the investigated outcomes, regardless of the instrumentation system used.

Materials and Methods

Sample size calculation

The sample size was estimated based on a previous study (Zuolo *et al.* 2018) in which an effect size of 0.9 was considered (G*Power 3.1 software for Windows; Heinrich Heine-Universität, Düsseldorf, Germany). An alpha-type error of 0.05 and power beta of 0.95 were also specified. The output indicated a minimum sample size of

7 teeth per group to observe significant diferences. Ten teeth were allocated for each group.

Sample Selection

Following prior approval from the Research Ethics Committee (reference n. 2.985.969, Supplementary material C), a total of 70 human mandibular incisors extracted for reasons not related to this study, with fully formed apices and intact crowns, were preselected using periapical radiographs. Teeth were selected based on the following inclusion criteria: straight and fully formed root with single root canal, and similar general dimensions related to length and pulp chamber. The sample were cleaned of surface debris, stored in a 0.9% saline solution at 4°C and used within 6 months after extraction.

To obtain an outline of the root canals, the specimens were scanned in a micro–computed tomographic (micro-CT) device (Sky- Scan 1174; Bruker microCT, Kontich, Belgium) using the following parameters: 50 kV and 800 mA, isotropic resolution of 22 µm, 180° rotation around the vertical axis, rotation step of 0.7°, frame averaging of 2, camera exposure time of 5200 ms and 0.5-mm-thick aluminium filter. Images were reconstructed with NRecon v.1.6.9 software (Bruker microCT) using 40% beam hardening correction and ring artifact correction of 8, resulting in the acquisition of 900 to 1000 transverse cross sections per teeth. After reconstruction of the images, the samples were matched to create 10 groups of paired teeth based on similar morphologic elements of the root canal (volume, surface area, and configuration). One tooth from each matched group was randomly assigned to the four experimental groups (n=10) according to the endodontic access cavity and root canal preparation protocol: traditional/TRUShape (T/TRU); traditional/MTwo (T/MT); contracted/TRUShape (C/TRU); and contracted/MTwo (C/MT).

Endodontic access cavities preparation

All preparation procedures (endodontic access cavities, root canal preparation, filling and restoration) were conducted under operative microscopy (DF Vasconcellos; Valença, Rio de Janeiro, RJ, Brazil) by a single endodontic specialist operator, who did not have prior access to the micro-CT data.

TEC were prepared with high-speed diamond burs (1011 e 3080; KG Sorensen, São Paulo, Brazil) following conventional guidelines already described in the literature (Özkurt-Kayahan *et al.* 2016, Mannan *et al.* 2001, Ingle 1985). The initial point of entry was the lingual surface of the crown, 1 mm above to the cingulum. The cavity was extended in the cervico-incisally and mesiodistally directions until the complete removal of the pulp chamber roof. Then, the pericervical dentin was partially removed in the lingual region, establishing direct access to the root canal (Fig. 1a and 1c).

Each CEC was prepared with high-speed diamond bur (1011; KG Sorensen). The point of entry was just short at the incisal edge on the lingual surface of the crown, with the bur held parallel to the long axis of the teeth until it ranges the pulp chamber. The cavity was not extended, preserving pericervical dentin and part of the pulp chamber roof (Fig. 1b and 1d).

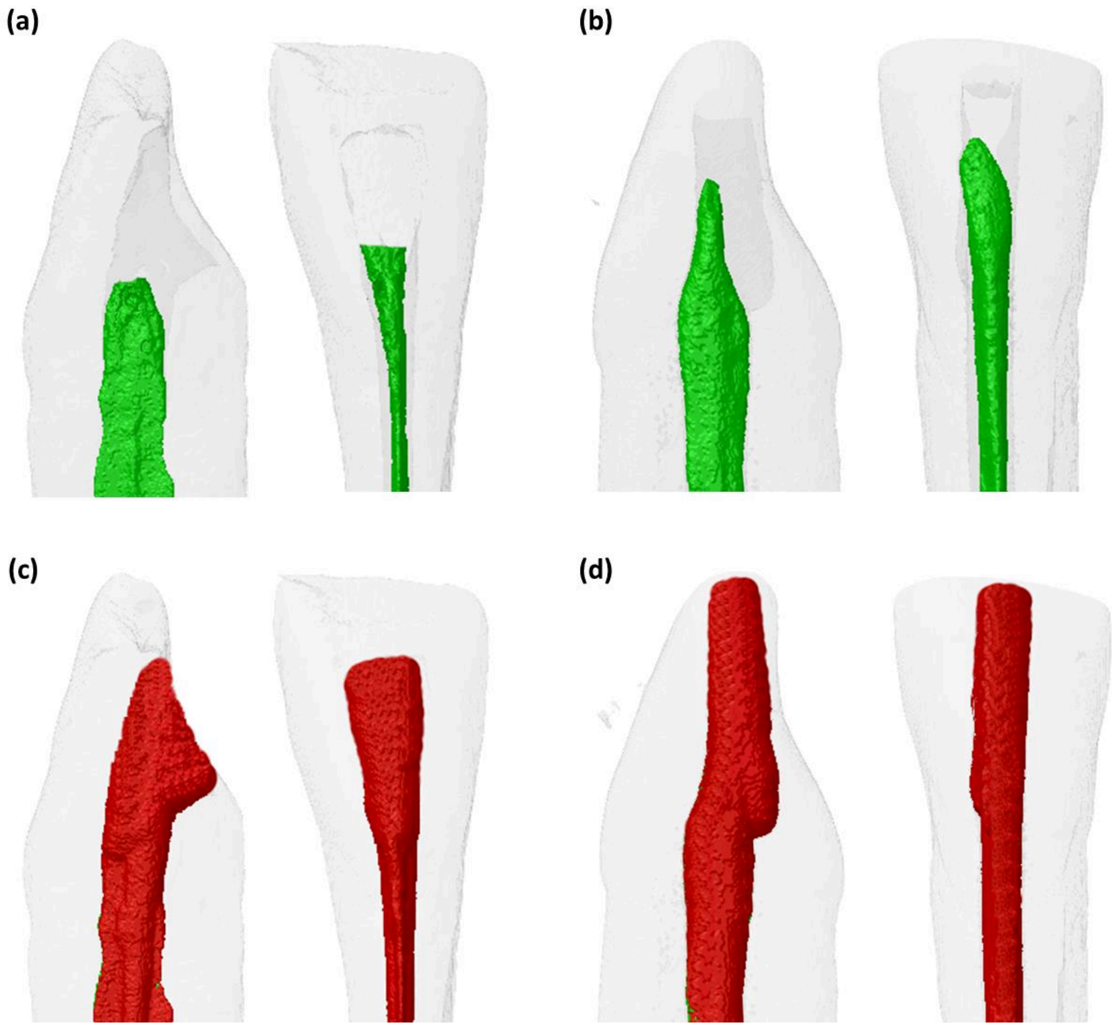

Figure 1 Representative 3D models of access cavities performed in traditional (a, c) and contracted groups (b, d). The green color represents the original root canal (a, b). The red color highlights the access cavity design (c, d).

Root Canal Preparation and Micro-CT Evaluation

Root canals were negotiated with a size 10 K-file (Dentsply Sirona Endodontics, Ballaigues, Switzerland) until its tip was visualized on the apical foramen, and the working length (WL) was established 1.0 mm shorter.

The preparation of the root canals in the T/TRU and C/TRU groups was performed with the TRUShape 3D Conforming Files system (Dentsply Tulsa Dental Specialties). The sequence of instruments used was: 20/.06v, 25/.06v and 30/.06v. Instruments were used with a gentle 2-3 mm in-and-out motion towards at the full WL driven by an endodontic engine (X-Smart Plus, Dentsply Sirona Endodontics) with a 16:1 contra-angle at 300 rpm and 3 Ncm, according to the manufacturer's instructions.

In the T/MT and C/MT groups, the root canal preparation was performed with the MTwo system (VDW GmbH, Munique, Germany). The sequence of instruments used was: 10/.04, 15/.05, 20/.06 and 30/.06. The instruments were used with a gentle 2-3 mm in-and-out motion towards to the full WL, driven by a endodontic engine (X-Smart Plus, Dentsply Maillefer), according to the manufacturer's instructions (300 rpm and 3 Ncm).

In all groups, each instrument was used in 1 tooth and then discarded. Among successive steps, the canals were irrigated with 2 mL of 2.5% sodium hypochlorite (NaOCl) solution with a 30-G Endo-Eze needle (Ultradent Products Inc, South Jordan, UT) inserted up to 2 mm from the apical foramen (Perez *et al.* 2017). Final irrigation was performed with 5 mL of 2.5% NaOCl solution and 5 mL of 17% EDTA for 3 minute followed by 5 mL of 2.5% NaOCl solution. Then, the canals were dried with absorbent paper points, and the specimens were submitted to a postoperative scan and reconstruction applying the aforementioned parameters.

The image stacks of the specimens after preparation were rendered and coregistered with their respective preoperative datasets using an affine algorithm of the 3D Slicer 4.5.0 software (available from http://www.slicer.org) (Zuolo *et al.* 2018). The noninstrumented canal area was determined by calculating the number of static voxels (voxels present in the same position on the canal surface before and after instrumentation) and expressed as a percentage of the total number of voxels present on the canal surface (De-Deus *et al.* 2019) according to the following formula:

$$\frac{\text{number of static voxels x 100}}{\text{total number of surface voxels}}$$

The quantification of accumulated hard tissue debris (AHTD) was expressed as the percentage of the total canal system volume after preparation for each specimen and undertaken as described elsewhere (Neves *et al.* 2015). The volume of dentin removed after preparation was calculated by subtracting pre-and postoperative segmented root dentin using morphologic operations (Fiji v.1.47n; Fiji, Madison, WI, USA).

Canal transportation and centering ratio were calculated at 3 cross-sectional levels (3, 5, and 7 mm distance from the apical end of the root) using the following equations (Gambill *et al.* 1996):

Degree of canal transportation = $(m_1-m_2) - (d_1-d_2)$

Canal centring ratio = $(m_1-m_2)/(d_1-d_2)$ or $(d_1-d_2)/(m_1-m_2)$

where m_1 is the shortest distance from the mesial margin of the root to the mesial margin of the noninstrumented canal; m_2 is the shortest distance from the mesial margin of the root to the mesial margin of the instrumented canal; d_1 is the shortest distance from the distal margin of the root to the distal margin of the noninstrumented canal and d_2 is the shortest distance from the distal margin of the root to the distal margin of the instrumented canal (Figure 2).

