UNIVERSIDADE FEDERAL DO RIO GRANDE DO SUL
FACULDADE DE ODONTOLOGIA

NATÁLIA BACKA ABRAHÃO

INFLUÊNCIA DA TÉCNICA OBTURADORA NA QUALIDADE DE OBTURAÇÕES AVALIADAS POR MICRO-CT: UMA REVISÃO SISTEMÁTICA

Porto Alegre

2021

NATÁLIA BACKA ABRAHÃO

INFLUÊNCIA DA TÉCNICA OBTURADORA NA QUALIDADE DE OBTURAÇÕES AVALIADAS POR MICRO-CT: UMA REVISÃO SISTEMÁTICA

Trabalho de Conclusão de Curso apresentado ao Curso de Graduação em Odontologia da Faculdade de Odontologia da Universidade Federal do Rio Grande do Sul como requisito parcial para obtenção do título de Cirurgiã-Dentista.

Orientador: Ricardo Abreu da Rosa

Porto Alegre

2021

NATÁLIA BACKA ABRAHÃO

INFLUÊNCIA DA TÉCNICA OBTURADORA NA QUALIDADE DE OBTURAÇÕES AVALIADAS POR MICRO-CT: UMA REVISÃO SISTEMÁTICA

Trabalho de Conclusão de Curso apresentado ao Curso de Graduação em Odontologia da Faculdade de Odontologia da Universidade Federal do Rio Grande do Sul como requisito parcial para obtenção do título de Cirurgiã-Dentista.

Orientador: Ricardo Abreu da Rosa

Porto Alegre, 20 de Maio de 2021.

Prof. Dr. Ricardo Abreu da Rosa

Universidade Federal do Rio Grande do Sul

Prof. Dr. Marcus Vinícius Reis Só

Universidade Federal do Rio Grande do Sul

Profª. Drª. Tathiane Larissa Lenzi

Universidade Federal do Rio Grande do Sul

Aos meus pais, Paulo e Angela, pelo apoio incondicional em todos os momentos da minha trajetória acadêmica;

À minha avó Terezinha Abrahão e à minha tia Rose Machado (em memória), grandes incentivadoras da minha carreira na odontologia, que infelizmente não puderam acompanhar a conclusão desta etapa.

AGRADECIMENTOS

Aos meus pais, Paulo e Angela Abrahão, por terem me ensinado desde cedo a importância dos estudos. Obrigada por sempre acreditarem nos meus sonhos e não medir esforços para me ajudar a realizá-los. O cuidado e incentivo de vocês me deram força para sempre seguir lutando por meus objetivos e a presença e apoio incondicional me proporcionaram a certeza de que eu não estava sozinha nesta trajetória. Ainda a eles e ao restante da minha família, por serem meus maiores fãs e por acreditarem que eu sou a melhor dentista do mundo, mesmo antes de formada.

Às minhas amigas e colegas de graduação, Ana Laura Machado (minha dupla ao longo destes anos), Bárbara Stefanello, Bianca Balbinot, Helena Scherer, Liliana Wolf e Paola Bainy, por terem dividido comigo desde os momentos de nervosismo pré-provas e inseguranças nos primeiros atendimentos, até as festas da SEMAC, viagens e verões que passamos juntas. Tudo foi muito mais fácil e leve quando estávamos apoiando umas às outras. Não teria sido tão especial, nem tão divertido, sem a presença de vocês.

Às minhas amigas da época da escola, Natália Silveira e Victória Rechden, pela compreensão quando tive que recusar convites porque tinha que realizar minhas atividades acadêmicas, por torcerem sempre por mim (desde os presentes na véspera do ENEM) e vibrarem com cada uma das minhas conquistas. Tenho em vocês um porto-seguro.

Aos meus colegas de Iniciação Científica, Charles Dall Agnol Jr. e Giovana Siocheta, e aos pós-graduandos, Igor de Bem, Gabriel Só e Theodoro Weissheimer, por terem dividido seus conhecimentos comigo e me apoiado no desenvolvimento das pesquisas acadêmicas. Foi muito importante ter com quem dividir as tardes no LABENDO e a ansiedade com a aproximação da entrega do TCC.

Ao meu orientador Ricardo Abreu da Rosa, por ter me aceitado como aluna de Iniciação Científica desde o 6º semestre da graduação. Obrigada por acreditar e investir em mim, mesmo quando eu duvidava, e por todo conhecimento que teve a generosidade de me passar, sempre de forma leve, próxima e paciente. Tu és para mim um exemplo de profissional e professor, que coloca dedicação e amor em tudo o que faz. Obrigada por estar sempre disponível para responder minhas milhares de dúvidas e por ser palavra que conforta e tranquiliza.

Ao professor Marcus Vinicius Reis Só, por aceitar contribuir com o meu trabalho, participando como membro da banca examinadora e por sempre me receber com alegria e entusiasmo nas atividades do time da endodontia.

À professora Tathiane Lenzi, por ter me apresentado o mundo encantado e cheios de desafios da Odontopeadiatria; por ter me ensinado que nenhum problema é tão grande que não possa ser resolvido com carinho, empatia e tranquilidade. Obrigada por aceitar fazer parte da banca examinadora e contribuir com o meu trabalho.

Aos meus preceptores de estágio, por terem dividido seus conhecimentos e experiências comigo e sempre confiarem em meu trabalho; e a toda a equipe da US Tristeza e da Clínica Médica-Odontológica da Brigada Militar, por terem me recebido com tanta generosidade e alegria.

Aos pacientes que tive a oportunidade de atender durante minha graduação, por terem confiado em mim e dividido comigo um pouco das suas histórias e rotina. Lembrarei sempre de vocês com muito carinho.

A todos os professores, técnicos e funcionários da Faculdade de Odontologia, que compartilharam este espaço tão especial ao longo destes anos de formação.

À Unidade Federal do Rio Grande do Sul por ter me oportunizado uma formação de excelência e me capacitado como cidadã. Tenho muito orgulho de ter feito parte desta instituição.

RESUMO

Esta revisão sistemática teve como objetivo investigar a influência da técnica obturadora na qualidade de obturações avaliadas por microtomografia computadorizada (micro-CT). A busca bibliográfica foi realizada em seis bases de dados eletrônicas (PubMed, Cochrane, Scopus, Web of Science, EMBASE e Open Gray). A estratégia de busca foi desenvolvida usando *MeSH terms* e *text words* (tw.), combinando os seguintes termos: 'Root canal filling', 'Root canal obturation', 'Obturation technique', 'Root canal filling technique', 'Dentin penetration', 'Tubule penetration', 'Gaps', 'Voids', 'Empty space', 'MicroCT', 'Micro-CT', 'Microcomputed tomography'. Os critérios de elegibilidade, com base na estratégia PIO, foram: (P) estudos *ex vivo* que usaram micro-CT para analisar a qualidade da obturação dos canais radiculares; (I) obturação de canais radiculares utilizando diferentes técnicas; (O) qualidade da obturação (presença de espaços vazios, gaps e penetração na dentina tubular). O risco de viés (RoB) dos estudos incluídos foi avaliado por meio de uma adaptação baseada em revisões sistemáticas anteriores. A busca inicial nas bases de dados resultou em 249 estudos. Cento e quarenta e oito estudos foram excluídos por estarem duplicados. Dos 101 estudos elegíveis, 31 preencheram os critérios de inclusão e foram selecionados para leitura completa. Dois estudos foram excluídos pois avaliavam material reparador (MTA). Vinte e nove estudos foram incluídos para análise, treze apresentaram alto risco de viés, quatorze moderado e apenas dois apresentaram baixo risco de viés. Nenhuma das técnicas de obturação apresentou-se livre de bolhas ou *gaps*. Quatro estudos relataram mais bolhas ao usar a técnica de cone único e dez relataram que a compactação lateral a frio apresentou um alto número de bolhas. Cinco estudos relataram menor porcentagem de bolhas usando carreadores de guta-percha, três apresentaram a compactação vertical a quente com menor prevalência de *gaps* e bolhas e dois relataram baixa porcentagem de bolhas associada à técnica termoplastificada injetável. Esta revisão sistemática mostrou que nenhuma técnica obturadora executada em dentes extraídos e avaliada por micro-CT é livre de bolhas ou *gaps*.

Esta revisão sistemática foi registrada no banco de dados PROSPERO (CRD42021235037).

Palavras-Chave: Endodontia. Obturação do canal radicular. Micro-CT. Revisão sistemática.

ABSTRACT

This systematic review aimed to investigate the influence of the filling technique on the quality of fillings evaluated by computerized microtomography (micro-CT). The bibliographic search was carried out in six electronic databases (PubMed, Cochrane, Scopus, Web of Science, EMBASE and Open Gray). The search strategy was developed using MeSH terms and text words (tw.), combining the following terms: ‘Root canal filling’, ‘Root canal obturation’, ‘Obturation technique’, ‘Root canal filling technique’, ‘Dentin penetration’, ‘Tubule penetration’, ‘Gaps’, ‘Voids’, ‘Empty space’, ‘MicroCT’, ‘Micro-CT’, ‘Microcomputed tomography’. The eligibility criteria, based on the PIO strategy, were: (P) ex vivo studies that used micro-CT to analyze the root canal filling quality; (I) root canal filling using different techniques; (O) quality of the filling (presence of empty spaces, gaps and penetration into the tubular dentin). The risk of bias (RoB) of the included studies was assessed through an adaptation based on previous systematic reviews. The initial search of the databases resulted in 249 studies. One hundred and forty-eight studies were excluded because they were duplicated. Of the 101 eligible studies, 31 met the inclusion criteria and were selected for full reading. Two studies were excluded because they evaluated repair material (MTA). Twenty-nine studies were included for analysis, thirteen were at high risk of bias, fourteen were moderate and only two were at low risk of bias. Four studies reported more voids when using single cone technique and ten reported that cold lateral compaction showed a high number of voids. Five studies reported lower percentage of voids using carrier-based gutta-percha, three presented warm vertical compaction with lower prevalence of gaps and voids and two reported low percentage of voids associated with the thermoplastic injectable technique. This systematic review showed that any obturation technique performed in extracted teeth and assessed by micro-CT is void or gap-free.

This systematic review was registered on the PROSPERO database (CRD42021235037).

Keywords: Endodontics. Root canal filling. Micro-CT. Systematic review.

SUMÁRIO

1 INTRODUÇÃO

O objetivo principal do tratamento endodôntico é a diminuição significativa de microrganismos e seus produtos em polpas não vitais através da combinação da instrumentação do sistema de canais radiculares, associada à limpeza química e posterior obturação com um material inerte (NG *et al.*, 2007). Esta etapa final do tratamento, que consiste na obturação dos canais radiculares, visa um preenchimento tridimensional e compacto, oferecendo condições de reparo dos tecidos perirradiculares (MARTINS *et al.*, 2011).

O sucesso do tratamento endodôntico tem natureza multifatorial, ou seja, o sucesso clínico deste tipo de tratamento depende de vários fatores, incluindo o conhecimento da morfologia do canal radicular e todo o processo desde o acesso a câmara pulpar e instrumentação até a conclusão da obturação e a restauração do dente tratado endodonticamente (KALENDER *et al.*, 2013). Canais radiculares não tratados, obturação pouco compactada, sobreobturação ou preenchimento insuficiente dos canais radiculares (mais de 2mm aquém do ápice radicular) podem ser identificados como possíveis razões para o insucesso do tratamento (BÜRKLEIN *et al.*, 2020).

Portanto, é possível afirmar que a qualidade da obturação radicular interfere no prognóstico para o dente tratado endodonticamente (KIRKEVANG; HØRSTED-BINDSLEV, 2002). O desejado é que a obturação seja o mais compacta possível, na tentativa de isolar microrganismos remanescente e prevenir novo crescimento microbiano, evitando alterações inflamatórias periapicais subsequentes. Quando inadequada, a obturação está associada com aumento da taxa de periodontite apical (BÜRKLEIN *et al.*, 2020).

No entanto, a realização adequada desta etapa do tratamento depende de uma adequada limpeza e modelagem do sistema de canais radiculares (KALENDER *et al.*, 2013) e é desafiada por vários fatores, como a complexa anatomia dos sistemas de canais radiculares que interfere no escoamento dos materiais obturadores pelas irregularidades dos canais radiculares, podendo resultar em um preenchimento deficiente, gerando espaços vazios dentro da massa obturadora (bolhas) e na interface entre a obturação e a dentina (*gaps*) (GILLEN *et al.*, 2011). Além disso, a técnica obturadora empregada e as propriedades dos materiais utilizados nesta etapa do tratamento, especialmente os cimentos endodônticos, influenciam na qualidade final da obturação (HAMMAD;

QUALTROUGH; SILIKAS, 2009; JAWORSKA; KIERKLO, 2016).

Visto que o volume de espaços vazios e *gaps* na obturação pode comprometer o sucesso do tratamento endodôntico, esses parâmetros devem ser considerados para determinar a qualidade dos materiais e técnicas obturadoras empregadas (WU *et al.*, 2003). Na Endodontia, a microtomografia computadorizada (micro-CT) tem sido usada para avaliação da anatomia interna dos dentes, da morfologia dos canais após preparo químico-mecânico e para qualificar a obturação dos canais radiculares (VERSIANI; PÉCORA; DE SOUSA-NETO, 2012). Em comparação com técnicas de imagem convencionais, como microscopia eletrônica de varredura, microscopia confocal e estereomicroscopia, a micro-CT oferece vantagens, incluindo as reconstruções 3D da amostra sem o requisito de seccioná-las e a possibilidade de digitalização repetida e manipulação de imagem usando softwares específicos (JUNG; LOMMEL; KLIMEK, 2005; KIERKLO *et al.*, 2014). Com isso, ao longo dos anos, diferentes técnicas de obturação foram propostas e vem sendo avaliadas em estudos *ex vivo* para avaliar a qualidade da obturação através de micro-CT (HO; CHANG; CHEUNG, 2016; LI, J. *et al.*, 2020; ROIZENBLIT *et al.*, 2019; SOMMA *et al.*, 2011).

A condensação lateral a frio é uma das técnicas mais conhecidas e utilizadas entre os cirurgiões-dentistas e consiste na colocação de cones de guta-percha auxiliares lateralmente a um cone principal associado ao uso de um cimento obturador. Contudo, esta técnica foi relacionada a obturações pouco homogêneas, ou seja, com grandes quantidades de cimento endodôntico e problemas com a capacidade de selamento apical (DE-DEUS *et al.*, 2008b; PENG *et al.*, 2007). Como uma tentativa de solucionar esses problemas, foram desenvolvidas técnicas de obturação com guta-percha termoplastificada, à medida que a guta-percha é aquecida, ela se torna mais plástica e se adapta melhor às irregularidades do sistema de canais radiculares (DE-DEUS *et al.*, 2008a).

Na técnica desenvolvida por McSpadden, preconizava-se a compactação da guta-percha por meio do calor desenvolvido pela rotação de um compactador com uma aparência semelhante a uma lima Hedstroem invertida (BEATTY; VERTUCCI; HOJJATIE, 1988; GILHOOLY *et al.*, 2001). Já na técnica híbrida de Tagger, foi proposta uma associação entre a técnica de condensação lateral e a técnica de compactação termomecânica de McSpadden, combinando o uso do compactador de McSpadden e um cone de guta-percha principal bem adaptado à porção apical, atuando como uma barreira para minimizar o extravasamento de material obturador (TAGGER *et al.*, 1984).