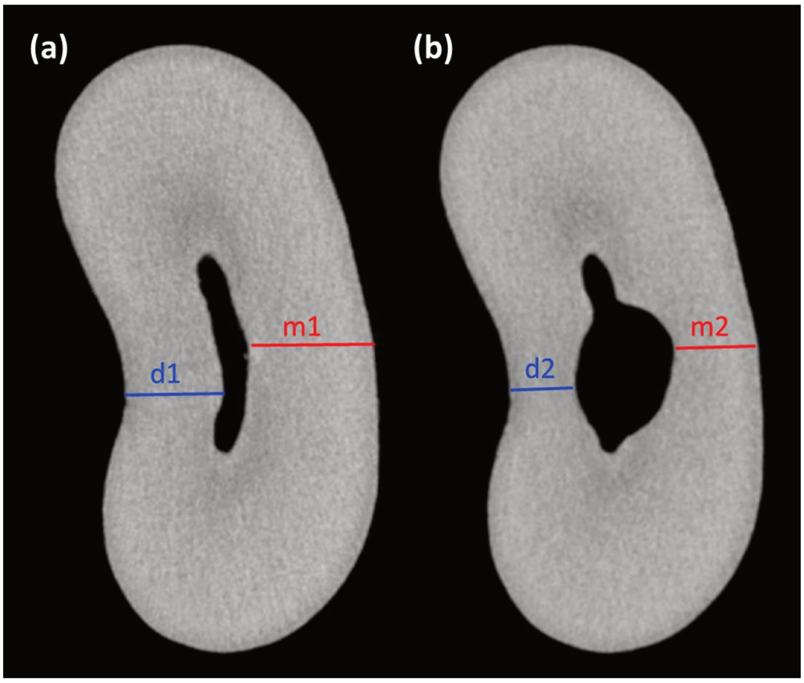

Figure 2 Measurement of dental walls in noninstrumented canal (a) and instrumented canal (b) in mandibular incisors.

Canal transportation equal to 0 means that no transportation occurred, a negative value means that transportation occurred in the distal direction, and a positive value indicates transportation in the mesial direction. The formula adopted for the centering ability calculation depends on the value obtained by the enumerator, which should always be lower than the values obtained by the differences. Therefore, values equal to 1 indicated perfect centering ability of the instrument, whereas values closer to 0 indicated a reduced ability of the instrument to maintain in the central axis of the root canal.

Root canal filling and Micro-CT evaluation

All the samples were filled with AH Plus sealer (Dentsply De Trey, Konstanz, Germany) and 30/.06 guttapercha cones (Endo Tanari Plus; Manacapuru, Brazil) using a single-cone technique associated with vertical condensation. The gutta-percha was removed up to 1mm below the cementoenamel junction with a heated plugger (Buchanan Plugger .04 Taper; SybronEndo Corporation, Orange, USA). The cleaning of the pulp chamber was performed in the same way for both groups. Remnants of root canal fillings were removed with endodontic explorer n. 5 and 6 followed by a 70% alcohol with a brush for conduit (MKLife, Porto Alegre, Brazil).

The access cavity of each tooth was filled with cotton pellets and a temporary dressing (Citodur; DoriDent, Wien, Austria) and the specimens were stored at 37°C and relative humidity of 100% for a week. After this period, the temporary restorative material was completely removed and a new micro-CT scan was performed using the following parameters: 50 kV and 80 mA, isotropic resolution of 22 µm, 360º rotation around the vertical axis, rotation step of 0.5º, frame averaging of 2, camera exposure time of 5200 ms and 0.5-mm-thick aluminium filter. Images were reconstructed with NRecon v.1.6.9 software (Bruker microCT) using 16% beam hardening correction and ring artifact correction of 8. The root filling quality was evaluated based on the quality of the root fillings, which was assessed by analysing the presence of voids (mm^3) inside the root canal filling (gutta-percha and sealer) and also between the root filling and dentine. Segmentation (binarization) of root fillings and voids were achieved based on the grey scale range required to recognize each object under study. Then, the percentages of voids and also root filling remnants present in the pulp chamber were quantified (Silva *et al.* 2020).

Load at Fracture

Prior to the fracture resistance test, endodontic cavities were filled with 37% phosphoric acid gel (Condac 37; FGM, Joinville, Brazil), rinsed with water, and air dried. After, 2 layers of the bonding agent (Single Bond Universal; 3M ESPE, St Paul, Minnesota, EUA) were applied interspersed by a light jet of air and each light-cured for 20 seconds (Radii-cal; SDI, Bayswater, Australia). The cavities were restored with Filtek Bulk Fill Flow (3M ESPE, Sumaré, Brasil) and light-cured for 20 seconds. A final increment was made with Filtek Z350 XT (3M ESPE) and light-cured for 40 seconds.

The specimens were mounted up to 2 mm apical to the cementoenamel junction in a customized cylinder fabricated with self-curing resin (JET; Clássico, Campo Limpo Paulista, Brazil) as reported in a previous study (Plotino *et al*. 2017). The specimens were fixed in a device (Odeme; Luzerna, Brazil) coupled to the bottom of the universal testing machine simulating the angle of 135° that is clinically formed by contact between the maxillary and mandibular central incisors in a Class I occlusal relationship (EMIC DL2000; EMIC, São José dos Pinhais, Brazil) and received a load on the incisal surface. A continuous compressive force was applied with a cilindrical crosshead at 1 mm/min until failure occurred (Fig. 3). The load at fracture was recorded in newtons (N).

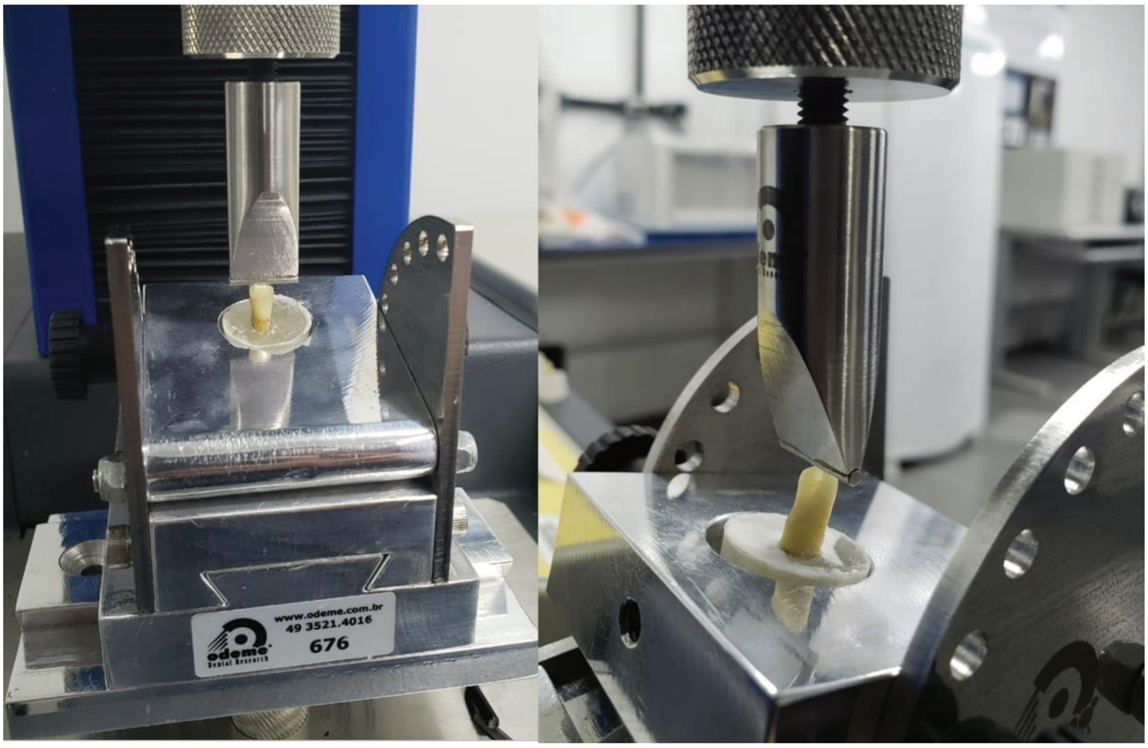

Figure 3 Device used for fixation and positioning of specimens subjected to fracture resistance tests in a universal testing machine.

Statistical Analysis

The normal distribution of the data was verified with the Shapiro-Wilk test ($P>0.05$). Data were statistically evaluated using two-way analysis of variance and the Bonferroni test to compare the results among the groups. All statistical procedures were performed with a cut-off for significance at 5%.

Results

The degree of homogeneity of all groups was confirmed with regards to length, volume and surface area of the root canals ($P>0.05$). No significant differences were observed in the comparison among the results of untouched canal area and percentage of accumulated hard tissue debris after root canal preparation in all groups ($P>0.05$). These results are summarized in Table 1 (Fig. 4). Table 2 presents the transportation and centering ratio values of allgroups; there was no significant difference among all groups (Fig. 4).

C/TRU and C/MT groups presented significantly more voids in root canal fillings that in T/TRU and T/MT groups ($P<0.05$). No significant differences were observed with regard to the percentage of root filling remnants in the pulp chamber after cleaning procedures in all groups (*P*>0.05) (Table 3, Fig. 5 and Appendix A). The mean values of load to fracture were not significantly different among all groups (*P*>0.05) (Table 3).