A técnica da compactação vertical a quente consiste em preencher o espaço do canal radicular com guta-percha termoplastificada com o uso de um transportador de calor e uma fina camada de cimento, que posteriormente são condensados apicalmente com um condensador a frio (DE-DEUS *et al.*, 2008b). Entretanto, estes tipos de técnicas de obturação podem ser associadas à risco de extravasamento de material e formação de vazios e lacunas ao longo da obturação, visto que quando aquecida, a guta-percha se expande e durante o resfriamento se contrai (MOELLER *et al.*, 2013; PENG *et al.*, 2007).

Técnicas injetáveis termoplastificadas foram introduzidas para melhorar a homogeneidade e a adaptação da guta-percha à superfície. Sistemas como Obtura II (Obtura Spartan, Fenton, MI, EUA) e Gutta Flow (Coltene/Whaledent, Altstätten, Suíça) foram desenvolvidos com o objetivo de superar as falhas de extrusão apical e encolhimento na condensação termoplastificada (ELDEEB, 1985; ÖZOK *et al.*, 2008). Já na técnica de obturação por termoplastificação não injetável, a guta-percha do tipo alfa é depositada em carreadores especiais (LI *et al.*, 2014) . Nesse método, a forma alfa de guta-percha, rígida em temperatura ambiente, torna-se viscosa e pegajosa em temperaturas mais altas (MARCIANO; MICHAILESCO, 1989; MARLIN; SCHILDER, 1973) e mais adaptável ao carreador e às paredes dentinárias (SHIPPER *et al.*, 2004). Os fabricantes de sistemas obturadores como GuttaCore (Dentsply Tulsa Dental Specialties, Tulsa, OK, EUA) e Thermafil (Dentsply Tulsa Dental Specialties), que utilizam este método de termoplastificação, afirmam que estes dispositivos aumentam a compressão da guta-percha contra as paredes do canal radicular e o fluxo do material obturador para os canais laterais (KABINI *et al.*, 2018).

O Sistema de condensação em ondas contínuas é comumente considerado uma das técnicas de obturação radicular mais eficazes (GOLDBERG; ARTAZA; DESILVIO, 2001; KECECI; CELIK UNAL; SEN, 2005), mas também é percebido como um método desafiador e que apresenta uma curva de aprendizado relativamente alta (MIRFENDERESKI *et al.*, 2009). A técnica consiste no posicionamento do cone principal com cimento obturador e introdução de um condensador conectado a um gerador de calor para plastificar a guta-percha apical (SOMMA *et al.*, 2011). Alguns autores afirmam que este método poderia gerar considerável tensão vertical e lateral, o que poderia aumentar o risco de fratura do dente em questão (BLUM; MACHTOU; MICALLEF, 1998; SHEMESH; WESSELINK; WU, 2010).

Dispositivos ultrassônicos, equipamentos comuns em consultórios odontológicos modernos, também podem ser utilizados para auxiliar na obturação de canais radiculares. Quando operado a seco, o calor de fricção gerado por um instrumento de ultrassom pode ser usado para plastificar a guta-percha durante a obturação (HO; CHANG; CHEUNG, 2016). Alguns estudos mostraram que a obturação usando energia ultrassônica produz boa adaptação da guta-percha às irregularidades da superfície do canal com menos espaços vazios (BAILEY *et al.*, 2004; DEITCH *et al.*, 2002).

As técnicas de obturação com guta-percha termoplastificada têm sido relatadas como vantajosas para o tratamento de canais radiculares irregulares (CELIKTEN *et al.*, 2016), enquanto a técnica de cone único ganhou popularidade por ser considerada de fácil aplicação, curto tempo de procedimento e baixo custo (CAVENAGO *et al.*, 2012). Neste método, o cone de guta-percha atua apenas como um transportador e caminho para o retratamento, sendo o sistema de canais sendo preenchido predominantemente pelo cimento endodôntico. Além disso, é uma técnica menos dependente do operador e que potencialmente reduz os danos às paredes dentinárias (KO *et al.*, 2020), entretanto, pode deixar vários vazios em canais de formato irregular (KIM *et al.*, 2018).

Percebendo a importância da qualidade da obturação para o sucesso do tratamento endodôntico e as vastas opções de diferentes técnicas obturadoras descritas na literatura atualmente, o objetivo desta revisão sistemática de literatura é responder a seguinte pergunta: “A técnica obturadora influencia na qualidade de obturações avaliadas por micro-CT?”.

2 OBJETIVOS

2.1 Objetivo Geral

Avaliar as evidências científicas disponíveis referentes as diferentes técnicas obturadoras e sua influência na qualidade de obturações avaliadas por Micro-CT.

2.2 Objetivos Específicos

Verificar e avaliar as evidências científicas que tenham verificado as diferentes técnicas obturadoras e sua influência na qualidade de obturações de dentes extraídos analisados em micro-CT quanto ao risco de viés e o nível de qualidade de evidência cientifica encontrada.

3 ARTIGO CIENTÍFICO

Este artigo será submetido no periódico International Endodontic Journal, e portanto, está formatado segundo as normas da revista.

ABSTRACT

Background Due to the importance of the quality of root canal filling for the success of the endodontic treatment and the various techniques described in the literature, the volume of gaps and voids in root canal fillings should be considered when determining the efficiency and quality of a filling material or technique, since these aspects can compromise the treatment's success rate.

Objectives To evaluate the scientific evidence available by analyzing the different filling techniques and their influence on the quality of root canal filling evaluated by micro-CT.

Methodology A systematic search of articles published until December 2020 was performed using MeSH and text words in the PubMed, Cochrane Library, LILACS, SciELO, Web of Science, EMBASE, Open Grey, and Grey Literature databases. The search strategy was developed using MeSH terms and text words (tw.). The eligibility criteria, based on the PIO strategy, were: (P) ex vivo studies that used micro-CT to analyze the root canal filling quality; (I) root canal filling using different techniques; (O) quality of the filling (presence of empty spaces, gaps and sealer penetration into the tubular dentin). The risk of bias (RoB) of the included studies was assessed through an adaptation based on previous systematic reviews. Relevant findings were summarized and evaluated. The overall quality of evidence was assessed through the Grading of Recommendations Assessment, Development, and Evaluation (GRADE) tool.

Results The initial search of the databases resulted in 249 studies. One hundred and forty-eight studies were excluded because they were duplicated. Of the 101 eligible studies, 31 met the inclusion criteria and were selected for full reading. Two studies were excluded because they evaluated repair material (MTA). Twenty-nine studies were included for analysis, thirteen were at high risk of bias, fourteen were moderate and only two were at low risk of bias. Four studies reported more voids when using single cone technique and ten reported that cold lateral compaction showed a high number of voids. Five studies reported lower percentage of voids using carrier-based gutta-percha, three presented warm vertical compaction with lower prevalence of gaps and voids and two reported low percentage of voids associated with the thermoplastic injectable technique.

Conclusions This systematic review showed that any obturation technique performed in extracted teeth and assessed by micro-CT is void or gap-free.

INTRODUCTION

Root canal treatment aims to eliminate vital or necrotic tissues, bacteria and endotoxins from the canal system and fill this space with gutta-percha and endodontic sealers (Azim *et al.* 2016). Root canal filling prevents bacterial migration and proliferation into the canals or periodontium (Kalender *et al.* 2013), ensuring a higher success rate of the treatment (Kirkevang & Hørsted-Bindslev 2002, Tavares *et al.* 2009).

To achieve a successful obturation, physicochemical properties of the filling materials (sealers and core material) and the obturation technique must be taken into consideration. Gutta-percha has been used since the late 1800s as an inert core material for filling root canal spaces in conjunction with different sealers. Sealers are used to fill root canal complexities, such as dentinal tubules, ramifications, and isthmus, that are not filled by gutta-percha (Cruse & Bellizzi 1980).

However, an adequate obturation of the root canal system involves several challenges, as the complex root canal anatomy, that interferes with the adherence and the homogeneity of the filling materials. Poor adhesion may create voids in the interface between filling material and dentin, which facilitates bacterial movement toward the apical third of the root, potentially leading to apical periodontitis (Gillen *et al.* 2011). Thus, the volume of gaps and voids in root canal fillings should be considered when determining the efficiency and quality of a filling material or technique, since these can compromise the treatment's success rate (Wu *et al.* 2003).

Micro-computed tomography (micro-CT) analysis has been used in endodontics to determine the area and volume of root canals in extracted teeth (Oi *et al.* 2004, Peters *et al.* 2000), to assess the efficiency of root canal preparation techniques (Gambill *et al.* 1996, Peters *et al.* 2003) and more recently, to determine the quality of the root canal filling (Celikten *et al.* 2015, Ho *et al.* 2016).

In comparison with conventional imaging techniques, such as scanning electron microscopy, confocal microscopy and stereomicroscopy, micro-CT offers several advantages, including a non-invasive three-dimensional reconstruction method, the existence *softwares* that highlight porosities, material, and interface defects in high details, as well as the relative facility in handling the equipment and *software* (Jung *et al.* 2005, Rodrigues *et al.* 2009).

Several filling techniques have been proposed and evaluated in ex-vivo studies, such as cold lateral compaction (Jaworska *et al.* 2015, Simsek *et al.* 2017, Suassuna *et al.* 2018), warm vertical compaction (Alshehri *et al.* 2016, Ko *et al.* 2020, Naseri *et al.* 2013), Tagger's hybrid technique (Martins *et al.* 2011, Nhata *et al.* 2014), single-cone technique (Alim; & Berker 2020, Ko *et al.* 2020, Suassuna *et al.* 2018), thermoplastic compaction (Jaworska & Kierklo 2016, Kierklo *et al.* 2014), carrier-based gutta-percha technique (Kabini *et al.* 2018, Martins *et al.* 2011, Zogheib *et al.* 2013) and ultrasonic activation of the sealer previously to obturation (Alcalde *et al.* 2017, Guimarães *et al.* 2014).

Due to the importance of the quality of root canal filling for the success of the endodontic treatment (Azim *et al.* 2016, Tavares *et al.* 2009) and the various techniques described in the literature (Alcalde *et al.* 2017, Alim & Berker 2020, Kierklo *et al.* 2014, Ko *et al.* 2020, Martins *et al.* 2011, Nhata *et al.* 2014, Suassuna *et al.* 2018), the aim of this systematic review was to evaluate the scientific evidence available by analyzing the different filling techniques and their influence on the quality of root canal filling evaluated by Micro-CT and to answer the following research question: "Does the obturation technique influences the filling quality of teeth?".

MATERIAL AND METHODS

This systematic review was registered in the PROSPERO database (CRD42021235037) and was developed following Preferred Reporting Items for Systematic Review and Meta-Analysis (PRISMA) recommendations (http://www prisma-statement.org).

Literature Search

The literature search was conducted in six electronic databases (PubMed, Cochrane, Scopus, Web of Science, EMBASE and Open Grey). The search included articles published until December 2020 without language or year restriction and were performed by two independent reviewers (N.B.A and G.B.S). The search strategy was developed using Medical Subject Heading (MeSH) terms and text words (tw.), combining the following terms: “Root canal filling”; “Root canal obturation”; “Obturation technique”; “Root canal filling technique”; “Dentin penetration”; “Tubule penetration”; “Gaps”; “Voids”; “Empty spaces”; “MicroCT”; “Micro-CT”; “Microcomputed tomography”. The Boolean operators “AND" and “OR” were applied to combine the terms and create the search results.

The search strategies for each database and findings are presented in **Supplementary File 1.** All articles selected were imported into Zotero reference manager to catalogue references and exclude duplicates.

Eligibility criteria

The eligibility criteria were performed using PIO strategy (PRISMA-P 2015) (Leong *et al.* 2020, Moher *et al.* 2015, Pérez-González *et al.* 2020) following this scheme:

* Population (P): extracted teeth
* Intervention (I): root canal filling with different obturation techniques
* Outcome (O): filling quality (presence of voids and gaps or empty spaces, dentin and tubule penetration)

Only ex-vivo studies that evaluated extracted teeth filled with different obturation techniques by micro-computed tomography.

Studies in animal models, randomized and non-randomized studies, systematic reviews with and without meta-analysis, literature reviews, longitudinal studies, opinion articles, letters, conference resumes, case reports, series of cases and ex vivo studies evaluating the quality of root canal filling by methods other than micro-computed tomography were excluded.

Selection of studies

Two authors (N.B.A. and G.B.S.) were responsible for selection of studies and examining the retrieved titles and abstracts of the selected studies. Duplicates were identified and excluded. When it was not possible to judge the studies by title and abstract, the full text was assessed.

The next stage consisted of reading the full texts based on the eligibility criteria through the PIO strategy. In case of disagreement of study inclusion, a third experienced author (T.W.) assessed the study.

Data extraction

Two authors (N.B.A. and G.B.S.) independently collected the data from the included studies. Disagreements were solved by a third author (T.W.). The following data were extracted: name of author(s); year of publication; sample size; group of teeth, root canal preparation technique; obturation technique; micro-CT scan parameters; evaluated parameters; outcomes; and main findings. In cases of missing data, the authors were contacted by email at least three times.

Risk of bias

Due to the absence of a specific tool to evaluate the risk of bias in ex vivo studies, risk of bias of the included studies was evaluated using an adaptation based on previous systematic reviews (Gorman *et al.* 2016, Silva *et al.*, 2018).

The following parameters were assessed:

* Description of sample size calculation;
* Selection and pairing of samples by micro-CT;
* Description of micro-CT parameters:
    - The following were considered: Description of the device used, kV, mA/uA, voxel/pixel size, rotation angle, rotation step, exposure time, filters and/or corrections;
* Description of obturation technique:
    - The following were considered: Description of the endodontic sealer, description of the core material, description of the obturation technique;
* Blinding of evaluators;

* Description of statistical analysis.

Each included study was judged with “yes” when parameters were founded, and “no" in case of parameters absence. In studies presenting partial data, authors were contacted at least three times by e-mail. If data was not possible to be achieved, parameters presenting partial data were judged as “no”. Articles with only one or two parameters were classified as high risk of bias; three or four parameters as moderate risk of bias; and five or more parameters, low risk of bias. Two authors (N.B.A. and G.B.S) evaluated independently the methodological quality of each study and a third author (T.W.) validated analysis.

RESULTS

Study Selection

Figure 1 presents the flow diagram of the search strategy. Initial identification through database searching resulted in 259 studies, in which 148 were excluded as they were duplicates. 31 records were selected after title and abstract reading (Alhashimi *et al.* 2016, Alim & Berker 2020, Alshehri *et al.* 2016, Angerame *et al.* 2012, Başer Can *et al.* 2016, Castagnola *et al.* 2018, Celikten *et al.* 2015, El-Ma’aita *et al.* 2012, Ho *et al.* 2016, Iglecias *et al.* 2017, Jaworska & Kierklo 2016, Kabini *et al.* 2018, Keleş *et al.* 2014, Keleş *et al.* 2017, Keleş & Keskin 2019, Kierklo *et al.* 2014, Ko *et al.* 2020, Li *et al.* 2014, Li *et al.* 2020, Martins *et al.* 2011, Mirfendereski *et al.* 2009, Moeller *et al.* 2013, Moinzadeh *et al.* 2015, Naseri *et al.* 2013, Nhata *et al.* 2014, Roizenblit *et al.* 2019, Selem *et al.* 2014, Simsek *et al.* 2017, Somma *et al.* 2011, Suassuna *et al.* 2018, Zogheib *et al.* 2012). After full text reading, two studies were excluded for having used MTA as an endodontic sealer (El-Ma’aita *et al.* 2012, Keleş *et al.* 2017). Therefore, twenty-nine studies were included for final analysis.

Data extraction

Table 1 presents the characteristics and main findings of the included studies.

The corresponding author of the studies with insufficient data were contacted by e-mail, but no additional information was obtained.

Regarding the group of teeth, eight studies used only mandibular molars (Alim & Berker 2020, Alshehri *et al.* 2016, Ho *et al.* 2016, Iglecias *et al.* 2017, Keleş & Keskin 2019, Martins *et al.* 2011, Roizenblit *et al.* 2019, Simsek *et al.* 2017), one study used maxillary molars (Naseri *et al.* 2013), nineteen studies used only single rooted teeth (Alhashimi *et al.* 2016, Angerame *et al.* 2012, Başer Can *et al.* 2016, Castagnola *et al.* 2018, Celikten *et al.* 2015, Jaworska & Kierklo 2016, Kabini *et al.* 2018, Keleş *et al.* 2014, Kierklo *et al.* 2014, Ko *et al.* 2020, Li *et al.* 2014, Li *et al.* 2020, Mirfendereski *et al.* 2009, Moinzadeh *et al.* 2015, Nhata *et al.* 2014, Selem *et al.* 2014, Somma *et al.* 2011, Suassuna *et al.* 2018, Zogheib *et al.* 2012) and one study used mandibular molars and single-rooted teeth (Moeller *et al.* 2013).

As for the obturation technique, three studies evaluated thermoplasticized injectable technique (Ho *et al.* 2016, Naseri *et al.* 2013, Simsek *et al.* 2017), sixteen used cold lateral compaction (Alim & Berker 2020, Başer Can *et al.* 2016, Celikten *et al.* 2015, Ho *et al.* 2016, Jaworska & Kierklo 2016, Keleş *et al.* 2014, Kierklo *et al.* 2014, Li *et al.* 2014, Martins *et al.* 2011, Moeller *et al.* 2013, Moinzadeh *et al.* 2015, Naseri *et al.* 2013, Nhata *et al.* 2014, Selem *et al.* 2014, Simsek *et al.* 2017, Suassuna *et al.* 2018), ten evaluated carrier-based gutta-percha systems (Alhashimi *et al.* 2016, Alim & Berker 2020, Castagnola *et al.* 2018, Celikten *et al.* 2015, Kabini *et al.* 2018, Li *et al.* 2014, Martins *et al.* 2011, Mirfendereski *et al.* 2009, Somma *et al.* 2011, Zogheib *et al.* 2012), one study used a polyethylene–hydroxyapatite carrier-based system (Alhashimi *et al.* 2016), fifteen used the single-cone technique (Alim & Berker 2020, Alshehri *et al.* 2016, Angerame *et al.* 2012, Başer Can *et al.* 2016, Castagnola *et al.* 2018, Celikten *et al.* 2015, Iglecias *et al.* 2017, Kabini *et al.* 2018, Keleş & Keskin 2019, Ko *et al.* 2020, Li *et al.* 2020, Moinzadeh *et al.* 2015, Roizenblit *et al.* 2019, Somma *et al.* 2011, Suassuna *et al.* 2018), eight studies evaluated continuous wave of condensation (Alim & Berker 2020, Angerame *et al.* 2012, Iglecias *et al.* 2017, Jaworska & Kierklo 2016, Kierklo *et al.* 2014, Nhata *et al.* 2014, Roizenblit *et al.* 2019, Somma *et al.* 2011), three studies employed the Tagger's hybrid technique (Martins *et al.* 2011, Nhata *et al.* 2014, Suassuna *et al.* 2018), six studies used warm vertical compaction (Alshehri *et al.* 2016, Keleş *et al.* 2014, Ko *et al.* 2020, Li *et al.* 2014, Naseri *et al.* 2013, Selem *et al.* 2014).

Concerning root canal preparation, two studies performed preparation with manual files and a final apical size between #30 and #35 (Alhashimi *et al.* 2016, Kierklo *et al.* 2014). One study used self-adjusting file (Simsek *et al.* 2017), four studies prepared the root canals with the ProFile® system with a final preparation diameter ranging from #30.06 to #35.04 (Ho *et al.* 2016, Jaworska & Kierklo 2016, Kierklo *et al.* 2014, Moeller *et al.* 2013), two studies used Revo-S #25.06 (Keleş *et al.* 2014, Simsek *et al.* 2017), nine studies performed preparation with ProTaper files with a final diameter varying from #25.06 to #30.09 (Alim & Berker 2020, Alshehri *et al.* 2016, Celikten *et al.* 2015, Kabini *et al.* 2018, Ko *et al.* 2020, Martins *et al.* 2011, Mirfendereski *et al.* 2009, Naseri *et al.* 2013, Somma *et al.* 2011). Two studies used Mtwo files with a final diameter of #30.06 and #40.06 (Angerame *et al.* 2012, Moinzadeh *et al.* 2015). One study prepared the canals up to a #40.08 diameter, with TF Files system (Zogheib *et al.* 2012). Three studies performed preparation with Reciproc instruments with final diameter ranging from #25.08 to #50.05 (Iglecias *et al.* 2017, Keleş & Keskin 2019, Suassuna *et al.* 2018). One study prepared the root canals with the Hero File with a final size of #45.02 (Nhata *et al.* 2014). Two studies performed root canal preparation with Vortex Blue® files, up to a final diameter of #30.04 and #40.04 (Li *et al.* 2014, Li *et al.* 2020). One study used EndoSequence #40.05 files (Başer Can *et al.* 2016). One study performed preparation with WaveOne #45.05 (Castagnola *et al.* 2018). Two studies used K3XF for root canal preparation and final preparation diameter ranging from #30.04 to #40.06 (Roizenblit *et al.* 2019, SELEM *et al.*, 2014).

When considering micro-CT scan parameters, a wide range of voxel size was observed, from 4µm to 30µm (Alhashimi *et al.* 2016, Alim & Berker 2020, Alshehri *et al.* 2016, Angerame *et al.* 2012, Başer Can *et al.* 2016, Castagnola *et al.* 2018, Celikten *et al.* 2015, Ho *et al.* 2016, Iglecias *et al.* 2017, Jaworska & Kierklo 2016, Kabini *et al.* 2018, Keleş *et al.* 2014, Keleş & Keskin 2019, Kierklo Keleş *et al.* 2014, Ko *et al.* 2020, Li *et al.* 2014, Li *et al.* 2020, Martins *et al.* 2011, Mirfendereski *et al.* 2009, Moeller *et al.* 2013, Moinzadeh *et al.* 2015, Naseri *et al.* 2013, Nhata *et al.* 2014, Roizenblit *et al.* 2019, Selem *et al.* 2014, Simsek *et al.* 2017, Somma *et al.* 2011, Suassuna *et al.* 2018, Zogheib *et al.* 2012)

Regarding the kilovoltage (kV) used for the micro-CT scanning, sixteen studies used kV varying from 90-110kV (Alshehri *et al.* 2016, Angerame *et al.* 2012, Başer Can *et al.* 2016, Castagnola *et al.* 2018, Celikten *et al.* 2015, Ho *et al.* 2016, Iglecias *et al.* 2017, Jaworska & Kierklo 2016, Keleş *et al.* 2014, Keleş & Keskin 2019, Kierklo *et al.* 2014, Ko *et al.* 2020, Li *et al.* 2020, Martins *et al.* 2011, Simsek *et al.* 2017, Somma *et al.* 2011), ten studies used kV between 50-80kV (Alhashimi *et al.* 2016, Alim & Berker

2020, Castagnola *et al.* 2018, Keleş & Keskin 2019, Mirfendereski *et al.* 2009, Nhata *et al.* 2014, Roizenblit *et al.* 2019, Selem *et al.* 2014, Suassuna *et al.* 2018) and three studies did not report this information (Kabini *et al.* 2018, Naseri *et al.* 2013, Zogheib *et al.* 2012).

Twenty-two studies reported microampere (µA) ranging from 50-100µA (Alhashimi *et al.* 2016, Alim & Berker 2020, Alshehri *et al.* 2016, Angerame *et al.* 2012, Başer Can *et al.* 2016, Castagnola *et al.* 2018, Celikten *et al.* 2015, Ho *et al.* 2016, Jaworska & Kierklo 2016, Keleş *et al.* 2014, Keleş & Keskin 2019, Kierklo Keleş *et al.* 2014, Ko *et al.* 2020, Li *et al.* 2020, Martins *et al.* 2011, Mirfendereski *et al.* 2009, Moeller *et al.* 2013, Moinzadeh *et al.* 2015, Nhata *et al.* 2014, Roizenblit *et al.* 2019, Simsek *et al.* 2017, Somma *et al.* 2011), four studies used µA varying from 222µA to 800µA (Iglecias *et al.* 2017, Li *et al.* 2014, Selem *et al.* 2014, SUASSUNA *et al.*, 2018) and three studies did not report this information (Kabini *et al.* 2018, Naseri *et al.* 2013, Zogheib *et al.* 2012).

Considering exposure time, four studies employed exposure time between 300ms and 600ms (Alim & Berker 2020, Ko *et al.* 2020, Li *et al.* 2020, Moinzadeh *et al.* 2015), five studies used 1700ms to 2800ms (Alshehri *et al.* 2016, Başer Can *et al.* 2016, Keleş *et al.* 2014, Keleş & Keskin 2019, Simsek *et al.* 2017), seven studies took 3000ms to 5900ms (Alhashimi *et al.* 2016, Angerame *et al.* 2012, Castagnola *et al.* 2018, Li *et al.* 2014, Naseri *et al.* 2013, Selem *et al.* 2014, Somma *et al.* 2011) and thirteen studies did not report this information (Celikten *et al.* 2015, Ho *et al.* 2016, Iglecias *et al.* 2017, Jaworska & Kierklo 2016, Kabini *et al.* 2018, Kierklo *et al.* 2014, Martins *et al.* 2011, Mirfendereski *et al.* 2009, Moeller *et al.* 2013, Nhata *et al.* 2014, Roizenblit *et al.* 2019, Suassuna *et al.* 2018, Zogheib *et al.* 2012).

Seven studies configurated a rotational angle of 180° (Başer Can *et al.* 2016, Castagnola *et al.* 2018, Keleş *et al.* 2014, Ko *et al.* 2020, Naseri *et al.* 2013, Simsek *et al.* 2017, Somma *et al.* 2011), fifteen studies reported 360º (Alhashimi *et al.* 2016, Alshehri *et al.* 2016, Celikten *et al.* 2015, Ho *et al.* 2016, Iglecias *et al.* 2017, Jaworska & Kierklo 2016, Kabini *et al.* 2018, Keleş *et al.* 2014, Keleş & Keskin 2019, Kierklo *et al.* 2014, Li *et al.* 2020, Mirfendereski *et al.* 2009, Roizenblit *et al.* 2019, Selem *et al.* 2014, Zogheib *et al.* 2012) and seven studies did not report this information (Alim & Berker 2020, Angerame *et al.* 2012, Martins *et al.* 2011, Moeller *et al.* 2013, Moinzadeh *et al.* 2015, Nhata *et al.* 2014, Suassuna *et al.* 2018). When considering rotation step, thirteen studies reported rotation step varying from 0.2º to 0.5º (Alhashimi *et al.* 2016, Alshehri *et al.* 2016, Angerame *et al.* 2012, Başer Can *et al.* 2016, Castagnola *et al.* 2018, Iglecias *et al.* 2017, Jaworska & Kierklo 2016, Keleş & Keskin 2019, Kierklo *et al.* 2014, Ko *et al.* 2020, Li *et al.* 2020, Roizenblit *et al.* 2019, Somma *et al.* 2011), nine studies reported a rotation step ranging from 0.6º to 1.5º (Ho *et al.* 2016, Kabini *et al.* 2018, Keleş *et al.* 2014, Li *et al.* 2014, Mirfendereski *et al.* 2009, Naseri *et al.* 2013, Selem *et al.* 2014, Simsek *et al.* 2017, Zogheib *et al.* 2012) and seven studies did not report the rotation step (Alim & Berker 2020, Celikten *et al.* 2015, Martins *et al.* 2011, Moeller *et al.* 2013, Moinzadeh *et al.* 2015, Nhata *et al.* 2014, Suassuna *et al.* 2018)

As for the evaluated outcomes, the majority of the studies, except one (Ho *et al.* 2016), evaluated the presence of voids, and six studies evaluated for gaps (Alhashimi *et al.* 2016, Alshehri *et al.* 2016, Li *et al.* 2014, Selem *et al.* 2014, Simsek *et al.* 2017, Zogheib *et al.* 2012).

Finally, regarding the outcomes and main findings none of the obturation technique was void- or gap-free. Five studies reported more voids when using single cone technique (Alim & Berker 2020, Başer Can *et al.* 2016, Castagnola *et al.* 2018, Iglecias *et al.* 2017, Kabini *et al.* 2018), on the other hand, two studies reported less voids associated with this technique (Moinzadeh *et al.* 2015, Suassuna *et al.* 2018). Nine studies reported that cold lateral compaction showed a high number of voids (Ho *et al.* 2016, Jaworska & Kierklo 2016, Keleş *et al.* 2014, Li *et al.* 2014, Moinzadeh *et al.* 2015, Naseri *et al.* 2013, Nhata *et al.* 2014, Selem *et al.* 2014, Suassuna *et al.* 2018) and two studies showed low number of voids (Alim & Berker 2020, Başer Can *et al.* 2016). Two studies reported more voids when using continuous wave of condensation (Mirfendereski *et al.* 2009, Alim & Berker 2020) and three studies reported less voids when using the same technique (Iglecias *et al.* 2017, Jaworska & Kierklo 2016, Nhata *et al.* 2014). Four studies reported lower percentage of voids using carrier-based gutta-percha (Castagnola *et al.* 2018, Kabini *et al.* 2018, Li *et al.* 2014, Mirfendereski *et al.* 2009). Three studies presented warm vertical compaction with lower prevalence of gaps and voids (Keleş *et al.* 2014, Li *et al.* 2014, Selem *et al.* 2014). Two studies reported low percentage of voids associated with the thermoplastic injectable technique (Ho *et al.* 2016, Naseri *et al.* 2013) and two studies associated with the Tagger's hybrid technique (Nhata *et al.* 2014, Suassuna *et al.* 2018)

Quality assessment

Table 2 summarizes the risk of bias of the included studies.