Table 1 Parameters of sound and prepared canals, percentages of untouched canal area and accumulated hard tissue debris (AHTD) after canal preparation with TRUShape (TRU) or MTwo (MT) instruments in teeth with traditional (T) and contracted (C) endodontic cavities

Groups	Sound canal volume (mm^3)	Prepared canal volume (mm^3)	Sound canal area (mm^2)	Prepared canal area (mm^2)	Untouched canal area (%)	AHTD (%)
T/TRU	5.12 ± 1.46^{A}	10.82 ± 1.94^{A}	51.23 ± 13.02^{A}	68.35 ± 10.39^{A}	8.79 ± 5.86^{A}	0.269 ± 0.475^{A}
T/MT	5.03 ± 1.91^{A}	11.31 ± 2.30^{A}	49.10 ± 12.03^{A}	69.50 ± 10.98^{A}	8.66 ± 4.32^{A}	0.234 ± 0.243^{A}
C/TRU	5.14 ± 1.85^{A}	11.83 ± 3.53^{A}	50.77 ± 13.30^{A}	74.54 ± 16.57^{A}	5.91 ± 4.72^{A}	0.283 ± 0.317^{A}
C/MT	5.54 ± 1.88^{A}	11.64 ± 1.86^{A}	55.45 ± 11.15^{A}	76.54 ± 11.26^{A}	4.84 ± 2.39^{A}	0.124 ± 0.170^{A}

Equal superscript letters in the same column represent absence of statistically significant differences among the different groups ($P>0.05$). Values presented in mean ± standard deviation.

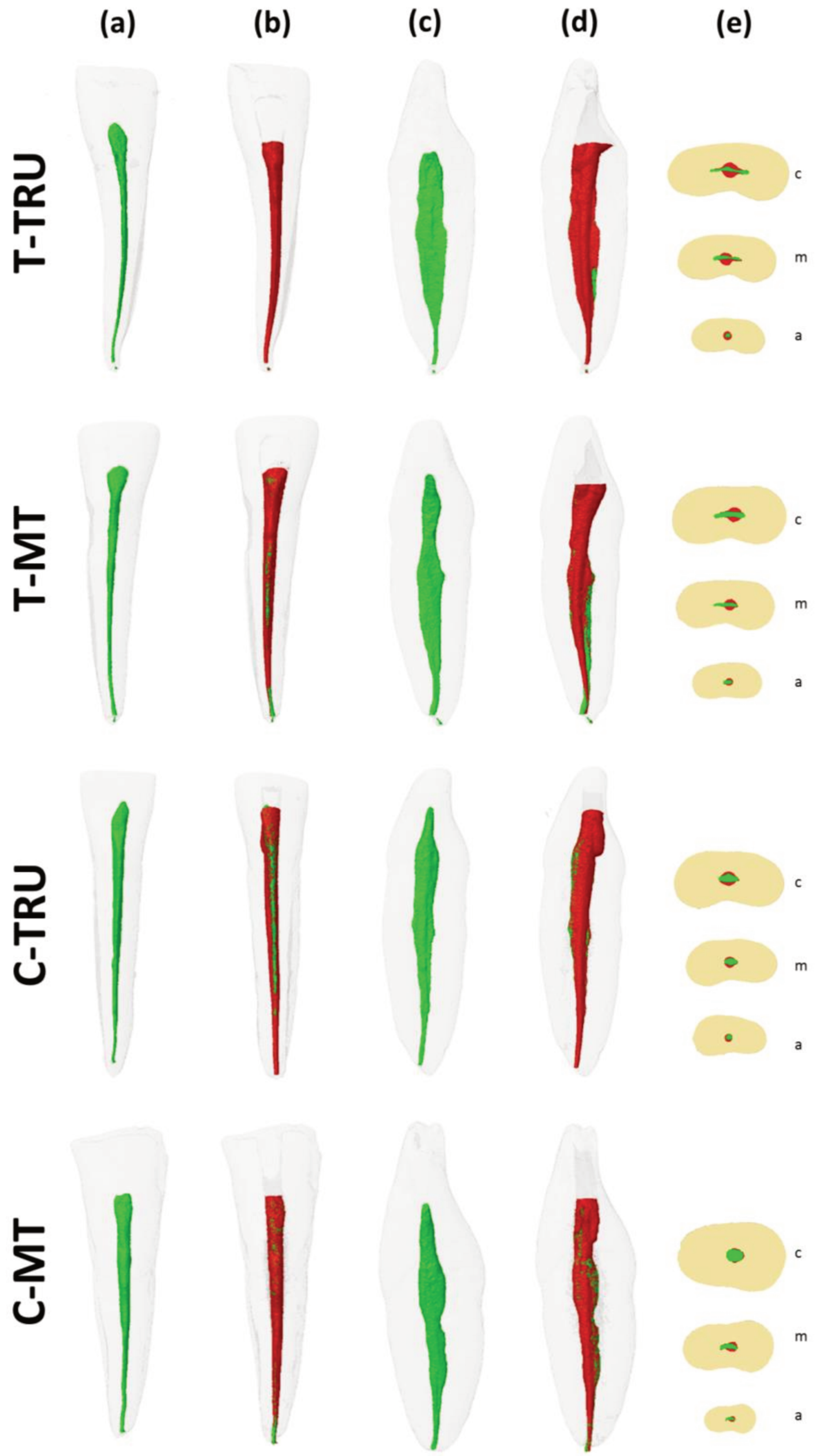

Figure 4 3D and 2D reconstructions of the anatomy of mandibular incisors from each experimental group, before (green) and after (red) access cavity and root canal preparation. Lingual (a, b) and lateral (c, d) views. Representative cross-sections of the superimposed root canals before and after preparation (e) at the coronal (c), middle (m) and apical (a) thirds.

Table 2 Mean ± standard deviation of canal transportation (mm), centring ratio values after canal preparation with TRUShape (TRU) or MTWO (MT) instruments in teeth with traditional (T) and contracted (C) endodontic cavities

Level	Assessment	T/TRU	T/MT	C/TRU	C/MT
3-mm	Transportation	-0.001±0.048^{A}	-0.008±0.053^{A}	0.032±0.041^{A}	0.011±0.027^{A}
	Centring ratio	0.699±0.234^{A}	0.580±0.204^{A}	0.547±0.279^{A}	0.740±0.190^{A}
5-mm	Transportation	-0.008±0.123^{A}	0.041±0,055^{A}	0.020±0.083^{A}	0.021±0.051^{A}
	Centring ratio	0.565±0.261^{A}	0.640±0.197^{A}	0.614±0.203^{A}	0.709±0.207^{A}
7-mm	Transportation	0.014±0.110^{A}	-0.002±0.086^{A}	0.02±0.101^{A}	0.018±0.105^{A}
	Centring ratio	0.515±0.281^{A}	0.614±0.203^{A}	0.591±0.149^{A}	0.630±0.266^{A}

Equal superscript letters in the same row represent absence of statistically significant differences among the different groups (*P*>0.05).

Table 3 Parameters of presence of voids after root canal fillings, volume of root filling remnants in the pulp chamber after the cleaning and load to fracture of teeth with traditional (T) and contracted (C) endodontic cavities

Groups	Filling voids (%)	Root filling remnants in the pulp chamber (mm^3)	Load to fracture (N)
T/TRU	3.93±4.45^{A}	0.058±0.05^{A}	356.65±258.44^{A}
T/MT	5.99±3.38^{A}	0.048±0.05^{A}	319.10±173.67^{A}
C/TRU	8.17±4.82^{B}	0.076±0.04^{A}	335.45±130.32^{A}
C/MT	9.49±5.30^{B}	0.078±0.07^{A}	448.75±109.77^{A}

Equal superscript letters in the same column represent absence of statistically significant differences among the different groups (*P*>0.05). Values presented in mean ± standard deviation.

Figure 5 Representative images of root canal after filling and pulp chamber cleaning procedures in teeth with traditional (T/TRU, T/MT) and contracted (C/TRU, C/MT) endodontic cavities. The gray color represents voids after root canal fillings.

Discussion

The use of CEC proposes a minimal removal of the dental structure, supposedly trying to increase the resistance to fracture of endodontically treated teeth (Clark & Khademi 2010). However, only few studies (Krishan *et al.* 2014, Plotino *et al.* 2017) reported positive results in relation to the increase of fracture resistance when CEC were performed. In fact, several studies demonstrated the inability of such type of procedure to increase the fracture resistance when compared to traditional access cavities (Moore *et al.* 2016, Chlup *et al.* 2017, Ivanoff *et al.* 2017, Rover *et al.* 2017, Özyürek *et al.* 2018, Corsentino *et al.* 2018, Sabeti *et al.* 2018, Silva *et al.* 2019). In addition, data related to some essential factors for a better prognosis of endodontic treatment, such as, the shaping and filling ability, and capacity of cleaning the pulp chamber in teeth with CEC are still limited. The present study evaluated the influence of CEC located at the incisal region of mandibular incisors on the shaping and filling ability, cleaning of the pulp chamber, and fracture resistance after root canal preparation with a superelastic NiTi rotary system or with a heat-treated S-Shaped rotary system. TEC were used as a reference technique for comparison.

Mandibular incisors were selected as oval-shaped canals present a challenge to the clinician. In order to reduce the risk of bias of this study, specimens selection was carried out by a pre-screening of 70 mandibular incisors based on anatomical and morphological configuration (volume, surface área and 3D configuration) using the micro-CT technology. Then, the samples were randomly assigned to the four experimental groups (n=10) according to the endodontic access cavity and root canal preparation protocol. The degree of homogeneity of the groups was confirmed with regard to length, volume and surface area of the root canals ($P>0.05$). Careful pairing of specimens reduces the risk of bias associated with a heterogeneity of root canal anatomy in the lower incisors and improve the internal validity of the present study.

In the current study, CEC located at the incisal region of mandibular incisors did not interfere in none of the tested root canal preparation outcomes (volume and area of the root canal, non-instrumented canal areas, canal transportation and centering ratio, and accumulated hard tissue debris), regardless of the rotatory system used. In fact, previous studies also demonstrated the possibility of performing adequate root canal preparation when using conservative endodontic cavities (Krishan *et al.* 2014, Moore *et al.* 2016). However, some studies have demonstrated that some aspects related to root canal preparation can be compromised when performing minimally invasive cavities (Rover *et al.* 2017, Silva *et al.* 2020). Rover *et al.* (2017) have reported greater canal transportation in CEC cavities performed in maxillary molars. Also, Silva *et al.* (2020) showed a higher percentage of accumulated hard tissue debris in ultraconservative endodontic cavities performed in mandibular premolars. These different results might be explained by the use of distinct teeth, root canal preparation and designs of cavities. Moreover, the anatomy of the selected incisors, with only one canal with small dimensions, and the absence of marked curvatures might have a direct relationship with the current results.