From twenty-nine studies included, two studies were considered as having a low risk of bias (Keleş *et al.* 2014, Keleş & Keskin, 2019). Fourteen studies were considered as having a moderate risk of bias (Alhashimi *et al.* 2016, Alshehri *et al.* 2016, Başer Can *et al.* 2016, Iglecias *et al.* 2017, Li *et al.* 2014, Li *et al.* 2020; Mirfendereski *et al.* 2009, Moeller *et al.* 2013, Moinzadeh *et al.* 2015, Roizenblit *et al.* 2019, Selem *et al.* 2014, Simsek *et al.* 2017, Somma *et al.* 2011, Suassuna *et al.* 2018) with major concerns regarding to the sample selection, sample size calculation and blinding of evaluator. Thirteen studies were considered as having a high risk of bias (Alim & Berker 2020, Angerame *et al.* 2012, Castagnola *et al.* 2018, Celikten *et al.* 2015, Ho *et al.* 2016, Jaworska & Kierklo 2016, Kabini *et al.* 2018, Kierklo *et al.* 2014, Ko *et al.* 2020, Martins *et al.* 2011, Naseri *et al.* 2013, Nhata *et al.* 2014, Zogheib *et al.* 2012) with major concerns regarding to the sample selection, sample size calculation, blinding of evaluator, and flaws in the description of the micro-CT scan parameters.

DISCUSSION

Voids and gaps in root canal obturation can denote a poor quality of the endodontic treatment. It is also known that voids and gaps are associated to bacterial leakage and probably a future endodontic failure (Gillen *et al.* 2011. Wu *et al.* 2003). Despite the various materials and techniques used for root canal filling described in the literature, it is necessary to assess the impact of the filling techniques on the incidence of voids and gaps in the root canal filling. Therefore, this systematic review searched for *ex vivo* studies that evaluated the influence of the obturation technique on the quality of root canal filling assessed by micro-CT.

This study was performed with a careful methodology, registered in the PROSPERO database. Six electronic databases were searched to provide a solid source of knowledge. Selection criteria was based on studies that indicate that micro-CT assessment present a more reliable and accurate data on the quality of the root canal filling (Sousa-Neto *et al.* 2018). Besides, micro-CT also enable the tridimensional and volumetric evaluation of the root canal filling and, for consequence, the presence of voids and gaps (Jung *et al.* 2005, Rodrigues *et al.* 2009).

A specific tool was performed to evaluate the risk of bias in ex vivo studies. Risk of bias of the included studies was evaluated using an adaptation based on previous systematic reviews (Gorman *et al.* 2016, Silva *et al.*, 2018). The evaluated parameters were selected by the authors considering the aspects that can interfere in the analysis of the quality on a root canal treatment.

Risk of bias assessment From the twenty-nine studies included, two studies were considered as having a low risk of bias (Keleş *et al.* 2014, Keleş & Keskin, 2019). Fourteen studies were considered as having a moderate risk of bias (Alhashimi *et al.* 2016, Alshehri *et al.* 2016, Başer Can *et al.* 2016, Iglecias *et al.* 2017, Li *et al.* 2014, Li *et al.* 2020; Mirfendereski *et al.* 2009, Moeller *et al.* 2013, Moinzadeh *et al.* 2015, Roizenblit *et al.* 2019, Selem *et al.* 2014, Simsek *et al.* 2017, Somma *et al.* 2011, Suassuna *et al.* 2018) with major concerns regarding to the sample selection, sample size calculation and blinding of evaluator. Thirteen studies were considered as having a high risk of bias (Alim & Berker 2020, Angerame *et al.* 2012, Castagnola *et al.* 2018, Celikten *et al.* 2015, Ho *et al.* 2016, Jaworska & Kierklo 2016, Kabini *et al.* 2018, Kierklo *et al.* 2014, Ko *et al.* 2020, Martins *et al.* 2011, Naseri *et al.* 2013, Nhata *et al.* 2014, Zogheib *et al.* 2012) with major concerns regarding to the sample selection, sample size calculation, blinding of evaluator, and flaws in the description of the micro-CT scan parameters.

Of the twenty-nine included studies, only five described the sample selection and pairing by micro-CT scans (Li *et al.* 2020, Keles *et al.* 2014, Iglecias Et Al. 2017, Keles & Keskin 2019, Roizenblit *et al.* 2019). Both parameters are essential to avoid selection bias because errors in this step could jeopardize the outcomes and the measurement of the data. The absence of anatomical matching of teeth at the baseline can impair the outcome evaluation and conclusions (De Deus *et al.* 2012). As consequence, these studies present poor internal validity (Babb *et al.* 2009).

Regarding micro-CT parameters, twelve studies apprised this domain (Ko *et al.* 2020, Alshehri *et al.* 2016, Alhashimi *et al.* 2016, Li *et al.* 2020, Keles *et al.* 2014, Başer Can *et al.* 2016, Castagnola *et al.* 2018, Keles & Keskin 2019, Selem *et al.* 2014, Li *et al.* 2014, Somma *et al.*2011). The description of micro-CT parameters is essential to permit reproducibly of the study and results could be compared with other studies in the future. A flaw in the description of parameters may hide some outcomes that could not be evaluated by futures studies due to absence of the entire data in the previous articles.

Evaluating Micro-CT Scan Parameters a wide range of voxel size was observed, from 4µm to 30µm (Alhashimi *et al.* 2016, Alim & Berker 2020, Alshehri *et al.* 2016, Angerame *et al.* 2012, Başer Can *et al.* 2016, Castagnola *et al.* 2018, Celikten *et al.* 2015, Ho *et al.* 2016, Iglecias *et al.* 2017, Jaworska & Kierklo 2016, Kabini *et al.* 2018, Keleş *et al.* 2014, Keleş & Keskin 2019, Kierklo *et al.* 2014, Ko *et al.* 2020, Li *et al.* 2014, LI, J. et al., 2020; Mirfendereski *et al.* 2009, Moeller *et al.* 2013, Moinzadeh *et al.* 2015, Naseri *et al.* 2013, Nhata *et al.* 2014, Roizenblit *et al.* 2019, Selem *et al.* 2014, Simsek *et al.* 2017, Somma *et al.* 2011, Suassuna *et al.* 2018, Zogheib *et al.* 2012). Another studies discuss differences in the quality of the micro-CT images and a consequent interpretation of the results when the voxel size was changed. The best resolution was achieved with values closer to 20µm (Yang *et al.* 2011, Sousa-Neto *et al.* 2018). Then, a voxel size set closer to 20µm could result on a better analysis of the fillings and a possibly greater appearance of voids and gaps.

Only six studies reported sample size calculation (Keles *et al.* 2014, Başer Can *et al.* 2016, Moinzadeh *et al.* 2015, Keles & Keskin 2019, Roizenblit *et al.* 2019, Mirfendereski *et al.* 2009). A correct sample size calculation can prevent the occurrence of type II statistical error (i.e., when statistical differences are not observed because the sample size was so small that the test could not detect) (Akobeng, 2016). Therefore, a small sample size could interfere in the results.

Finally, only five studies showed blinding of the evaluators (Simsek *et al.* 2017, Suassuna *et al.* 2018, Alshehri *et al.* 2016, Celikten *et al.* 2015, Moeller *et al.* 2013). The blinding of the evaluator is important to avoid bias of data mensuration. Due to these failures, only two studies were classified as low risk of bias (Keles & Keskin 2019, Keles *et al.* 2014). All studies reported the statistical analysis performed.

When assessing the main findings, five studies reported more voids when using the single cone technique, compared to the techniques of cold lateral compaction (Alim & Berker 2020, Başer Can *et al.* 2016), carrier-based gutta-percha (Castagnola *et al.* 2018, Kabini *et al.* 2018) and continuous wave of condensation (Iglecias *et al.* 2017). This can be explained due to the difficult to control the portion of sealer around the gutta-percha cone, producing a non-uniform filling causing a poor sealer adaptation (Kabini *et al.* 2018). Another hypothesis is because a single round cone difficultly would fit without gaps on an irregular-shaped canal (Weis *et al.* 2004). However, the single cone technique is more effective using a paired gutta-percha cone with the system of rotary and reciprocating files instead of hand files (Gordon *et al.* 2005). Besides, the single cone technique can be improved using bioceramic or epoxy resin-based sealers instead zinc oxide and eugenol-based sealer that have more dimensional stability (Carvalho Junior *et al.* 2007). Bioceramic sealers also can expand through hygroscopic expansion after setting time (Ha et al. 2017). Furthermore, ultrasonic activation of the sealer can promote a better flow and filling of the canal irregularities decreasing the presence of gaps and voids, regardless of the technique used. (Alcalde *et al.* 2017, Guimarães *et al.* 2014).

Nine studies reported that cold lateral compaction showed a high number of voids, compared to warm vertical compaction (Keleş *et al.* 2014, Li *et al.* 2014, Selem *et al.* 2014), single-cone technique (Moinzadeh *et al.* 2015, Suassuna *et al.* 2018), thermoplasticized injectable technique (Ho *et al.* 2016, Naseri *et al.* 2013), continuous wave of condensation technique (Jaworska & Kierklo 2016, Nhata *et al.* 2014) and hybrid Tagger technique (Nhata *et al.* 2014, Suassuna *et al.* 2018). This finding can be justified when the filling, after lateral compaction, is generally gutta-percha cones tightly pressed together, but still separated (Marciano et al. 2011), and a poorer adaptation of the gutta-percha cone to the canal walls can be the result of an inadequate pressure during compaction with finger spreaders (Peng *et al.* 2007). Besides the fact that gutta-percha does not adhere to the canal walls, and it is possible to move during compaction. Gutta-percha has poorer flow ability compared to the sealer and probably would not fill the canal irregularities, letting voids and gaps on an irregular-shaped canal (Weis *et al.* 2004).

This systematic review reveals that four studies reported lower percentage of voids using carrier-based gutta-percha compared to single-cone technique (Castagnola *et al.* 2018, Kabini *et al.* 2018), cold lateral compaction (Li *et al.* 2014) and continuous wave of condensation technique (Mirfendereski et al. 2009). Carrier-based gutta-percha id composed by a two-phase gutta-percha (i.e., alpha- and beta-phase). In the alfa-phase, the gutta-percha that cover the core, is more adhesive and, when heated, becomes highly flowable helping in the adaptation to the canal walls and to the irregularities (Combe *et al.* 2011).

Regarding warm vertical compaction three studies presented lower prevalence of gaps and voids when this technique was compared to cold lateral compaction (Keleş *et al.* 2014, Li *et al.* 2014, Selem *et al.* 2014). The application of a heater during compaction enables that the filling material flow toward the canal irregularities and enhance the adaptation of the filling material with the main and lateral canals (Tanomaru *et al.* 2011, Venturi *et al.* 2006). As the same, when compared to cold lateral compaction, two studies reported low percentage of voids associated with the thermoplastic injectable technique

(Ho *et al.* 2016, Naseri *et al*. 2013). These results can be justified by the better flow of gutta-percha when used in injectable systems. When plasticized, gutta-percha results in a better homogeneous mass with less voids and better adaptation to the root canal walls (De-Deus *et al.* 2006).

Due to the heterogeneity of the methodological aspects (i.e., group of teeth, canal preparation technique, endodontic sealers used, micro-CT parameters, blinding of evaluators) of the evaluated studies, a meta-analysis was not possible to be performed. Another limitation of the study is that it was not possible to establish a possible relation between all micro-CT scan parameters and the analysis of micro-CT images because some studies did not describe this aspects.

The success of endodontic treatment has a multifactorial nature, and the influence of the filling technique is only one of the parameters to be considered. The clinical success of this type of treatment depends on several other factors, such as the apical limit of the root canal filling, the endodontic sealer, the pulp and periapical pathological condition, some systemic, diseases, and the fact that it is a primary or secondary treatment.

Further systematic reviews are needed to individually assess each of the parameters that can influence the clinical success of this type of treatment. In addition, more randomized, non-randomized clinical trials, longitudinal studies, and systematic reviews should be performed to assess the success and survival rates of endodontically teeth considering these multiple factors that impact the result of endodontic treatments.

CONCLUSION

This systematic review showed that any obturation technique performed in extracted teeth is void or gap-free. The presence of gaps and voids in the root canal filling depends on many factors, such as the internal anatomy of the teeth, preparation technique, filling material, filling technique and the clinical dentist expertise.

Conflict of Interest statement

The authors have stated explicitly that there are no conflicts of interest in connection with this article.

REFERENCES

Akobeng AK (2016). Understanding type I and type II errors, statistical power and sample size. *Acta Paediatrica* **105**, 605–609.

Alcalde MP, Bramante CM, Vivian RR, Amorso-Silva PA, Andrade FB, Duarte MAH (2017) Intradentinal antimicrobial action and filling quality promoted by ultrasonic agitation of epoxy resin-based sealer in endodontic obturation. *Journal of Applied Oral Science* **25**, 641–649.

Alhashimi RA, Mannocci F, Sauro S (2016) Experimental polyethylene–hydroxyapatite carrier-based endodontic system: an in vitro study on dynamic thermomechanical properties, sealing ability, and measurements of micro-computed tomography voids. *European Journal of Oral Sciences* **124**, 279–286.

Alim BA, Berker YG (2020) Evaluation of different root canal filling techniques in severely curved canals by micro-computed tomography. *The Saudi Dental Journal* **32**, 200–205.

Alshehri M, Alamri HM, Alshwaimi E, Kujan O (2016) Micro-computed tomographic assessment of quality of obturation in the apical third with continuous wave vertical compaction and single match taper sized cone obturation techniques: Comparison of two root canal obturation techniques. *Scanning* **38**, 352–356.

Angerame D, De Biasi M, Pecci R *et al.* (2012) Analysis of single point and continuous wave of condensation root filling techniques by micro-computed tomography. *Annali dell'Istituto Superiore Di Sanita* **48**, 35–41.

Azim AA, Griggs JA, Huang GTJ (2016) The Tennessee study: factors affecting treatment outcome and healing time following nonsurgical root canal treatment. *International Endodontic Journal* **49**, 6–16.

Babb BR, Loushine RJ, Bryan TE et al. (2009) Bonding of self-adhesive (self-etching) root canal sealers to radicular dentin. *Journal of Endodontics* **35**, 578–582.

Keleş, A, Aslan B (2016) Micro-CT evaluation of the quality of root fillings when using three root filling systems. *International Endodontic Journal* **50**, 499–505.

Castagnola R, Marigo L, Pecci R *et al.* (2018) Micro-CT evaluation of two different root canal filling techniques. *European Review for Medical and Pharmacological Sciences* **22**, 4778–4783.

Carvalho-Junior JR, Correr-Sobrinho L, Correr AB, Sinhoreti MA, Consani S, Sousa-Neto MD (2007) Solubility and dimensional change after setting of root canal sealers: a proposal for smaller dimensions of test samples. *Journal of Endodontics* **33**, 1110-6.

Celikten B, Uzuntas CF, Orhan AI *et al.* (2015) Micro-CT assessment of the sealing ability of three root canal filling techniques. *Journal of Oral Science* **57**, 361–366.

Combe EC, Cohen BD, Cummings K (2001) Alpha- and beta-forms of gutta-percha in products for root canal filling. *International Endodontic Journal* **34**, 447-51.

Cruse W, Bellizzi R (1980) A historic review of endodontics, 1689-1963, part 2. *Journal of Endodontics* **6**, 532–535.

De-Deus G, Gurgel-Filho ED, Magalhães KM, Coutinho-Filho T (2006) A laboratory analysis of gutta-percha-filled area obtained using Thermafil, System B and lateral condensation. *International Endodontic Journal* **39**, 378-383.

De-Deus G, Simoes-Carvalho M, Belladonna FG *et al.* (2020) Creation of well-balanced experimental groups for comparative endodontic laboratory studies: a new proposal based on micro-CT and in silico methods. *International Endodontic Journal* **53**, 974–985.

El-Ma'aita AM, Qualtrough AJE, Watts DC (2012) A Micro–Computed Tomography Evaluation of Mineral Trioxide Aggregate Root Canal Fillings. *Journal of Endodontics* **38**, 670–672.

Gambill JM, Alder M, Del Rio CE (1996) Comparison of nickel-titanium and stainless steel hand-file instrumentation using computed tomography. *Journal of Endodontics* **22**, 369–375.

Gillen BM, Looney SW, Gu L-S *et al.* (2011) Impact of the Quality of Coronal Restoration versus the Quality of Root Canal Fillings on Success of Root Canal Treatment: A Systematic Review and Meta-analysis. *Journal of Endodontics* **37**, 895–902.

Gordon MPJ, Love RM, Chandler NP (2005) An evaluation of .06 tapered gutta-percha cones for filling of .06 taper prepared curved root canals. *International Endodontic Journal* **38**, 87-96.

Gorman CM, Ray NJ, Burke FM (2016) The effect of endodontic access on all-ceramic crowns: A systematic review of in vitro studies. *Journal of Dentistry* **53**, 22–29.

Guimarães BM, Amoroso-Silva PA, Alcalde MP, Marciano MA, Andrade FB, Duarte MAH (2014) Influence of Ultrasonic Activation of 4 Root Canal Sealers on the Filling Quality. *Journal of Endodontics* **40**, 964–968.

Ha JH, Kim HC, Kim YK, Kwon TY (2018) An Evaluation of Wetting and Adhesion of Three Bioceramic Root Canal Sealers to Intraradicular Human Dentin. *Materials* **25**,1286.

Ho ESS, Chang JWW, Cheung GSP (2016) Quality of root canal fillings using three gutta-percha obturation techniques. *Restorative Dentistry & Endodontics* **41**, 22-28.

Iglecias EF, Freire LG, Candeiro GTM, dos Santos M, Antoniazzi JH, Gavini G (2017) Presence of Voids after Continuous Wave of Condensation and Single-cone Obturation in Mandibular Molars: A Micro-computed Tomography Analysis. *Journal of Endodontics*, **43**, 638–642.

Jaworska M, Kierklo A (2016) Use of microcomputed tomography for the evaluation of canal filling quality depending on the part of root canal. *Journal of Stomatology* **69**, 638–646.

Jung M, Lommel D, Klimek J (2005) The imaging of root canal obturation using micro-CT. *International Endodontic Journal*, **38**, 617–626.

Kabini SN, Moodley DS, Parker ME, Patel N (2018) An in-vitro comparative micro-computed tomographic evaluation of three obturation systems. *South African Dental Journal* **73**, 216–220.

Kalender A, Orhan K, Aksoy U, Basmaci F, Er F, Alankus A (2013) Influence of the Quality of Endodontic Treatment and Coronal Restorations on the Prevalence of Apical Periodontitis in a Turkish Cypriot Population. *Medical Principles and Practice* **22**, 173-177.

Keleş A, Alcin H, Kamalak A, Versiani MA (2014) Micro-CT evaluation of root filling quality in oval-shaped canals. *International Endodontic Journal* **47**, 1177–1184.

Keleş A, Torabinejad M, Keskin C, Sah D, Uzun I, Alçin H (2017) Micro-CT evaluation of voids using two root filling techniques in the placement of MTA in mesial root canals of Vertucci type II configuration. *Clinical Oral Investigations* **22**, 1907–1913.

Keleş A, Keskin C (2019) Presence of voids after warm vertical compaction and single‐cone obturation in band‐shaped isthmuses using micro‐computed tomography: A phantom study. *Microscopy Research and Technique* **83**, 370–374.

Kierklo A, Tabor Z, Pawińska M, Jaworska M (2014) A Microcomputed Tomography-Based Comparison of Root Canal Filling Quality following Different Instrumentation and Obturation Techniques. *Medical Principles and Practice* **24**, 84–91.

Kirkevang L, Hørsted‐Bindslev P (2002) Technical aspects of treatment in relation to treatment outcome. *Endodontic Topics* **2**, 89-102.

Ko S-Y, Choi HW, Jeong E-D (2020) Main and Accessory Canal Filling Quality of a Premixed Calcium Silicate Endodontic Sealer According to Different Obturation Techniques. *Materials* **13**, 4389.

Leong DJX, de Souza NN, Sultana R, Yap AU (2020) Outcomes of endodontically treated cracked teeth: a systematic review and meta-analysis. *Clinical Oral Investigations* **24**, 465–473.

Li G, Niu L, Selem LC *et al.* (2014) Quality of obturation achieved by an endodontic core-carrier system with crosslinked gutta-percha carrier in single-rooted canals. *Journal of Dentistry* **42**, 1124–1134.

Li J, Bergeron BE, Chao J, Xu T, Tay FR, Fana B (2020) Micro-computed tomography evaluation of root canal filling quality with apical negative pressure. *Journal of Dentistry* **100**, 103431.

Marciano MA, Ordinola-Zapata R, Cunha TV *et al.* (2011) Analysis of four gutta-percha techniques used to fill mesial root canals of mandibular molars. *International Endodontic Journal* **44**, 321-329

Martins SC, Mello J, Martins CC, Maurício A, Ginjeirad A (2011) Comparação da obturação endodôntica pelas técnicas de condensação lateral, híbrida de Tagger e

Thermafil: estudo piloto com Micro-tomografia computorizada. *Revista Portuguesa de Estomatología, Medicina Dentária e Cirugia Maxilofacial* **52**, 59–69.

Mirfendereski M, Roth K, Fan B *et al.* (2009) Technique Acquisition in the Use of Two Thermoplasticized Root Filling Methods by Inexperienced Dental Students: A Microcomputed Tomography Analysis. *Journal of Endodontics* **35**, 1512–1517.

Moeller L, Wenzel A, Wegge-Larsen AM, Ding M, Kirkevang LL (2013) Quality of root fillings performed with two root filling techniques. An in vitro study using micro-CT. *Acta Odontologica Scandinavica* **71**, 689–696.

Moher D, Shamseer L, Clarke M *et al.* (2015) Preferred reporting items for systematic review and meta-analysis protocols (PRISMA-P) 2015 statement. *Systematic Reviews* **4**, 1.

Moinzadeha AT, Zerbsta W, Boutsioukisa C, Shemesha H, Zaslansky P (2015) Porosity distribution in root canals filled with gutta percha and calcium silicate cement. *Dental Materials* **31**, 1100–1108.

Naseri M, Kangarlou A, Khavid A, Goodini M (2013) Evaluation of the quality of four root canal obturation techniques using micro-computed tomography. *Iranian Endodontic Journal* **8**, 89–93.

Nhata J, Machado R, Vansan LP *et al.* (2014) Micro-computed tomography and bond strength analysis of different root canal filling techniques. *Indian Journal of Dental Research* **25**, 698-701.

Oi T, Saka H, Ide Y. Three-dimensional observation of pulp cavities in the maxillary first premolar tooth using micro-CT. *International Endodontic Journal* **37**, 46–51.

Peng L, Ye L, Tan H, Zhou X (2007) Outcome of Root Canal Obturation by Warm Gutta-Percha versus Cold Lateral Condensation: A Meta-analysis. *Journal of Endodontics* **33**, 106–109.

Pérez-González F, Molinero-Mourelle P, Sánchez-Labrador L *et al.* (2020) Assessment of clinical outcomes and histomorphometric findings in alveolar ridge augmentation procedures with allogeneic bone block grafts: A systematic review and meta-analysis. *Medicina Oral Patología Oral y Cirugia Bucal* **25**, 291-298.

Peters OA, Laib A, Rüegsegger P, Barbakow F (2000) Three-dimensional Analysis of Root Canal Geometry by High-resolution Computed Tomography. *Journal of Dental Research* **79**, 1405–1409.

Peters OA, Peters CI, Schonenberger K, Barbakow F (2003) ProTaper rotary root canal preparation: assessment of torque and force in relation to canal anatomy. *International Endodontic Journal* **36**, 93–99.

Rodrigues FP, Lib J, Silikas N, Ballester RY, Watts DC (2009) Sequential software processing of micro-XCT dental-images for 3D-FE analysis. *Dental Materials* **25**, e47–e55.

Roizenblit RN, Soares FO, Lopes RT, dos Santos BC, Gusman H (2019) Root canal filling quality of mandibular molars with EndoSequence BC and AH Plus sealers: A micro‐CT study. *Australian Endodontic Journal* **46**, 82–87.

Selem LC, Li G, Niu L, Bergeron BE *et al.* (2014) Quality of Obturation Achieved by a Non–gutta-percha–based Root Filling System in Single-rooted Canals. *Journal of Endodontics* **40**, 2003–2008.

Silva EJNL, Rover G, Belladonna FG, De-Deus G, Teixeira CS, Fidalgo TKS (2018) Impact of contracted endodontic cavities on fracture resistance of endodontically treated teeth: a systematic review of in vitro studies. *Clinical Oral Investigations*, 22, 109–118.

Şimşek N, Keleş A, Ahmetoğlu F, Akinci1L, Er K (2017) 3D Micro-CT Analysis of Void and Gap Formation in Curved Root Canals. *European Endodontic Journal* **2**, 22.

Somma F, Cretella G, Carotenuto M *et al.* (2011) Quality of thermoplasticized and single point root fillings assessed by micro-computed tomography: μCT analysis of root fillings. *International Endodontic Journal* **44**, 362–369.

Sousa-Neto MD, Silva-Sousa YC, Mazzi-Chaves JF *et al.* (2018) Root canal preparation using micro-computed tomography analysis: a literature review. *Brazilian Oral Research* **32**, e66.

Suassuna FCM, Maia AMA, Melo DP, Antonino ACD, Gomes ASL, Bento PM (2018) Comparison of microtomography and optical coherence tomography on apical endodontic filling analysis. *Dentomaxillofacial Radiology* **47**, 20170174.

Tanomaru-Filho M, Silveira GF, Reis JM, Bonetti-Filho I, Guerreiro-Tanomaru JM (2011) Effect of compression load and temperature on thermomechanical tests for gutta-percha and Resilon®. *International Endodontic Journal* **44**, 1019-23.

Tavares PBL, Bonte E, Boukpessi T, Siqueira Jr JF, Lasfargues J (2009) Prevalence of Apical Periodontitis in Root Canal–Treated Teeth From an Urban French Population: Influence of the Quality of Root Canal Fillings and Coronal Restorations. *Journal of Endodontics* **35**, 810–813.

Venturi M, Di Lenarda R, Breschi L (2006) An ex vivo comparison of three different gutta-percha cones when compacted at different temperatures: rheological considerations in relation to the filling of lateral canals. *International Endodontic Journal* **39**, 648-56.

Weis MV, Parashos P, Messer HH (2004) Effect of obturation technique on sealer cement thickness and dentinal tubule penetration. *International Endodontic Journal* **37**, 653-63.

Wu M-K, van der Sluis LWM, Ardila CN, Wesselink PR (2003) Fluid movement along the coronal two-thirds of root fillings placed by three different gutta-percha techniques: Evaluation of three obturation techniques. *International Endodontic Journal* **36**, 533–540.

Yang G, Yuan G, Yun X, Zhou X, Liu B, Wu H (2011) Effects of two nickel-titanium instrument systems, Mtwo versus ProTaper universal, on root canal geometry assessed by micro-computed tomography. *Journal of Endodontics* **37**, 1412-1416.

Zogheib C, Naaman A, Sigurdsson A, Medioni E, Bourbouze G, Arbab-Chirani R (2012) Comparative micro-computed tomographic evaluation of two carrier-based obturation systems. *Clinical Oral Investigations* **17**, 1879–1883.

Table 1. Characteristics of the included studies.

Author(s) - (Year of publication)	Sample Size (Per Group)	Group of teeth	Root canal preparation technique	Obturation Technique	Micro-CT Scan Parameters	Evaluated Parameters	Outcomes	Main Findings
Alhashimi *et al.* (2016)	N = 8 (n=4)	Maxillary canines	Manual (up to size #30)	HA/PE: Composite carrier-based hydroxyapatite-reinforced polyethylene CB: Carrier-based gutta-percha (GuttaCore + AH Plus sealer)	Voxel size: 6.5 µm kV: 80 µA: 80 Exposure time: 3100ms Rotational angle: 360º Rotation step: 0.4º	Volume of voids and gaps.	HA/PE carrier-based composite has higher flexibility than CB and comparable sealing ability; Therefore, this newly developed HA/PE obturation system may be considered as a suitable alternative for root-canal obturation.	Obturation with GuttaCore showed a lower percentage of voids volume than obturation with the experimental HA/PE

Alim and Berker (2020)	N = 60 (n=15)	Mandibular first molars	ProTaper Next (17.04- 25.06)	CLC: Cold Lateral Compaction technique (GP + AH Plus sealer) SC: Single-cone technique (GP + AH Plus sealer) CWC: Continuous Wave of Condensation technique (GP + AH Plus sealer) CB: Carrier-based gutta-percha (GuttaCore + AH Plus sealer)	Voxel Size: 20 µm kV: 70 µA: 114 Exposure time: 600ms	Void area	The percentage of filled area at 2 mm was the lowest for SC; At 5 mm, CLC and CB presented lower number of voids compared to SC and CWC. At 8 mm, the filled area was similar for all techniques.	The most successful techniques at 2 and 5mm were CLC and CB, respectively; All techniques can be used for effective filling as long as a good condensation is achieved.

Alshehri *et al*. (2016)	N = 32 (n=16)	Mandibular first molar teeth	ProTaper F3 (30.09)	WV: Warm vertical compaction (GP + AH Plus sealer) SC: Single-cone technique (GP + AH Plus sealer)	Voxel Size: 8.99 µm kV: 100 µA: 100 Exposure time: 1700ms Rotational angle: 360° Rotation Step: 0.4°	Percentage and volume of voids/gaps.	Voids were more often found in canals obturated using WV compared to SC.	The quality of obturation in the apical third of the root with the WV and SC is comparable.
Angerame *et al.* (2012)	N = 24 (n=12)	Single-rooted teeth	Mtwo Files (10.04 - 30.06)	SC: Single-cone technique (GP + AH Plus sealer) CWC: Continuous Wave of Condensation technique (GP + AH Plus sealer)	Voxel size: 19.1 µm kV: 100 µA: 98 Exposure time: 5.9s Rotation step: 0.45°	Volume of voids.	Both techniques demonstrated good filling ability; No difference between the groups was found in percentage of filling material volume and voids.	No difference of root canal filling ability and void between the filling techniques.