Root canal preparation in the present study was performed with M-Two or TRUShape rotary instruments. Some studies have evaluated the shaping ability of these two types of instruments (Peters *et al.* 2015, Guimarães *et al.* 2017, Zuolo *et al.* 2018, Jensen *et al.* 2019, Oliveira *et al.* 2019); however, to the best of the author's knowledge, this is the first time that different instruments are tested with different access cavities types. In previous studies, while some authors demonstrated that TRUShape instruments promoted lower canal transportation (Oliveira *et al*. 2019), greater preservation of dentine (Bortoluzzi *et al.* 2015) and less non-instrumented canal areas (Jensen *et al.* 2019) when compared to a conventional NiTi rotary system, others showed similar shaping and cleaning ability (Peters *et al.* 2015, Zuolo *et al.* 2018). In the present study, no significant difference was observed among groups in relation to the shaping ability of the different systems used for root canal preparation. The straight-line access promoted by the additional wear in the pericervical dentin performed in TEC, and the access performed at the incisal region in CEC may have contributed to the results obtained in the present study.

With regard to the root canal filling, the results of the present study demonstrated that both groups where CEC was performed (C/TRU and C/MT) presented significantly more voids in root canal filling ($P<0.05$). Therefore, the null hypothesis was partially rejected. To the best of the author's knowledge, only Silva *et al.* (2020) performed a similar evaluation and demonstrated no difference in the filling ability of 2-rooted maxillary premolars treated with traditional or ultraconservative access cavities. The controversial results between the studies might be explained by the different cross-sectional anatomy of the teeth used. Conservative cavities make it difficult to insert thermocompactors in depth. This procedure is essential for correct compaction of root canal filling, especially in teeth with oval-shaped canals and isthmus, such as the mandibular incisors used in the current study. In contrast, 2-rooted maxillary premolars present circular canals, which may have favored root canal filling. Regarding the root filling remnants in the pulp chamber after cleaning procedures, no differences was observed in the present study ($P>0.05$). In contrast, Silva *et al.* (2020) found greater percentage of root filling remnants in the pulp chamber after cleaning procedure in the ultraconservative access cavity group. In the present group, the straight-line access, the miniature anatomy of the pulp chamber of the mandibular incisors and additional cleaning performed with a small brush may have contributed to the different results obtained.

In the present study, the location and design of the endodontic access cavity of mandibular incisors did not affect the fracture resistance of the teeth, regardless of the rotary system used. This result is in agreement with previous studies that reported that CEC did not affect the fracture resistance of maxillary premolars (Chlup *et al.* 2017, Silva *et al.* 2019) and molars (Moore *et al*. 2016, Rover *et al.* 2017, Sabeti *et al.* 2018), and mandibular premolars (Chlup *et al.* 2017, Ivanoff *et al.* 2017) and molars (Corsentino *et al.* 2018, Özyürek *et al.* 2018). During the fracture resistance test, the specimens were fixed in a specific device and a load was applied that simulated the angle of 135° formed by contact between the maxillary and mandibular central incisors in a Class I occlusal relationship. It is possible to suppose that if the same loading was applied for all specimes, them this condition would not be significant (Castro *et al.* 2012). However, the absence of studies that evaluated the fracture resistance of mandibular incisors with similar in vitro condition makes it difficult to discuss the results of the present study. As demonstrated in previous studies (Nissan *et al.* 2007, Özkurt-Kayahan & Kayahan 2016), although the access at the incisal region resulted in a thin layer of enamel around the incisal border, the definitive restoration with composite resin was able to restore the structural resistance of the mandibular incisors.

Despite the discrepancies in the methodology presented by laboratory studies, most of them did not report favorable results associated with CEC (Moore *et al*. 2016, Rover *et* *al.* 2017, Corsentino *et al.* 2018). This fact was clearly pointed-out in a systematic review of in vitro studies. According to this study, there is no evidence to support the use of CEC over traditional access cavity to increase the fracture resistance of human teeth (Silva *et al.* 2018). Also, negative impacts on root canal treatment such as, canal transportation, greater amounts of remaining hard tissue debris, filling ability, difficulty of pulp chamber cleaning, and commitment of bleaching in anterior teeth were reported (Rover *et al.* 2017, Marchesan *et al.* 2018, Neelakantan *et al.* 2018, Silva *et al.* 2019) and may discourage the use of CEC.

Conclusions

CEC located at the incisal region of mandibular incisors did not interfere in the root canal preparation. However, CEC may compromise root canal filling. Also, CEC were not associated with an increase in fracture resistance of mandibular incisor. Therefore, there was no true benefit associated with this type of access cavity in mandibular incisors.

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5 CONCLUSÕES

Com base nos resultados obtidos, por meio dos dois estudos que contemplam esta tese foi possível concluir que:

1) Não foram encontradas evidências científicas que suportem a premissa de que os AEMI são capazes de aumentar a resistência à fratura de elementos dentais tratados endodonticamente quando comparados aos AET.
2) A localização e o design da cavidade de acesso endodôntico não interferem no preparo do sistema de canais radiculares em incisivos inferiores.
3) O AEMI compromete a obturação do sistema de canais radiculares em incisivos inferiores.
4) O AEMI não interfere na capacidade de limpeza da câmara pulpar após a obturação do sistema de canais radiculares em incisivos inferiores.
5) O AEMI não foi associado ao aumento da resistência à fratura em incisivos inferiores.

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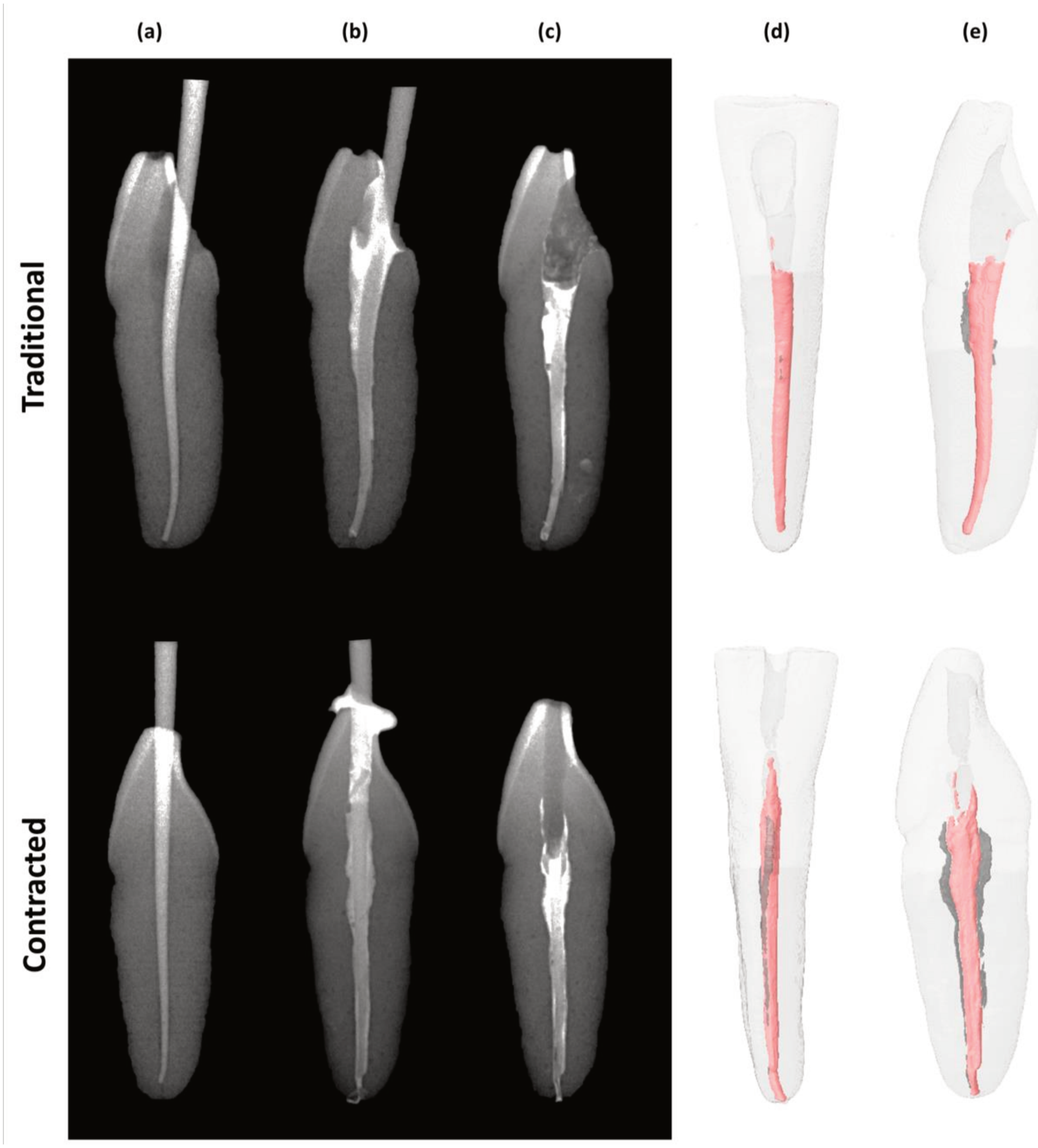
APÊNDICE A – Obturação dos canais radiculares



Appendix D Representative images of root canal during and after root canal filling and pulp chamber cleaning procedures in teeth with traditional (T/TRU, T/MT) and contracted (C/TRU, C/MT) endodontic cavities. Periapical radiographs of: cone proof (a), root canal filling (b), and after pulp chamber cleaning procedures (c). 3D reconstructions after root canal filling and pulp chamber cleaning procedures: lingual (d) and lateral (e) views. The gray color represents voids after root canal fillings.

ANEXO A – Artigo 1 (Publicado na periódico Clinical Oral Investigation)

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REVIEW

Impact of contracted endodontic cavities on fracture resistance of endodontically treated teeth: a systematic review of in vitro studies

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Abstract

Objective This systematic review was performed to answer the following question: do contracted endodontic cavities (CECs) increase resistance to fracture in extracted human teeth compared to traditional endodontic cavities (TECs)?