Baser Can *et al.* (2016)	N = 30 (n=10)	Single-rooted premolar teeth	Endosequence (40/0.06)	CLC: Cold Lateral Compaction technique (GP + EndoREZ) CLC: Cold Lateral Compaction technique (GP + AH Plus sealer) SC: Single-cone technique (ActiV GP Root Canal Obturation System)	Voxel size: 13.68µm kV: 100 µA: 100 Exposure time: 2000ms Rotational angle: 180º Rotation step: 0.4°	Percentage of canal filling and voids.	The percentage volume of filling material in SC was significantly lower than in the CLC groups (with no significant difference between them); The percentage volume of voids in the SC was significantly higher than in the CLC groups (with no significant difference between them); The analysis of middle thirds showed that there was no significant difference between the three groups with respect to percentage volume of voids.	None of the systems achieved completely homogeneous , void-free root fillings; SC was associated with a higher percentage volume of voids than the other groups.

Castagnola *et al.* (2018)	N = 40 (n=20)	Single-rooted teeth	Pathfiles (15.02) WaveOne Large (45.05)	SC: Single-cone technique (GP + AH Plus sealer) CB: Carrier-based gutta-percha (GuttaCore Obturator)	Voxel size: 19.14µm kV: 100 µA: 98 Exposure time: 5900ms Rotational angle: 180º Rotation step: 0.45°	Presence (Frequency) and Mean (mm^3) of internal, external and combined voids.	SC showed a statistically significant high frequency of combined and external voids in the coronal third. CB showed a statistically significant low frequency of external voids in the coronal third of the canal.	Even if no samples were free of voids in this study, CB in vitro is better and more adaptable than the SC.
Celikten *et al*. (2015)	N = 30 (n=10)	First mandibular premolars	ProTaper F3 (30.09)	SC: Single-cone technique (GP + EndoSequence BC Sealer) CLC: Cold Lateral Compaction technique (GP + EndoSequence BC Sealer) CB: Carrier-based gutta-percha (Thermafil + EndoSequence BC Sealer)	Voxel size: 13.47 µm kV: 100 µA: 100 Rotational angle: 360º	Presence and volume of voids.	There were no differences in relation to filling material volume or voids. The obturation techniques had comparable filling characteristics; The SC technique had the largest void volumes, and CB the smallest void volumes, at all levels.	Voids were present for all root filling obturation techniques.

Ho *et al.* (2016)	N = 33 (n=11)	Mandibular first molars	ProFile (30/0.06)	CLC: Cold Lateral Compaction technique (GP without sealer) UL: Energized warm lateral compaction with ultrasonic spreader (GP without sealer) TT: Thermoplasticized Injectable Technique (GP + Obtura II)	Voxel size: 7.9µm kV: 100 µA: 100 Rotational angle: 360º Rotation step: 1.5°	Percentage volume of GP and the amount of GP present in every 2 mm segment of the canal.	The overall gutta-percha volume was significantly lower in CLC group than in UL and TT groups; In UL and TT, the density of gutta-percha increased significantly towards the coronal aspect; The mean volume fraction of the root canal space occupied by GP was significantly lower in the CLC than in UL or TT, with no significant differences between UL and TT.	TT and UL produced a comparable quality of GP obturation in the root canal system, with significantly denser root filling than was observed in CLC.

Iglecias *et al*. (2017)	N = 24 (n=12)	Mesial canals of mandibular molar teeth	Reciproc Blue R25 (25.08)	SC: Single-cone technique (GP + AH Plus selaer) CWC: Continuous Wave of Condensation technique (GP + AH Plus selaer)	Voxel size: 17.42mm kV: 90 µA: 278 Rotational angle: 360º Rotation step: 0.5°	Percentage volume of voids and filling material.	In the cervical third, CWC was associated with a significantly lower mean percentage of voids than SC; SC group showed similar filling material volumes in all root canal thirds. In CWC group, the coronal third presented significantly greater volume of filling material when compared with middle and apical thirds.	The SC technique yields similar obturation quality except in the coronal third when compared with the CWC in curved canals.

Jaworska and Kierklo (2016)	N = 80 (n=20)	Single-rooted teeth	S-file (35/0.02) or ProFile system (35/0.04)	CWC: Continuous Wave of Condensation technique (GP + Tubli-Seal - System B + Obtura II) CLC: Cold Lateral Compaction (GP + Tubli-Seal)	Voxel size: 12µm kV: 110 µA: 50 Rotational angle: 360º Rotation step: 0.2°	Number and volume (mm3) of internal voids (i-voids) and external voids (e-voids).	In the apical third of the root, there was no statistically significant differences in the volume of i-voids and e-voids; In the middle and coronal thirds, the mean volume of i-voids was statistically significantly higher among CLC compared to CWCh.	There was statistically significant difference in the volume of i-voids only in the middle and coronal third, with higher among the CLC canals compared to CWC.
Kabini *et al.* (2018)	N = 90 (n=30)	Central incisor teeth	ProTaper Files (18.02 - 30.09)	CB: Carrier-based gutta-percha (GuttaCore + AH Plus sealer) SC: Single-cone technique (GP + AH Plus sealer) CB: Carrier-based gutta-percha	Voxel size: 15 µm Rotational angle: 360º Rotation step: 0.6º	Volume of voids.	Voids for SC was found to be greater than that of CB (Thermafil) and CB (GuttaCore); Both CB groups showed good sealing ability in root canals compared with the SC.	None of the materials was gap-free especially at 1mm from apex.

				(Thermafil + AH Plus sealer)				
Keleş and Keskin (2019)	N = 20 (n=10)	Mesial roots of mandibular first molars	Reciproc Blue R25 (25.08)	SC: Single-cone technique (GP + AH Plus selaer) WV: Vertical compaction technique (BeeFill + GP + AH Plus sealer)	Voxel size: 9µm kV: 90 µA: 111 Exposure time: 1800ms Rotational angle: 360º Rotation step: 0.5°	Void and filling percentages.	No significant difference of void and filling percentages values of the SC and WV techniques.	Similar void and filling percentages values of the SC and WV techniques.
Keles *et al*. (2014)	N = 24 (n=12)	Single-rooted maxillary premolars	Revo-S (25/0.06)	CLC: Cold Lateral Compaction technique (GP + AH Plus sealer) WV: Warm vertical compaction (GP Dia-Gun Obturation System + AH Plus sealer)	Voxel size: 12.5 µm kV: 90 µA: 112 Exposure time: 2600ms Rotational angle: 180º Rotation step: 0.6°	Percentage of canal filling and voids.	WV had a significantly smaller void volume than CLC in the coronal and middle thirds, and no statistical difference between groups was observed in the volume of filling materials in middle level; In the apical third, there was no significant differences in the	No filling technique produced void-free root canal fillings; WV was associated with a lower percentage volume of voids than CLC.

							percentage volume of filling materials and voids between groups.	
Kierklo *et al*. (2014)	N =80 (n=20)	Mandibular premolars	Manual S Files (15.02 - 35.02) ProFile (25.04 - 35.04)	CLC: Cold Lateral Compaction technique (GP + TubliSeal) CWC: Continuous Wave of Condensation technique (GP + TubliSeal)	Voxel size: 10.6 µm kV: 110 µA: 50 Rotational angle: 360º Rotation step: 0.2º	Voids, internal voids and parietal voids.	CLC produced voids mainly between the canal wall and the filling; With CWC, the internal voids were particularly common, except for in the apical third of the canal where there were mostly parietal voids.	None of the root canal instrumentati on and filling methods Produced void-free obturation

Ko *et al*. (2020)	Main canal obturation: N = 30 (n=10) Accessory canal fillings: N = 75 (N=25)	Single-rooted teeth	ProTaper F3 (30.09)	SC: Single-cone technique (GP + EndoSeal TCS) SC/UA: Single-cone technique with Ultrasonic activation (GP + EndoSeal TCS) WV: Warm vertical compaction (GP + EndoSeal TCS)	Voxel Size: 30 µm kV: 100 µA: 100 Exposure time: 316ms Rotational angle: 180º Rotation step: 0.4º	Percentage and volume of voids.	It is recommended to use ultrasound when technique is used with calcium silicate sealers; SC has the potential to be used as a useful method for root canal filling if it is adequately applied.	Voids were found in all the groups and there was no significant difference between groups.
Li *et al*. (2014)	N = 30 (n=10)	Single-rooted premolars	Vortex Blue (40/0.04)	CB: Carrier-based gutta-percha (GuttaCore Obturator + ThermaSeal Plus sealer) WV: Warm vertical compaction (GP + ThermaSeal Plus sealer) CLC: Cold Lateral Compaction technique	Voxel size: 14.52µm kV: 50 µA: 800 Exposure time: 4000ms Rotational angle: 360º Rotation step: 0.9°	Gaps and voids.	There were no statistically significant differences in the volumetric distribution of gaps and voids between CLC and WV techniques, and between WV and CB; Significantly higher percentages of gaps, interfacial gaps and voids were found in	None of the obturation techniques produced completely gap- and void-free root fillings; Both CB and WV, in turn, had significantly lower incidences of

				(GP + ThermaSeal Plus sealer)			CLC, when compared with CB.	gaps and voids than LCL.
Li *et al*. (2020)	N = 20 (n=10)	Mandibular premolars	Vortex Blue (20.04 - 30.04)	NPS + SC: Apical Negative Pressure sealer application combined with the Single-cone (GP + iRoot SP sealer) SS + SC: Syringe-assisted sealer application combined with the Single-cone (GP + iRoot SP sealer)	Voxel size: 10μm kV: 90 μA: 88μ Exposure time: 500ms Rotational angle: 360º Rotation step: 0.5º	Volume percentage of voids.	The combination of NPS delivery and a single size- and taper-matching GP master cone produces fewer voids than the single-cone technique.	Voids were identified in all teeth from both groups. The percentage of voids in the NPS + SC group was significantly lower than the SS +SC group.

Martins *et al*. (2011)	N = 15 (n=5)	Mandibular molars teeth	ProTaper Files (18.02 - 30.09)	CLC: Cold Lateral Compaction technique (GP + AH26 sealer) HT: Hybrid Tagger technique (GP + AH26 sealer) CB: Carrier-based gutta-percha (Thermafil+ AH26 sealer)	Voxel size: 5 µm kV: 100 µA: 100	Volume of voids.	No statistical significance between the three techniques; The CLC obtained the best results in regarding an appropriate apical seal.	None of the tested techniques allowed a filling free of voids
Mirfendereski *et al*. (2009)	N = 32 (n=16)	Single-rooted teeth	ProTaper Universal up to F3 or F4	CB: Carrier-based gutta-percha (ProTaper Universal Obturator System) CWC: Continuous Wave of Condensation (System B)	Voxel size: 7µm kV: 75 µA: 100 Rotational angle: 360º Rotation step: 0.9°	Void and obturation volume.	CB had a significantly smaller void volume than CWC.	CB had a smaller void volume than CWC.
Moeller *et al*. (2013)	N = 67 (n=34 and 33)	17 mandibular molars, 46	Profile (35/0.04)	CLC: Cold Lateral Compaction technique (GP + AH Plus sealer)	Voxel size: 10µm kV: 70	Proportion and distribution of	There was a tendency that CLC resulted in fewer voids in the apical	No statistically significant difference in

		premolars and 4 canines		HT: Hybrid technique (GP master cone with AH Plus sealer + Thermafil)	µA: 85	cross-sections with voids.	than in the cervical part of the root filling. The opposite pattern was seen for HT; In relation to the proportion of micro-CT sections with voids, the two root filling techniques did not differ significantly.	percentage of voids between two root filling techniques; A 40% reduction in obturation time was found for the HT compared to the CLC.
Moinzadeh *et al.* (2015)	N = 20 (n=10)	Maxillary and mandibular canines	Mtwo (40/0.06)	SC: Single-cone technique (GP + Smartpaste Bio) CLC: Cold Lateral Compaction technique (GP + Smartpaste Bio)	Voxel size: 10µm kV: 70 µA: 114 Exposure time: 300ms	Percentage volume of voids and filling material.	SC exhibited significantly less percentage of voids (in the coronal and middle thrids) and lower median percentage of voids than CLC.	The percentage of voids associated with CLC was found to be significantly higher than SC.

Naseri *et al.* (2013)	N = 20 (n=5)	Maxillary first molars	ProTaper Files (18.02 - 30.09)	CLC: Cold Lateral Compaction technique (GP + AH26 sealer) WV: Warm vertical compaction (GP + AH26 sealer) TT: Thermoplasticized Injectable Technique (Obtura II + GP + AH26 sealer) TT: Thermoplasticized Injectable Technique (Gutta Flow + AH 26 sealer)	Voxel size: 19.5 µm Exposure time: 3000ms Rotational angle: 180º Rotation step: 0.9º	Volume percentage of voids and obturation materials.	TT (GuttaFlow) and CLC had the highest and the lowest volume percentage of obturation materials, respectively; TT (Obtura II) and CLC had the lowest and the highest volume percentage of voids, respectively.	None of the root canal filled teeth were gap-free.

Nhata *et al.* (2014)	N = 30 (n=10)	Mandibular incisors	Hero Files (45.02)	CLC: Cold Lateral Compaction technique (GP + AH Plus sealer) CWC: Continuous Wave of Condensation technique (GP + AH Plus sealer) HT: Hybrid Tagger technique (GP + AH Plus sealer)	Voxel size: 22.6 µm kV: 70 µA: 140	Filling voids.	Less voids were observed when GP was heated within the root canal on with CWC and HT when compared to CLC; CLC was associated with more voids than the other techniques.	Presence of voids at the interface between the root canal and the filling material in all filling techniques.
Roizenblit *et al.* (2019)	N = 20 (n=10)	Mandibular molars	K3 files (30/0.04)	SC: Single-cone technique (GP + EndoSequence BC sealer) CWC: Continuous wave of Condensation technique (GP + AH Plus sealer)	Voxel size: 14.8mm kV: 70 µA: 114 Rotational angle: 360º Rotation step: 0.3°	Void and obturation volume.	There was not significantly different between the groups; All specimens had a lower filling volume than the post-instrumentation volume.	No sample reached the complete filling of the root canal system and there was no difference in the volume of voids between the groups.

Selem *et al*. (2014)	N = 40 (n=10)	Single-rooted premolars	K3XF (40/0.04 – 0.06)	WV-NGP: Warm Vertical compaction (Non–gutta-percha–based filling material + sealer) WV-GP: Warm Vertical compaction (Gutta-percha + sealer) CLC-NGP: Cold Lateral Compaction technique (Non–gutta-percha–based filling material + sealer) CLC-GP: Cold Lateral Compaction technique (Gutta-percha + sealer)	Voxel size: 14.52µm kV: 50 µA: 800 Exposure time: 4000ms Rotational angle: 360º Rotation step: 0.9°	Gap and voids.	There was no difference in the void area percentage distribution between the groups. However, significantly more canal areas were occupied by voids when CLC was used compared with those in the WV.	None of the groups produced completely gap and void-free fillings; Significantly more canal areas were occupied by voids when CLC was used compared with those in the WV.
Şimşek *et al*. (2017)	N = 40 (n=10)	Mandibular first molars	SAF (Self-adjusting file) Revo-S (25.04 - 25.06)	TT: Thermoplasticized Injectable Technique (GP + AH Plus sealer)	Voxel size: 13.7 µm kV: 100 µA: 100 Exposure time: 2800ms Rotational angle: 180º	Volume of filling, voids and gaps.	All the tested techniques produced voids and gaps.	None of the tested techniques produced void-free or gap-free fillings.

				CLC: Cold Lateral Compaction technique (GP + AH Plus sealer)	Rotation step: 0.6º			
Somma *et al*. (2011)	N = 30 (n=10)	Single-rooted teeth	ProTaper Universal (S1 and S2; F1, F2 and F3); Pathfiles (13, 16 and 19)	SC: Single-cone technique (GP + AH Plus sealer) CB: Carrier-based gutta-percha (Thermafil + AH Plus sealer) CWC: Continuous Wave of Condensation technique (System B + AH Plus sealer)	Voxel size: 19.1µm kV: 100 µA: 98 Exposure time: 5900ms Rotational angle: 180º Rotation step: 0.45º	Void and obturation volume.	No statistically significant difference was found in percentage of filling material volume and void distribution.	No difference in terms of root canal filling ability and void distribution were found amongst the three different filling techniques. The single-point technique was more effective in narrow round canals.

Suassuna *et al*. (2018)	N = 45 (n=15)	Inferior premolars	Reciproc Files (40.06-50.05)	CLC: Cold Lateral Compaction technique (GP + AH Plus sealer) SC: Single-cone technique (GP + AH Plus sealer) HT: Hybrid Tagger technique (GP + AH Plus sealer)	Voxel size: 11 µm kV: 80 µA: 222	Number of voids and dimension.	The micrometric evaluation methods (µCT and OCT) showed voids on the apical filling, frequently between GP cone/dentine and GP cone/cement interfaces; There are significant differences between obturation techniques with higher numbers for CLC.	CLC showed the largest number of voids; No statistical difference for frequency and size of voids between the SC and HT.
Zogheib *et al*. (2012)	N = 54 (n=27)	Single-canal teeth	TF Files (40.08)	CB: Carrier-based gutta-percha (Thermafil + AH Plus sealer) CB: Carrier-based gutta-percha (RealSeal 1 + AH Plus sealer)	Voxel size: 4 µm Rotational angle: 360º Rotation step: 0.6º	Area and volume of voids and gaps.	Both filling techniques showed ability to fill the root canals; No difference in the percentage of voids in the apical third between both materials and at the 3- or the 5- mm level; Both displayed different amounts of voids in obturations, with no	Both CB techniques produced a good sealing ability in root canals, but none was gap free

significant difference between Thermafil and RealSeal.

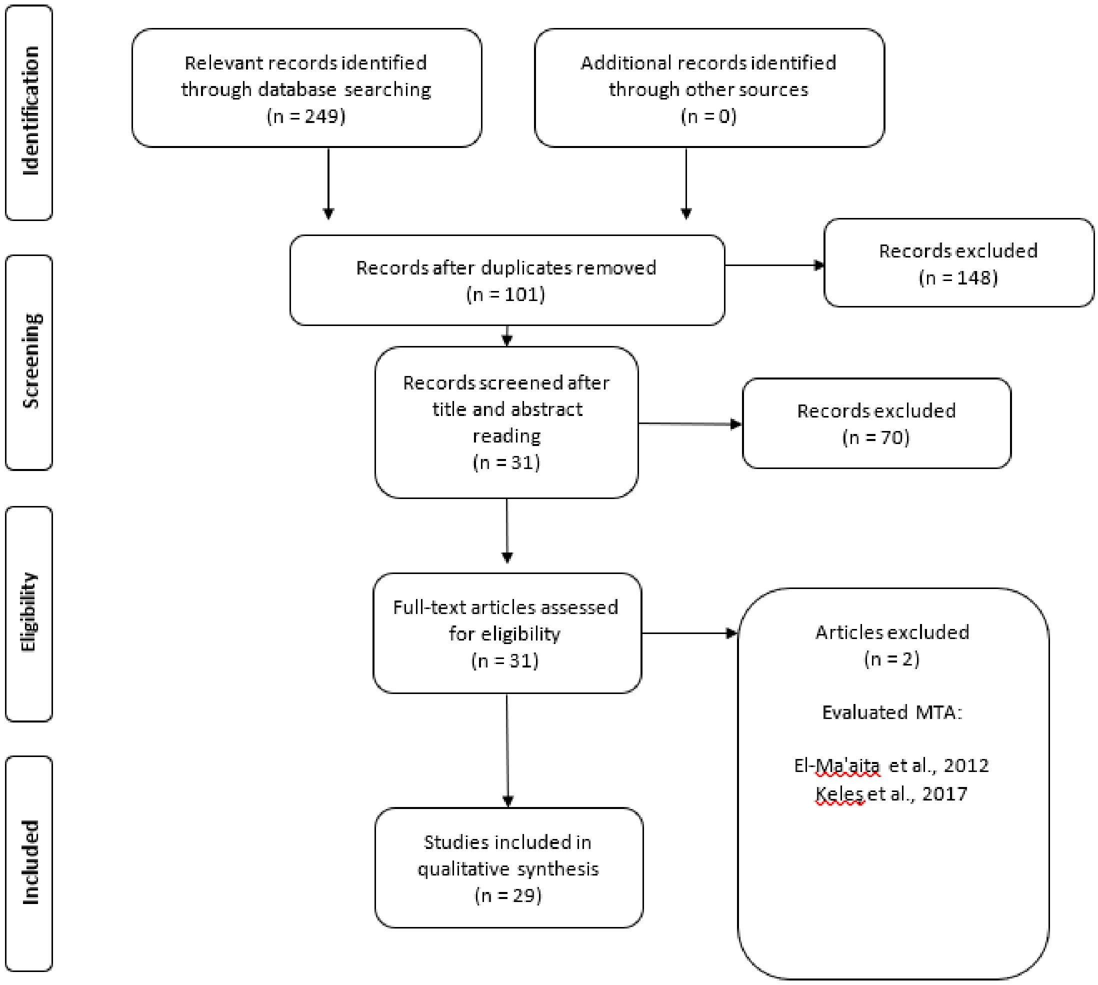
Table 2. The risk of bias of the included studies.

Author(s)	Sample Size Calculation	Sample Selection and Pairing by Micro-CT	Micro-CT Scan Parameters	Obturation Technique	Blinding of the Evaluators	Statistical Analysis	Risk of Bias
Şimşek *et al*. (2017)	No	No	Yes	Yes	Yes	Yes	MODERATE
Kierklo *et al*. (2015)	No	No	No	Yes	No	Yes	HIGH
Kabini *et al.* (2018)	No	No	No	No	No	Yes	HIGH
Angerame *et al*. (2012)	No	No	No	Yes	No	Yes	HIGH
Zogheib *et al*. (2012)	No	No	No	No	No	Yes	HIGH
Martins *et al*. (2011)	No	No	No	Yes	No	Yes	HIGH
Suassuna *et al*. (2018)	No	No	No	Yes	Yes	Yes	MODERATE

Alim & Berker (2019)	No	No	No	Yes	No	Yes	HIGH
Naseri *et al*. (2013)	No	No	No	Yes	No	Yes	HIGH
Alhashimi *et al.* (2016)	No	No	Yes	Yes	No	Yes	MODERATE
Ko *et al*. (2020)	No	No	Yes	No	No	Yes	HIGH
Alshehri *et al*. (2015)	No	No	Yes	Yes	Yes	Yes	MODERATE
Nhata *et al*.m (2014)	No	No	No	Yes	No	Yes	HIGH
Li *et al*. (2020)	No	Yes	Yes	Yes	No	Yes	MODERATE
Celikten *et al*. (2015)	No	No	No	No	Yes	Yes	HIGH
Keles *et al*. (2014)	Yes	Yes	Yes	Yes	No	Yes	LOW
Baser Can *et al.*(2016)	Yes	No	Yes	Yes	No	Yes	MODERATE
Castagnola *et al*. (2018)	No	No	Yes	No	No	Yes	HIGH
Moinzadeh *et al.* (2015)	Yes	No	No	Yes	No	Yes	MODERATE

Iglecias *et al*. (2017)	No	Yes	No	Yes	No	Yes	MODERATE
Keleş & Keskin (2019)	Yes	Yes	Yes	Yes	No	Yes	LOW
Selem *et al*. (2014)	No	No	Yes	Yes	No	Yes	MODERATE
Li *et al*. (2014)	No	No	Yes	Yes	No	Yes	MODERATE
Ho *et al*. (2016).	No	No	No	Yes	No	Yes	HIGH
Moeller *et al*. (2013)	No	No	No	Yes	Yes	Yes	MODERATE
Somma *et al*. (2011)	No	No	Yes	Yes	No	Yes	MODERATE
Roizenblit *et al*. (2019)	Yes	Yes	No	Yes	No	Yes	MODERATE
Mirfendereski *et al*. (2009)	Yes	No	No	Yes	No	Yes	MODERATE
Jaworska & Kierklo (2016)	No	No	No	Yes	No	Yes	HIGH

Figure 1. PRISMA flow diagram representing the systematic review process.



Supplementary File 1. Search strategy in each database.

Database	Search strategy	Findings
PubMed	#1: (((((((root canal filling[MeSH Terms]) OR (root canal filling[Title/Abstract])) OR (root canal obturation[MeSH Terms])) OR (root canal obturation[Title/Abstract])) OR (obturation technique[MeSH Terms])) OR (obturation technique[Title/Abstract])) OR (root canal filling technique[MeSH Terms])) OR (root canal filling technique[Title/Abstract])	5.987
	#2: (((((((((dentin penetration[MeSH Terms]) OR (dentin penetration[Title/Abstract])) OR (tubule penetration[MeSH Terms])) OR (tubule penetration[Title/Abstract])) OR (gaps[MeSH Terms])) OR (gaps[Title/Abstract])) OR (voids[MeSH Terms])) OR (voids[Title/Abstract])) OR (empty spaces[MeSH Terms])) OR (empty spaces[Title/Abstract])	80.072
	#3: (((((MicroCT[MeSH Terms]) OR (MicroCT[Title/Abstract])) OR (Micro-CT[MeSH Terms])) OR (Micro-CT[Title/Abstract])) OR (microcomputed tomography[MeSH Terms])) OR (microcomputed tomography[Title/Abstract])	16.495
	#1 AND #2 AND #3	58
Cochrane Library	#1: (root canal filling):ti,ab,kw OR (root canal obturation):ti,ab,kw OR (obturation technique):ti,ab,kw OR (root canal filling technique):ti,ab,kw	971
	#2: (dentin penetration):ti,ab,kw OR (tubule penetration):ti,ab,kw OR (gaps):ti,ab,kw OR (voids):ti,ab,kw OR (empty spaces):ti,ab,kw	2.900
	#3: (dentin penetration):ti,ab,kw OR (tubule penetration):ti,ab,kw OR (gaps):ti,ab,kw OR (voids):ti,ab,kw OR (empty spaces):ti,ab,kw	270
	#1 AND #2 AND #3	12
Scopus	#1 (TITLE-ABS-KEY (root AND canal AND filling) OR TITLE-ABS-KEY (root AND canal AND obturation) OR TITLE-ABS-KEY (obturation AND technique) OR TITLE-ABS-KEY (root AND canal AND filling AND technique))	12.367

	#2 (TITLE-ABS-KEY (dentin AND penetration) OR TITLE-ABS-KEY (tubule AND penetration) OR TITLE-ABS-KEY (gaps) OR TITLE-ABS-KEY (voids) OR TITLE-ABS-KEY (empty AND spaces))	1.061.023
	#3 (TITLE-ABS-KEY (microct) OR TITLE-ABS-KEY (micro-ct) OR TITLE-ABS-KEY (microcomputed AND tomography))	18.801
	#1 AND #2 AND #3	75
Web of Science (All Databases)	#1: TOPIC: (root canal filling) OR TOPIC: (root canal obturation) OR TOPIC: (obturation technique) OR TOPIC: (root canal filling technique)	13.266
	#2: TOPIC: (dentin penetration) OR TOPIC: (tubule penetration) OR TOPIC: (gaps) OR TOPIC: (voids) OR TOPIC: (empty spaces)	2.229.434
	#3: TOPIC: (MicroCT) OR TOPIC: (Micro-CT) OR TOPIC: (microcomputed tomography)	21.248
	#1 AND #2 AND #3	71
EMBASE	#1: 'root canal filling':ti,ab,kw OR 'root canal obturation':ti,ab,kw OR 'obturation technique':ti,ab,kw OR 'root canal filling technique':ti,ab,kw	1.994
	#2: 'dentin penetration':ti,ab,kw OR 'tubule penetration':ti,ab,kw OR gaps:ti,ab,kw OR voids:ti,ab,kw OR 'empty spaces':ti,ab,kw	94.001
	#3: microct:ti,ab,kw OR 'micro ct':ti,ab,kw OR 'microcomputed tomography':ti,ab,kw	17.175
	#1 AND #2 AND #3	33
Open Grey	#1: (“root canal filling” OR “root canal obturation” OR “obturation technique” OR “root canal filling technique”)	27
	#2: (“dentin penetration” OR “tubule penetration” OR “gaps” OR “voids” OR “empty spaces”)	1.285
	#3: (“MicroCT” OR “Micro-CT” OR “microcomputed tomography”)	28
	#1 AND #2 AND #3	0

4 CONSIDERAÇÕES FINAIS

Este estudo pode concluir que nenhuma técnica de obturação realizada em dentes extraídos e avaliada por micro-CT é capaz de dar origem a obturações do sistema de canais radiculares livres de bolhas ou *gaps*. A presença destas bolhas ou *gaps* na obturação do canal radicular depende de muitos fatores como anatomia interna dos dentes, técnica de preparo, material obturador, técnica de obturação e experiência clínica do dentista.

Entretanto, é importante destacar que o sucesso do tratamento endodôntico tem natureza multifatorial, ou seja, a influência da técnica obturadora é apenas um dos parâmetros a ser considerado. O sucesso clínico deste tipo de tratamento depende de vários outros fatores, como o limite apical da obturação, o cimento endodôntico utilizado, o estado patológico pulpar, as condições sistêmicas do paciente e o fato de ser um tratamento primário ou secundário (retratamento).

Nesta revisão sistemática foi proposto avaliar a influência de diferentes técnicas obturadoras na qualidade da obturação de dentes ex-vivo, através exclusivamente do método de micro-CT. Portanto, os achados deste estudo não podem ser extrapolados para a realidade clínica, visto que apenas um parâmetro foi analisado por meio de um método de análise específico.

Outras revisões sistemáticas são necessárias para avaliar individualmente cada um dos parâmetros que podem influenciar o sucesso clínico deste tipo de tratamento. Além disso, é importante que mais ensaios clínicos randomizados, não randomizados, estudos longitudinais e revisões sistemáticas sejam executadas para avaliar a cicatrização tecidual considerando estes múltiplos fatores que impactam no resultado final dos tratamentos endodônticos.

REFERÊNCIAS

AKOBENG, A. K. Understanding type I and type II errors, statistical power and sample size. **Acta Paediatrica**, [*s. l.*], v. 105, n. 6, p. 605–609, 2016. Disponível em: https://doi.org/10.1111/apa.13384. Acesso em: 06 abr. 2021.

ALCALDE, M. P. *et al.* Intradentinal antimicrobial action and filling quality promoted by ultrasonic agitation of epoxy resin-based sealer in endodontic obturation. **Journal of Applied Oral Science**, [*s. l.*], v. 25, n. 6, p. 641–649, 2017. Disponível em: https://doi.org/10.1590/1678-7757-2017-0090. Acesso em: 22 mar. 2021.