Methods A literature search without restrictions was carried out in PubMed, Science Direct, Scopus, Web of Science, and Open Grey databases. Articles were selected by two independent reviewers. In addition, a reference and hand search was also fulfilled. All included in vitro studies evaluated the influence of CECs on strength to fracture in extracted human teeth and compared to TECs. The quality of the selected studies was evaluated and they were classified as having a low, moderate or high risk of bias.

Results A total of 810 articles were obtained in the electronic search. After the application of the eligibility criteria, reference and hand search, and duplicate removal, six studies were included in this systematic review. All included studies evaluated the influence of CECs on strength to fracture in extracted human teeth and compared to TECs. Characteristics investigated in the selected articles included the sample size and tooth type, access cavity design, filling and restoration procedures, load at fracture test characteristics, and results. The studies demonstrated large variability among the fracture resistance values and standard deviations and low power. Three of the reviewed studies presented low risk of bias and the other three showed medium risk of bias.

Conclusion Overall, this systematic review of in vitro studies showed that there is no evidence that supports the use of CECs over TECs for the increase of fracture resistance in human teeth.

Clinical relevance Recently, CECs have gained attention in endodontics due to maximum tooth structure preservation including the pericervical dentin, which could improve the strength to fracture of endodontically treated teeth. However, the influence of access cavity design on fracture resistance remains limited and controversial.

Keywords Dental pulp cavity · Fracture strength · Minimally invasive · Systematic review

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Introduction

Obtaining an appropriate access cavity is essential for a successful treatment of the root canal system and has a significant impact on subsequent procedures [1]. Traditionally, endodontic access advocates the removal of caries and definitive restorations, preserving the healthy structure of the tooth. The shape of the access cavity is defined primarily by the morphology of the individual pulp chamber of the tooth to be treated. The roof of the pulp chamber is completely removed in order to locate all orifices of the root canals and provide direct access to the apical foramen or to the initial curvature of the canal by removing cervical dentin protrusions and enlarging the canal orifice [2]. Adequate endodontic access is essential for the efficient localization, measurement, chemomechanical preparation, and root canal filling. In addition, adequate root canal access can prevent iatrogenic complications such as the deviation of the original anatomy of the root canal during instrumentation and fracture of endodontic instruments [2, 3]. The non-location of a root canal or inefficient chemical-mechanical preparation can lead to the persistence of infection after treatment and, consequently, to failure [2]. However, according to some authors, traditional endodontic access removes a large amount of dentin structure, which may weaken the dental structure, and supposedly reduces its fracture resistance [4, 5].

Following the trend of minimally invasive dentistry, Clark and Khademi [4] introduced a new model of endodontic access, focusing on the minimal removal of the tooth structure. Diverging from the general basic principles of traditional coronary openings, these conservative accesses preserve part of the roof of the pulp chamber, and the pericervical and pericingular dentin. According to these authors, the current model of endodontic accesses does not lead to long-term success, since they structurally compromise the tooth by removing an excessive amount of dentin, which predisposes to tooth fracture [4]. From this, some concepts have been disclosed in an attempt to improve the resistance of endodontically treated teeth. One of these concepts would be the preservation of the pericervical dentin, which can be defined as the area approximately 4 mm above and 6 mm below the bone crest. This structure is responsible for the transmission of occlusal forces to the root. According to Clark et al. [6], the safest way to avoid damaging this dentin is preserving part of the ceiling (0.5 to 3 mm) around the entire pulp chamber, which would reduce the flexion of the cusps and, consequently, the fracture index of the tooth. Following this rationale, in this new modality of access called conservative or contracted endodontic access, the maintenance of the pericingular dentin plays an important role, since there is a concentration of tension forces in the cingulum when the incisors are in function and their removal would result in lower fracture resistance [7].

Previous studies showed conflicting results regarding the influence of access cavity on fracture resistance of endodontic treated teeth [8–13]. Thus, the influence of contracted endodontic cavities (CECs) on fracture resistance outcomes remains controversial. This systematic review was performed to answer the following question: do CECs increase resistance to fracture in extracted human teeth compared to traditional endodontic cavities (TECs)?

Methods

Study design

A systematic review of all studies that assessed the influence of access cavity design on fracture resistance in extracted human teeth was undertaken. TECs were used as a reference for comparison. This systematic review was registered in the PROSPERO database (PROSPERO registry number CRD 42017071644) and followed the recommendations of the PRISMA statement for the report of this systematic review [14].

Literature search strategy

A systematic search without restrictions was performed by two independent reviewers in the electronic databases PubMed, Science Direct, Scopus, Web of Science, and Open Grey from their inception through July 22, 2017. Detailed individual search strategies for each database were performed using the following terms from Medical Subject Heading terms (MeSH) or text word (tw) and their combinations: "dental pulp cavity" (MeSH), "dental pulp necrosis" (MeSH), "endodontic cavity" (tw), "traditional endodontic cavity" (tw), "contracted endodontic cavity" (tw), "conservative endodontic cavity" (tw), "minimally invasive endodontics" (tw), "stress fracture" (MeSH), "fatigue" (MeSH), "strength to fracture" (tw), "resistance to fracture" (tw) "fracture strength" (tw), "biomechanical responses" (tw), and "fracture resistance" (tw). The "AND" and "OR" Boolean operators were applied to combine keywords (Appendix 1). In addition, a reference search was made in the reference lists of all selected articles and a hand search was performed in the *Journal of Endodontics* and the *International Endodontic Journal*. Experts were also contacted to identify unpublished and ongoing studies.

Eligibility criteria

It included studies which the primary objective was to evaluate the influence of CECs on fracture resistance compared to TECs in human teeth when. The following eligibility criteria were based on the PICOS strategy [14]: extracted fully formed (mature) human teeth (P—participants), contracted endodontic cavities technique (I—intervention), studies that compare traditional endodontic cavities technique (C—comparison), fracture resistance values as an outcome (O—outcome), and in vitro transversal studies (S—study design). Although the PICO strategy is generally used for clinical trials, all of the included in vitro studies presented an intervention. Thus, PICO strategy was adapted for this purpose. No language or time restrictions were applied.

It excluded reviews, letters, opinion articles, conference abstracts, case reports, serial case, studies performed in animals, studies that included immature or artificial teeth.

Selection study process

Two independent reviewers (G. R. and F. G. B.) selected all references in two stages. In stage 1, both reviewers evaluated the titles and abstracts of the published studies and then applied the eligibility criteria. Full articles were retrieved and examined when their title and abstract did not provide enough information for a final decision. In stage 2, the selected full articles were independently reviewed and screened by the same two reviewers (G. R. and F. G. B.). Disagreements on eligibility criteria of a study were discussed between the reviewers until a decision was obtained by consensus. If there was no consensus, a third reviewer (E. J. S.) resolved any discrepancies. After the full-text analyses of the potentially relevant studies, the selected studies were included in this systematic review. Articles appearing in more than one database search were considered only once.

Data collection process

Two reviewers (G. R. and F. G. B.) performed data extraction in all the included studies independently. Any potential conflict was resolved by discussion with a third reviewer (E. J. S.). The following information was extracted from each study and recorded: study characteristics (authors, year, and country), sample characteristics (tooth type and sample size), endodontic procedures (access cavity design,

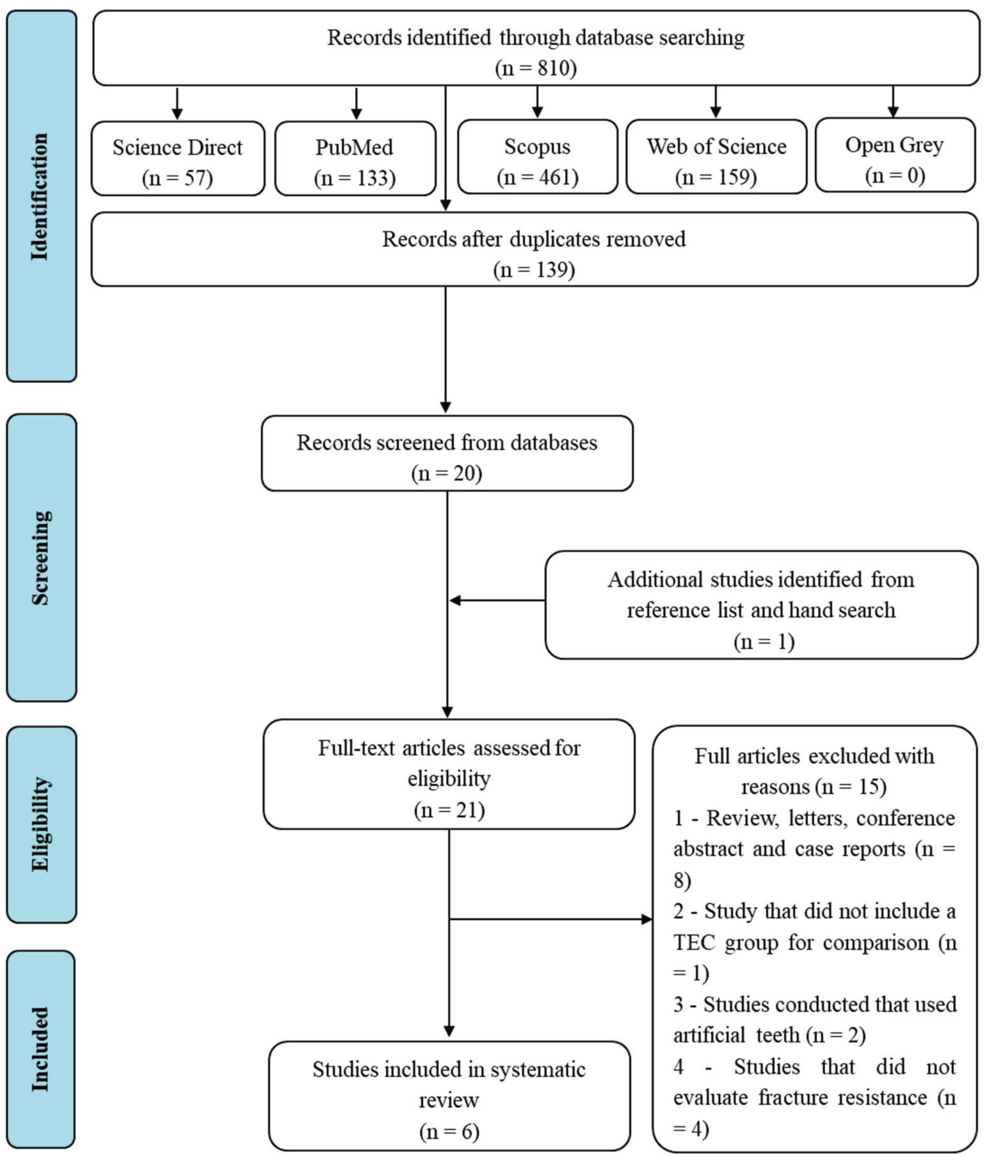

Fig. 1 Flow diagram outlining the study identification and screening process adapted from PRISMA recommendation [14]

filling, and restoration), strength to fracture (load at fracture test characteristics and results), and other findings (root canal detection, instrumentation efficacy, and fracture patterns, when present).

Study quality assessment

The quality of the selected studies was evaluated using an adaptation of the methods used in previous systematic reviews performed with in vitro studies [15, 16]. Two reviewers (G. R. and F. G. B.) independently assessed the methodological quality of each included study using the following parameters: (1) sample size calculation, (2) samples with similar dimensions, (3) presence of a control group (intact teeth), (4) execution of filling procedures, (5) presence of coronal restoration, and (6) correct statistical analysis carried out. The blinding of the operator was not considered since the shapes of the access cavities are very different and allow the operator to identify the performed treatment. The parameters reported in original studies were assigned as "Yes" and missing information was assigned as "No." The articles were classified as having a low risk of bias if five or six items were reported, a moderate risk of bias if three or four items were reported, and a high risk of bias if one or two parameters were reported. The third reviewer (E. J. S.), when needed, resolved any disagreement into the reviewers.

The power of studies was calculated based on the fracture resistance means, standard deviations, and sample size for each group of teeth. The power analysis is able to measure the effect size that can be detected using a given sample size. For this purpose, a confidence interval of 95% and a two-tailed test using OpenEpi 3.04.04 software were adopted.

Results

Study selection

The identification process and the eligibility criteria of the studies are shown in Fig. 1. A total of 810 articles were obtained in the electronic search: 57 from Science Direct, 133 from PubMed, 461 from Scopus, 159 from Web of Science, and 0 from Open Grey. After the application of the eligibility criteria, the discarding of duplicates, and the inclusion of one study identified from reference lists, 21 articles were selected for full-text assessment. After reading the complete articles, 15 of them were excluded [1, 4, 6, 7, 17–27]; the reasons are explained in Table 1. As a result, six studies fulfilled the eligibility criteria and were included in this systematic review [8–13].

Table 1 Excluded studies and the respective reasons for each exclusion

Studies	Exclusion reason
Ahmed and Gutmann [17] Boveda and Kishen [18] Bürklein and Shäfer [19] Clark and Khademi [7] Clark and Khademi [4] Clark et al. [6] Gluskin et al. [20] Khademi et al. [21]	1. Review, letters, abstract conference, and case reports
Al Amri et al. [22]	2. Study that did not include a TECs group for comparison
Bonessio et al. [23] Yuan et al. [24]	3. Studies conducted that used artificial teeth
Eaton et al. [25] Niemi et al. [26] Varghese et al. [27] Yahata et al. [1]	4. Studies that did not evaluate fracture resistance

Study characteristics

All included studies evaluated the influence of CECs on strength to fracture in extracted human teeth and compared to TECs. The studies analyzed different teeth: maxillary incisors [8], premolars [10, 12] and molars [9, 12, 13], and mandibular premolars [8, 10–12] and molars [8, 12]. Sample sizes also presented discrepancies ranging from 30 [13] to 160 [12]. Before the resistance test, some studies did not perform filling [8, 9, 11], restoration procedures [8], and periodontal ligament simulation [8, 10–12]. It was observed that there are differences in the methodology in fracture resistance tests: some authors [8–13] applied a continuous compressive force at the central fossa at a 30° angle, while one author [11] at a 45° angle and other [8] at a 135° angle. The crosshead diameter varied among the studies and also its speed: some authors [10–12] used a crosshead of 0.05 mm/min and others [8, 9, 13] used 0.10 mm/min. The studies also demonstrated large variability among the fracture resistance values and standard deviations. Characteristic details of all selected studies [8–13] are summarized in Table 2.

Strength to fracture results of individual studies

Table 2 summarizes the characteristics of the included studies and the main statistical findings. Chlup et al. [10] did not observe statistically significant differences between TEC and CEC groups in maxillary and mandibular premolars. Ivanoff et al. [11] did not find statistically significant differences between CEC, TEC, and control groups in mandibular premolars restored with mesial-occlusal composites. Krishan et al. [8] found mean load at fracture for CECs significantly higher than for TECs, and it did not differ significantly from control

Table 2 Summary of descriptive characteristics of included studies

Authors, year, country	Study design	Sample size (n)	Tooth type	Groups size, number of samples (n), and power[a] analysis assessment (PA)	Load at fracture test	Mean load at failure values (N) ± standard deviation	Analysis of resistance test results	Other outcomes
Chlup et al. [10] Czechia	In vitro	60	Maxillary and mandibular premolars	CEC (n = 10/tooth type) TEC (n = 10/tooth type) Control (intact teeth/n = 10/ tooth type) PA—maxillary premolars = 34.84% PA—mandibular premolars = 11.69%	After the simulation of the alveolar bone, a continuous compressive force was applied at the central fossa at a 30° angle from the long axis of the tooth with a diameter of 3/16-in. crosshead at 0.5 mm/min until failure occurred	Maxillary premolars: CEC (860.0 ± 206.8 N) TEC (687.4 ± 279.4 N) Control (745.0 ± 418.6 N) Mandibular premolars: CEC (1079.0 ± 383.2 N) TEC (946.6 ± 384.1 N) Control (1171.8 ± 568.0 N)	No statistically significant difference was observed between TEC and CEC in maxillary and mandibular premolars.	
Ivanoff et al. [11] USA	In vitro	45	Mandibular premolars	CEC (n = 15) TEC (n = 15) Control (intact teeth/n = 15) PA—mandibular premolars = 1.14%	After the simulation of the alveolar bone, a continuous compressive force was applied at the central fossa at a 45° angle from the long axis of the tooth with a 3.6-mm spherical crosshead at 0.5 mm/min until failure occurred	CEC (600.9 ± 360.3 N) TEC (601.7 ± 307.9 N) Control (609.7 ± 279.1 N)	There was no statistically significant difference in resistance to failure between any of the groups. Modifying access outline to a contracted design did not improve fracture resistance of mandibular premolars restored with mesial-occlusal composites	All three groups had an equal number of “favorable” (repairable) and “unfavorable” failures (7:8), defined as irreparable failures or root fractures below the level of simulated bone
Krishan et al. [8] Canada	In vitro	90	Maxillary incisors, mandibular premolars, and molars	CEC (n = 10/tooth type) TEC (n = 10/tooth type) Control (intact teeth/n = 10/tooth type) PA—maxillary incisors = 95.76% PA—mandibular premolars = 100% PA—mandibular molars = 100%	After the simulation of the alveolar bone, a continuous compressive force was applied at the central fossa at a 30° angle in premolars and molars and at a 135° angle in incisors from the long axis of the tooth. With a spherical crosshead at 1 mm/min until failure occurred	Maxillary incisors: CEC (1134.6 ± 109.2 N) TEC (1305.2 ± 97.6 N) Control (1276.6 ± 93.8 N) Mandibular premolars: CEC (586.8 ± 116.9 N) TEC (328.4 ± 56.7 N) Control (634 ± 458.6 N) Mandibular molars:	In premolars and molars, the mean load at fracture for CEC was significantly higher than for TEC, and it did not differ significantly from control group. In the TEC group, the load at fracture in premolars and molars was significantly lower than in control group. For incisors, the mean load at fracture did not	- CEC afforded conservation of coronal dentin in incisors, premolars, and molars - CEC was associated with the risk of compromised canal instrumentation only in the distal canals of molars

Table 2 (continued)

Authors, year, country	Study design	Sample size (n)	Tooth type	Groups size, number of samples (n), and power[a] analysis assessment (PA)	Load at fracture test	Mean load at failure values (N) ± standard deviation	Analysis of resistance test results	Other outcomes
						CEC (1586.9 ± 196.8 N) TEC (641.7 ± 62.0 N) Control (2029.1 ± 259.7 N)	differ significantly among the 3 groups	
Moore et al. [9] Canada	In vitro	39	Maxillary molars	CEC (n = 14) TEC (n = 14) Control (intact teeth/n = 11) PA—maxillary molars = 42.57%	After the simulation of the periodontal ligament and alveolar bone, cyclically fatigued (1 million cycles, 5–50 N, 15 Hz) directed at 30° angle from the tooth's long axis and, subsequently, continuous compressive force was applied with a 5-mm spherical crosshead at 1 mm/min until failure occurred	CEC (1703 ± 558 N) TEC (1384 ± 377 N) Control (2457 ± 941 N)	Load at failure for CEC did not differ significantly from TEC and was lower for both groups when compared to control group	- Instrumentation efficacy was not significantly impacted by endodontic cavity design
Plotino et al. [12] Italy	In vitro	160	Maxillary molars and premolars Mandibular molars and premolars	NEC (n = 10/tooth type) CEC (n = 10/tooth type) TEC (n = 10/tooth type) Control (intact teeth/n = 10/tooth type) PA—maxillary molars = 35.71% PA—maxillary premolars = 70.40% PA—mandibular molars = 66.70% PA—mandibular premolars = 30.22%	After the simulation of the alveolar bone, a continuous compressive force was applied at the central fossa at a 30° angle from the long axis of the tooth with a 6-mm spherical crosshead at 0.5 mm/min until failure occurred	Maxillary molars: NEC (1170 ± 432 N) CEC (1143 ± 506 N) TEC (810 ± 425 N) Control (1172 ± 598 N) Maxillary premolars: NEC (805 ± 204 N) CEC (821 ± 324 N) TEC (498 ± 250 N) Control (913 ± 188 N) Mandibular molars: NEC (1459 ± 278 N) CEC (1401 ± 495 N) TEC (923 ± 393 N) Control (1572 ± 639 N) Mandibular premolars: NEC (945 ± 267 N) CEC (929 ± 384 N) TEC (704 ± 310 N)	No difference was observed between CEC, NEC ("ninja"), access cavity designs, and intact teeth. Teeth with TEC showed lower strength than other groups	- Intact teeth showed more restorable fractures than all the prepared ones

Table 2 (continued)

Authors, year, country	Study design	Sample size (n)	Tooth type	Groups size, number of samples (n), and power[a] analysis assessment (PA)	Load at fracture test	Mean load at failure values (N) ± standard deviation	Analysis of resistance test results	Other outcomes
Rover et al. [13] Brazil	In vitro	30	Maxillary molars	CEC (n = 15) TEC (n = 15) PA—maxillary molars = 5.33%	After the simulation of the periodontal ligament and alveolar bone, a continuous compressive force was applied at the central fossa at a 30° angle from the long axis of the tooth with a 4-mm spherical crosshead at 1 mm/min until failure occurred	Control (1006 ± 313 N) CEC (996.30 ± 490.78 N) TEC (937.55 ± 347.25 N)	Load at failure for CEC did not differ significantly from TEC	- The ultrasonic troughing associated with an operating microscope was essential to the location of the root canals with CEC - Instrumentation efficacy was not significantly impacted by endodontic cavity design

[a] The power analyses were calculated based on the provided sample size, mean, and standard deviation

group in mandibular premolars and molars. In the TEC group, the load at fracture in mandibular premolars and molars was significantly lower than in control group. For maxillary incisors, the mean load at fracture did not differ significantly among the three groups. Moore et al. [9] and Rover et al. [13] showed that load at failure for CECs did not differ significantly from TEC group, and it was lower for both groups when compared to intact teeth [9] in maxillary molars. Plotino et al. [12] evaluated maxillary and mandibular molars and premolars. No difference was observed between CECs, "ninja" endodontic cavities (NECs), and intact teeth in all types of teeth. TEC showed lower strength than other groups.

Study quality assessment

Of the six studies included, three of them presented low risk of bias [9, 12, 13] and the other three showed medium risk of bias [8, 10, 11]. The results are described in Table 3 according to the parameters considered in the analysis.

The power analysis demonstrated low power of the studies varying from 1.14% [11] to 70.40% [12]. The higher power was found in the Krishan et al. [8] study that obtained 100% of power. The power analysis of all selected studies [8–13] was showed in Table 2.

Discussion

The reduction of tooth structure is suggested to be one relevant reason of fractures in root canal filled teeth. Traditional endodontic cavity design is considered the second main cause of tooth structure loss [28]. Therefore, CECs were recently proposed to reduce the fracture risk of endodontically treated teeth [4]. Within this background and all the attention that this access design approach has gained in endodontics, this systematic review of in vitro studies focused on accessing the impact of CECs on fracture resistance of endodontically treated teeth.

A total of 810 studies were obtained from the electronic search. However, after the eligibility criteria and the discard of duplicates, only six of them [8–13] were included. It is important to emphasize that the six studies included were classified as low/moderate risk of bias. Even though it was not comparable due to the important discrepancies in the methodology of the included studies, in these cases, the meta-analysis is not recommended. Only two of the studies included in this review presented an improved fracture resistance of CECs compared to TECs [8, 12]. Krishan et al. [8] showed that mandibular premolars and molars had a higher mean load at fracture for CECs, while no differences were observed for maxillary incisors. However, the authors in this study performed the fracture test without filling and restoration of the teeth, which made it present

Table 3 Quality assessment and risk of bias

Study	Sample size calculation	Samples with similar dimensions	Control group (intact teeth)	Performance of filling procedures	Performance of restoration procedures	Statistical analysis carried out	Risk of bias
Chlup et al. [10]	No	No	Yes	Yes	Yes	Yes	Moderate
Ivanoff et al. [11]	No	Yes	Yes	No	Yes	Yes	Moderate
Krishan et al. [8]	Yes	Yes	Yes	No	No	Yes	Moderate
Moore et al. [9]	Yes	Yes	Yes	No	Yes	Yes	Low
Plotino et al. [12]	No	Yes	Yes	Yes	Yes	Yes	Low
Rover et al. [13]	Yes	Yes	No	Yes	Yes	Yes	Low

a moderate risk of bias. Moreover, it is well established that restoration of endodontic cavities restore the fracture strength of teeth up to 72% of that of intact teeth [9, 29]. In the other study, Plotino et al. [12] evaluated, besides CECs and TECs, the fracture resistance of NECs and found that TECs presented lower fracture strength than CECs and NECs in maxillary and mandibular premolars and molars. No statistical significance was found in the fracture resistance mean values of CECs and NECs.

CECs were found not to improve fracture resistance of teeth according to the four other studies included in this review [9–11, 13]. Ivanoff et al. [11] showed that modifying access outline to a contracted design did not improve fracture resistance of mandibular premolars restored with mesial-occlusal composites. In addition, Chlup et al. [10] did not observe statistically significant difference between TEC and CEC groups in maxillary and mandibular premolars. Moreover, Moore et al. [9] and Rover et al. [13], the two studies that presented low risk of bias and similar methodology, demonstrated no statistical difference between TEC and CEC in maxillary molars ($p > 0.05$).

Additionally, the power analysis of the studies demonstrated that only Krishan et al. [8] were adequately powered to find significant results since the power of this study was higher than 80%. The large variability among the fracture resistance values, as demonstrated through the high standard deviation, and the limited sample size are two important reasons for the low power of the studies. The findings presented here reinforce the need of the conduction of powdered in vitro studies prior to clinical trial conduction. However, it is important to consider that the extrapolation of the in vitro results for in vivo repercussion must be done with caution since is hard to determine which fracture resistance difference would clinically impact.

It is consensus that CECs affect tooth structure preservation including pericervical dentin [4, 20]. However, this type of access design does not reflect the clinical daily routine once it can mainly be performed on sound teeth, which does not occur frequently. It is paramount that an ideal endodontic access cavity should permit the location of all canals, an efficient preparation (with a complete removal of pulp tissue, debris, and necrotic materials) and filling of root canals without procedural errors [2, 3]. Nonetheless, CECs might enhance the possibility of missing some root canal orifices [13] and impact negatively on the instrumentation efficacy [8, 13]. Moreover, to date, no study has evaluated the ability of root canal disinfection after performing CECs; it is possible that this cavity modality hinders an adequate cleaning and disinfection of the root canal system, compromising the long-term prognosis of endodontically treated teeth. Therefore, clinicians should be cautious and focus on performing a "necessary invasive endodontics," aiming to preserve the maximum of tooth structure during root canal therapy but without compromising the treatment outcomes.

The electronic search retrieved in vitro studies. Since it consists in an actual theme, there were no randomized clinical trials available yet. The clinical trials present higher strength of evidence, and for this reason, its findings can directly impact institutional policies, such as to guide federal government healthy policies, provide new teaching concepts among academic institutions, and to finally establish the most efficient procedure for the patients [30]. It is well known that in vitro studies do not simulate clinical oral condition. In the included studies, the applied methodology did not include the reproduction cary progression and the challenges of teeth restoration under clinical conditions, irreproducible oral hygiene status, cariogenic and erosive challenges, masticatory forces, and other variables found in clinical conditions. Although clinical trials present higher strength of evidence compared to the in vitro studies, the in vitro studies provide preliminary important responses that are important to design further clinical trials.

Other important highlight is the high clinical research workforce and costs, and for this reason, the assessment of the cost–benefit is important before being conducted [31]. In this sense, this systematic revision was conducted preliminarily demonstrating no in vitro benefit of CECs. Additionally, it is suggested that prior to conducting clinical trials, it is necessary to perform in vitro studies that evaluate other relevant outcomes, such as canal location, instrumentation efficacy, and root canal disinfection to avoid treatment failure and consequently clinical damage to the patients.

Conclusion

Although in vitro studies present limitations, the included studies have a satisfactory methodological quality contributing with a preliminary important information regarding this subject. Additionally, more in vitro studies are necessary to evaluate the quality of root canal preparation and disinfection before planning clinical studies. Finally, randomized controlled trials and retrospective and prospective studies are warranted before indicating this new access modality. In the overall analysis, this systematic review demonstrated that there is no scientific evidence that supports the use of CECs over TECs for the increase of fracture resistance in human teeth.

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Compliance with ethical standards

Conflict of interest Emmanuel João Nogueira Leal Silva, Gabriela Rover, Felipe Gonçalves Belladonna, Gustavo De-Deus, Cleonice Teixeira, and Tatiana Fidalgo declare that they have no conflict of interest.

Ethical approval For this type of study, ethical approval is not required.

Informed consent For this type of study, formal consent is not required.

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ANEXO B – Estratégia de busca aplicada nas bases de dados

Supplementary material: Search strategy in the databases.

Database	Search strategy	Findings
Pubmed	**#1** (“dental pulp cavity”[MeSH Terms] OR “dental pulp cavity”[Title/Abstract] OR “endodontic cavity”[Title/Abstract] OR “endodontic access”[Title/Abstract]OR “endodontic access cavity”[Title/Abstract] OR “access cavity designs”[Title/Abstract] OR “access cavity preparation”[Title/Abstract] OR “traditional endodontic cavities”[Title/Abstract] OR “traditional endodontic cavity”[Title/Abstract] OR “traditional endodontic access cavities”[Title/Abstract] OR “traditional endodontic access cavity”[Title/Abstract] OR “contracted endodontic access cavities”[Title/Abstract] OR “contracted endodontic access cavity”[Title/Abstract] OR “contracted endodontic cavity”[Title/Abstract] OR “contracted endodontic cavities”[Title/Abstract] OR “conservative endodontic cavity”[Title/Abstract] OR “conservative access cavity”[Title/Abstract]OR “conservative endodontic cavities”[Title/Abstract] OR “conservative endodontic access cavities”[Title/Abstract] OR “conservative endodontic access cavity”[Title/Abstract] OR “minimally invasive preparation”[Title/Abstract] OR “minimal endodontic treatment intervention”[Title/Abstract] OR “minimally invasive endodontics”[Title/Abstract] OR “minimally-invasive intervention”[Title/Abstract])	8,186
	#2 (“Stress Fracture”[MeSH] OR “fatigue”[MeSH] OR “Stress Fracture”[Title/Abstract] OR “fatigue”[Title/Abstract] OR "fracture resistance"[Title/Abstract] OR "resistance to fracture"[Title/Abstract] OR "fracture strength"[Title/Abstract] OR "biomechanical responses"[Title/Abstract])	88,089
	# 1 and # 2	**133**
Science Direct	**#1** TITLE-ABS-KEY(dental pulp cavity) OR TITLE-ABS-KEY(endodontic cavity) OR TITLE-ABS-KEY(endodontic access) OR TITLE-ABS-KEY(endodontic access cavity) OR TITLE-ABS-KEY(access cavity designs) OR TITLE-ABS-KEY(access cavity preparation) OR TITLE-ABS-KEY(traditional endodontic cavities) OR TITLE-ABS-KEY(traditional endodontic cavity) OR TITLE-ABS-KEY(traditional endodontic access cavities) OR TITLE-ABS-KEY(traditional endodontic access cavity) OR TITLE-ABS-KEY(contracted endodontic access cavities) OR TITLE-ABS-KEY(contracted endodontic access cavity) OR TITLE-ABS-KEY(contracted endodontic cavity) OR TITLE-ABS-KEY(contracted endodontic cavities) OR TITLE-ABS-KEY(conservative endodontic cavity) OR TITLE-ABS-KEY(conservative access cavity) OR TITLE-ABS-KEY(conservative endodontic cavities) OR TITLE-ABS-KEY(conservative endodontic access cavities) OR TITLE-ABS-KEY(conservative endodontic access cavity) OR TITLE-ABS-KEY(minimally invasive preparation) OR TITLE-ABS-KEY(minimal endodontic treatment intervention) OR TITLE-ABS-KEY(minimally invasive endodontics) OR TITLE-ABS-KEY(minimally-invasive intervention)	2,697
	#2 TITLE-ABS-KEY(Stress Fracture) OR TITLE-ABS-KEY(fatigue) OR TITLE-ABS-KEY(fracture resistance) OR TITLE-ABS-KEY(resistance to fracture) OR TITLE-ABS-KEY(fracture strength) OR TITLE-ABS-KEY(biomechanical responses)	101,505
	# 1 and # 2	**57**
Scopus	**#1** TITLE-ABS-KEY(dental pulp cavity) OR TITLE-ABS-KEY(endodontic cavity) OR TITLE-ABS-KEY(endodontic access) OR TITLE-ABS-KEY(endodontic access cavity) OR TITLE-ABS-KEY(access cavity designs) OR TITLE-ABS-KEY(access cavity preparation) OR TITLE-ABS-KEY(traditional endodontic cavities) OR TITLE-ABS-KEY(traditional endodontic cavity) OR TITLE-ABS-KEY(traditional endodontic access cavities) OR TITLE-ABS-KEY(traditional endodontic access cavity) OR TITLE-ABS-KEY(contracted endodontic access cavities) OR TITLE-ABS-KEY(contracted endodontic access cavity) OR TITLE-ABS-KEY(contracted endodontic cavity) OR TITLE-ABS-KEY(contracted endodontic cavities) OR TITLE-ABS-KEY(conservative endodontic cavity) OR TITLE-ABS-KEY(conservative access cavity) OR TITLE-ABS-KEY(conservative endodontic cavities) OR TITLE-ABS-KEY(conservative endodontic access cavities) OR TITLE-ABS-KEY(conservative endodontic access cavity) OR TITLE-ABS-KEY(minimally invasive preparation) OR TITLE-ABS-KEY(minimal endodontic treatment intervention) OR TITLE-ABS-KEY(minimally invasive endodontics) OR TITLE-ABS-KEY(minimally-invasive intervention)	21,087
	#2 TITLE-ABS-KEY (stress AND fracture) OR TITLE-ABS-KEY (fatigue) OR TITLE-ABS-KEY (fracture AND resistance) OR TITLE-ABS-KEY (resistance AND to AND fracture) OR TITLE-ABS-KEY (fracture AND strength) OR TITLE-ABS-KEY (biomechanical AND responses)	543,276
	#1 and #2	**461**
Web of Science	**#1** TS=(“dental pulp cavity” OR “endodontic cavity” OR “endodontic access” OR “endodontic access cavity” OR “ access cavity designs” OR “access cavity preparation” OR “traditional endodontic cavities” OR “traditional endodontic cavity”	2,595

	OR "traditional endodontic access cavities" OR "traditional endodontic access cavity" OR "contracted endodontic access cavities" OR "contracted endodontic access cavity" OR "contracted endodontic cavity" OR "contracted endodontic cavities" OR "conservative endodontic cavity" OR "conservative access cavity" OR "conservative endodontic cavities" OR "conservative endodontic access cavities" OR "conservative endodontic access cavity")	
	#2 TS=("Stress Fracture" OR "fatigue" OR "fracture resistance" OR "resistance to fracture" OR "fracture strength" OR "biomechanical responses")	200,710
	#1 and #2	**159**
Open grey - SIGLE	**#1** dental pulp cavity OR endodontic cavity OR endodontic access OR endodontic access cavity OR access cavity designs OR access cavity preparation OR traditional endodontic cavities OR traditional endodontic cavity OR traditional endodontic access cavities OR traditional endodontic access cavity OR contracted endodontic access cavities OR contracted endodontic access cavity OR contracted endodontic cavity OR contracted endodontic cavities OR conservative endodontic cavity OR conservative access cavity OR conservative endodontic cavities OR conservative endodontic access cavities OR conservative endodontic access cavity	9
	#2 Stress Fracture OR fatigue OR fracture resistance OR resistance to fracture OR fracture strength OR biomechanical responses	5,255
	# 1 and #2	**0**

ANEXO C – Parecer do Comitê de Ética em Pesquisa

PARECER CONSUBSTANCIADO DO CEP

DADOS DO PROJETO DE PESQUISA

Título da Pesquisa: Impacto das cavidades de acesso minimamente invasivas nos outcomes do tratamento endodôntico

Pesquisador: CLEONICE DA SILVEIRA TEIXEIRA

Área Temática:

Versão: 1

CAAE: 99352818.4.0000.0121

Instituição Proponente: Universidade Federal de Santa Catarina

Patrocinador Principal: Financiamento Próprio

DADOS DO PARECER

Número do Parecer: 2.985.969

Apresentação do Projeto:

Trata-se de um Projeto de Tese de doutorado orientado pela profa. Cleonice da Silveira Teixeira vinculado ao Programa de Pós-graduação em Odontologia que pretende investigar o impacto de acesso minimamente invasivas nos outcomes do tratamento endodontico. Os dentes molares serão utilizados após retirada por motivos desvinculados da pesquisa e serão doados pelos participantes após assinatura do TCLE e do Termo de doação dos dentes.

Objetivo da Pesquisa:

Objetivo Primário:

Substanciar cientificamente as teorias estabelecidas a respeito da efetividade dos diferentes tipos de acessos endodônticos minimamente invasivos.

Objetivo Secundário:

Revisar sistematicamente a literatura e responder a seguinte questão: o acesso endodôntico minimamente invasivo aumenta a resistência à fratura de dentes humanos extraídos comparados ao acesso endodôntico tradicional? Avaliar a influência da localização e design da cavidade de acesso endodôntica na eficácia da instrumentação, qualidade da obturação e resistência à fratura de incisivos inferiores;Determinar o impacto do acesso endodôntico minimamente invasivos em molares inferiores.Determinar o impacto do acesso endodôntico
minimamente invasivos em molares inferiores.

Avaliação dos Riscos e Benefícios:

Riscos:

Não há riscos diretos relacionados ao estudo, apenas riscos inerentes aos procedimentos da extração dentária que não serão realizadas pelos executores da pesquisa. Porém, acrescentamos que, apesar dos esforços e das providências necessárias tomadas pelos pesquisadores, sempre existe a remota possibilidade de quebra de sigilo, ainda que involuntária e não intencional.

Benefícios:

O fato de poder contribuir para a melhora do procedimento de abertura coronária realizada durante o tratamento endodôntico a partir da doação voluntária do seu dente para esta pesquisa.

Comentários e Considerações sobre a Pesquisa:

Pesquisa adequadamente delineada e fundamentada. procedimentos metodológicos descritos e claros. Documentação adequada a tramitação.

Considerações sobre os Termos de apresentação obrigatória:

TCLE adequado a resolução 466/2012. Termo de doação incluso no processo de tramitação.

Recomendações:

sem recomendações.

Conclusões ou Pendências e Lista de Inadequações:

Conclusão: aprovado.

Considerações Finais a critério do CEP:

Este parecer foi elaborado baseado nos documentos abaixo relacionados:

Tipo Documento	Arquivo	Postagem	Autor	Situação
Informações Básicas do Projeto	PB_INFORMAÇÕES_BÁSICAS_DO_PROJETO_1222804.pdf	20/09/2018 22:10:39		Aceito
Projeto Detalhado / Brochura Investigador	Projeto.pdf	20/09/2018 22:09:32	Gabriela Rover	Aceito
TCLE / Termos de Assentimento / Justificativa de Ausência	TCLE.pdf	20/09/2018 14:44:29	Gabriela Rover	Aceito
Declaração de Instituição e Infraestrutura	DeclaracaoInstituicao.pdf	20/09/2018 14:43:24	Gabriela Rover	Aceito

Folha de Rosto	FolhaDeRosto.pdf	20/09/2018 14:42:54	Gabriela Rover	Aceito

Situação do Parecer:
Aprovado

Necessita Apreciação da CONEP:
Não

FLORIANOPOLIS, 28 de Outubro de 2018

Assinado por:
Maria Luiza Bazzo
(Coordenador(a))