ALHASHIMI, R. A.; MANNOCCI, F.; SAURO, S. Experimental polyethylene-hydroxyapatite carrier-based endodontic system: an in vitro study on dynamic thermomechanical properties, sealing ability, and measurements of micro-computed tomography voids. **European Journal of Oral Sciences**, [*s. l.*], v. 124, n. 3, p. 279–286, 2016. Disponível em: https://doi.org/10.1111/eos.12265. Acesso em: 22 mar. 2021.

ALIM, A.; BERKER, G. Evaluation of different root canal filling techniques in severely curved canals by micro-computed tomography. **The Saudi Dental Journal**, [*s. l.*], v. 32, n. 4, p. 200–205, 2020. Disponível em: https://doi.org/10.1016/j.sdentj.2019.08.009. Acesso em: 22 mar. 2021.

ALSHEHRI, M. *et al.* Micro-computed tomographic assessment of quality of obturation in the apical third with continuous wave vertical compaction and single match taper sized cone obturation techniques: Comparison of two root canal obturation techniques. **Scanning**, [*s. l.*], v. 38, n. 4, p. 352–356, 2016. Disponível em: https://doi.org/10.1002/sca.21277. Acesso em: 22 mar. 2021.

ANGERAME, D. *et al.* Analysis of single point and continuous wave of condensation root filling techniques by micro-computed tomography. **Annali dell'Istituto Superiore Di Sanita**, [*s. l.*], v. 48, n. 1, p. 35–41, 2012. Disponível em: https://doi.org/10.4415/ANN_12_01_06. Acesso em: 22 mar. 2021.

AZIM, A. A.; GRIGGS, J. A.; HUANG, G. T.-J. The Tennessee study: factors affecting treatment outcome and healing time following nonsurgical root canal treatment. **International Endodontic Journal**, [*s. l.*], v. 49, n. 1, p. 6–16, 2016. Disponível em: https://doi.org/10.1111/iej.12429. Acesso em: 22 mar. 2021.

BABB, B. R. *et al.* Bonding of Self-adhesive (Self-etching) Root Canal Sealers to Radicular Dentin. **Journal of Endodontics**, [*s. l.*], v. 35, n. 4, p. 578–582, 2009. Disponível em: https://doi.org/10.1016/j.joen.2009.01.005. Acesso em: 06 abr. 2021.

BAILEY, G. C. *et al.* Root canal obturation by ultrasonic condensation of gutta-percha. Part II: an in vitro investigation of the quality of obturation. **International Endodontic Journal**, [*s. l.*], v. 37, n. 10, p. 694–698, 2004. Disponível em: https://doi.org/10.1111/j.1365-2591.2004.00858.x. Acesso em: 06 abr. 2021.

BAŞER CAN, E. D.; KELEŞ, A.; ASLAN, B. Micro-CT evaluation of the quality of root fillings when using three root filling systems. **International Endodontic Journal**, [*s. l.*], v. 50, n. 5, p. 499–505, 2016. Disponível em: https://doi.org/10.1111/iej.12644. Acesso em: 22 mar. 2021.

BEATTY, R. G.; VERTUCCI, F. J.; HOJJATIE, B. Thermomechanical compaction of gutta-percha: effect of speed and duration. **International Endodontic Journal**, [*s. l.*], v. 21, n. 6, p. 367–375, 1988. Disponível em: https://doi.org/10.1111/j.1365-2591.1988.tb00903.x. Acesso em: 06 abr. 2021.

BLUM, J.-Y.; MACHTOU, P.; MICALLEF, J.-P. Analysis of forces developed during obturations. Wedging effect: Part II. **Journal of Endodontics**, [*s. l.*], v. 24, n. 4, p. 223–228, 1998. Disponível em: https://doi.org/10.1016/S0099-2399(98)80100-3. Acesso em: 06 abr. 2021.

BÜRKLEIN, S. *et al.* Quality of root canal fillings and prevalence of apical radiolucencies in a German population: a CBCT analysis. **Clinical Oral Investigations**, [*s. l.*], v. 24, n. 3, p. 1217–1227, 2020. Disponível em: https://doi.org/10.1007/s00784-019-02985-y. Acesso em: 06 abr. 2021.

CARVALHO JUNIOR, J. *et al.* Solubility and Dimensional Change after Setting of Root Canal Sealers: A Proposal for Smaller Dimensions of Test Samples. **Journal of Endodontics**, [*s. l.*], v. 33, n. 9, p. 1110–1116, 2007. Disponível em: https://doi.org/10.1016/j.joen.2007.06.004. Acesso em: 06 abr. 2021.

CASTAGNOLA, R. *et al.* Micro-CT evaluation of two different root canal filling techniques. **European Review for Medical and Pharmacological Sciences**, [*s. l.*], v. 22, n. 15, p. 4778–4783, 2018. Disponível em: https://doi.org/10.26355/eurrev_201808_15611. Acesso em: 22 mar. 2021.

CAVENAGO, B. C. *et al.* Interfacial adaptation of an epoxy-resin sealer and a self-etch sealer to root canal dentin using the System B or the single cone technique. **Brazilian Dental Journal**, [*s. l.*], v. 23, n. 3, p. 205–211, 2012. Disponível em: https://doi.org/10.1590/S0103-64402012000300004. Acesso em: 06 abr. 2021.

CELIKTEN, B. *et al.* Evaluation of root canal sealer filling quality using a single-cone technique in oval shaped canals: An *In vitro* Micro-CT study: Evaluation of sealer filling quality in oval shaped canals. **Scanning**, [*s. l.*], v. 38, n. 2, p. 133–140, 2016. Disponível em: https://doi.org/10.1002/sca.21249. Acesso em: 06 abr. 2021.

CELIKTEN, B. *et al.* Micro-CT assessment of the sealing ability of three root canal filling techniques. **Journal of Oral Science**, [*s. l.*], v. 57, n. 4, p. 361–366, 2015. Disponível em: https://doi.org/10.2334/josnusd.57.361. Acesso em: 22 mar. 2021.

COMBE, E. C.; COHEN, B. D.; CUMMINGS, K. Alpha- and beta-forms of gutta-percha in products for root canal filling: Gutta-percha. **International Endodontic Journal**, [*s. l.*], v. 34, n. 6, p. 447–451, 2001. Disponível em: https://doi.org/10.1046/j.1365-2591.2001.00415.x. Acesso em: 06 abr. 2021.

CRUSE, W.; BELLIZZI, R. A historic review of endodontics, 1689-1963, part 2. **Journal of Endodontics**, [*s. l.*], v. 6, n. 4, p. 532–535, 1980. Disponível em: https://doi.org/ 10.1016/S0099-2399(80)80201-9. Acesso em: 23 abr. 2021.

DE-DEUS G. *et al.* Creation of well-balanced experimental groups for comparative endodontic laboratory studies: a new proposal based on micro-CT and in silico methods. **International Endodontic Journal**, [*s. l.*], v. 53, n. 7, p. 974–985, 2020. Disponível em: https://10.1111/iej.13288. Acesso em: 23 abr. 2021.

DE-DEUS, G. et al. A laboratory analysis of gutta-percha-filled area obtained using Thermafil, System B and lateral condensation. **International Endodontic Journal**, [s. l.], v. 39, n. 5, p. 378–383, 2006. Disponível em: https://doi.org/10.1111/j.1365-2591.2006.01082.x. Acesso em: 03 mai. 2021.

DE-DEUS, G. *et al.* Limited Ability of Three Commonly Used Thermoplasticized Gutta-Percha Techniques in Filling Oval-shaped Canals. **Journal of Endodontics**, [*s. l.*], v. 34, n. 11, p. 1401–1405, 2008a. Disponível em: https://doi.org/10.1016/j.joen.2008.08.015. Acesso em: 06 abr. 2021.

DE-DEUS, G. *et al.* The effect of the canal-filled area on the bacterial leakage of oval-shaped canals. **International Endodontic Journal**, [*s. l.*], v. 41, n. 3, p. 183–190, 2008b. Disponível em: https://doi.org/10.1111/j.1365-2591.2007.01320.x. Acesso em: 06 abr. 2021.

DEITCH, A. *et al.* A Comparison of Fill Density Obtained by Supplementing Cold Lateral Condensation with Ultrasonic Condensation. **Journal of Endodontics**, [*s. l.*], v. 28, n. 9, p. 665–667, 2002. Disponível em: https://doi.org/10.1097/00004770-200209000-00009. Acesso em: 06 abr. 2021.

ELDEEB, M. E. The sealing ability of injection-molded thermoplasticized gutta-percha. **Journal of Endodontics**, [*s. l.*], v. 11, n. 2, p. 84–86, 1985. Disponível em: https://doi.org/10.1016/S0099-2399(85)80124-2. Acesso em: 06 abr. 2021.

EL-MA'AITA, A. M.; QUALTROUGH, A. J. E.; WATTS, D. C. A Micro–Computed Tomography Evaluation of Mineral Trioxide Aggregate Root Canal Fillings. **Journal of Endodontics**, [*s. l.*], v. 38, n. 5, p. 670–672, 2012. Disponível em: https://doi.org/10.1016/j.joen.2012.01.009. Acesso em: 22 mar. 2021.

GAMBILL, J. M.; ALDER, M.; DEL RIO, C. E. Comparison of nickel-titanium and stainless steel hand-file instrumentation using computed tomography. **Journal of Endodontics**, [*s. l.*], v. 22, n. 7, p. 369–375, 1996. Disponível em: https://doi.org/10.1016/S0099-2399(96)80221-4. Acesso em: 23 abr. 2021.

GILHOOLY, R. M. P. *et al.* Comparison of lateral condensation and thermomechanically compacted warm α-phase gutta-percha with a single cone for obturating curved root canals. **Oral Surgery, Oral Medicine, Oral Pathology, Oral Radiology, and Endodontology**, [*s. l.*], v. 91, n. 1, p. 89–94, 2001. Disponível em: https://doi.org/10.1067/moe.2001.110416. Acesso em: 06 abr. 2021.

GILLEN, B. M. *et al.* Impact of the Quality of Coronal Restoration versus the Quality of Root Canal Fillings on Success of Root Canal Treatment: A Systematic Review and Meta-analysis. **Journal of Endodontics**, [*s. l.*], v. 37, n. 7, p. 895–902, 2011. Disponível em: https://doi.org/10.1016/j.joen.2011.04.002. Acesso em: 06 abr. 2021.

GOLDBERG, F.; ARTAZA, L.; DESILVIO, A. Effectiveness of Different Obturation Techniques in the Filling of Simulated Lateral Canals. **Journal of Endodontics**, [*s. l.*], v. 27, n. 5, p. 362–364, 2001. Disponível em: https://doi.org/10.1097/00004770-200105000-00015. Acesso em: 22 06 abr. 2021.

GORDON, M. P. J.; LOVE, R. M.; CHANDLER, N. P. An evaluation of .06 tapered gutta-percha cones for filling of .06 taper prepared curved root canals. **International Endodontic Journal**, [*s. l.*], v. 38, n. 2, p. 87–96, 2005. Disponível em: https://doi.org/10.1111/j.1365-2591.2004.00903.x. Acesso em: 06 abr. 2021.

GORMAN, C. M.; RAY, N. J.; BURKE, F. M. The effect of endodontic access on all-ceramic crowns: A systematic review of in vitro studies. **Journal of Dentistry**, [*s. l.*], v. 53, p. 22–29, 2016. Disponível em: https://doi.org/10.1016/j.jdent.2016.08.005. Acesso em: 22 mar. 2021.

GUIMARÃES, B. M. et al. Influence of Ultrasonic Activation of 4 Root Canal Sealers on the Filling Quality. Journal of Endodontics, [s. l.], v. 40, n. 7, p. 964–968, 2014. Disponível em: https://doi.org/10.1016/j.joen.2013.11.016. Acesso em: 23 abr. 2021.

HA, J.-H. *et al.* An Evaluation of Wetting and Adhesion of Three Bioceramic Root Canal Sealers to Intraradicular Human Dentin. **Materials**, [*s. l.*], v. 11, n. 8, p. 1286, 2018. Disponível em: https://doi.org/10.3390/ma11081286. Acesso em: 06 abr. 2021.

HAMMAD, M.; QUALTROUGH, A.; SILIKAS, N. Evaluation of Root Canal Obturation: A Three-dimensional In Vitro Study. **Journal of Endodontics**, [*s. l.*], v. 35, n. 4, p. 541–544, 2009. Disponível em: https://doi.org/10.1016/j.joen.2008.12.021. Acesso em: 22 06 abr. 2021.

HO, E. S. S.; CHANG, J. W. W.; CHEUNG, G. S. P. Quality of root canal fillings using three gutta-percha obturation techniques. **Restorative Dentistry & Endodontics**, [*s. l.*], v. 41, n. 1, p. 22, 2016. Disponível em: https://doi.org/10.5395/rde.2016.41.1.22. Acesso em: 22 mar. 2021.

IGLECIAS, E. F. *et al.* Presence of Voids after Continuous Wave of Condensation and Single-cone Obturation in Mandibular Molars: A Micro-computed Tomography Analysis. **Journal of Endodontics**, [*s. l.*], v. 43, n. 4, p. 638–642, 2017. Disponível em: https://doi.org/10.1016/j.joen.2016.11.027. Acesso em: 22 mar. 2021.

JAWORSKA, M.; KIERKLO, A. Use of microcomputed tomography for the evaluation of canal filling quality depending on the part of root canal. [*s. l.*], v. 69, n. 6, p. 638–646, 2016. Disponível em: https://doi.org/10.5604/00114553.1230584. Acesso em: 22 mar. 2021.

JUNG, M.; LOMMEL, D.; KLIMEK, J. The imaging of root canal obturation using micro-CT. **International Endodontic Journal**, [*s. l.*], v. 38, n. 9, p. 617–626, 2005. Disponível em: https://doi.org/10.1111/j.1365-2591.2005.00990.x. Acesso em: 22 mar. 2021.

KABINI, S. *et al.* An in-vitro comparative micro-computed tomographic evaluation of three obturation systems. [*s. l.*], v. 73, n. 4, p. 216–220, 2018. . Acesso em: 22 mar. 2021.

KALENDER, A. *et al.* Influence of the Quality of Endodontic Treatment and Coronal Restorations on the Prevalence of Apical Periodontitis in a Turkish Cypriot Population.

Medical Principles and Practice, [*s. l.*], v. 22, n. 2, p. 173–177, 2013. Disponível em: https://doi.org/10.1159/000341753. Acesso em: 06 abr. 2021.

KECECI, A. D.; CELIK UNAL, G.; SEN, B. H. Comparison of cold lateral compaction and continuous wave of obturation techniques following manual or rotary instrumentation. **International Endodontic Journal**, [*s. l.*], v. 38, n. 6, p. 381–388, 2005. Disponível em: https://doi.org/10.1111/j.1365-2591.2005.00954.x. Acesso em: 06 abr. 2021.

KELEŞ, A. *et al.* Micro-CT evaluation of root filling quality in oval-shaped canals. **International Endodontic Journal**, [*s. l.*], v. 47, n. 12, p. 1177–1184, 2014. Disponível em: https://doi.org/10.1111/iej.12269. Acesso em: 22 mar. 2021.

KELEŞ, A. *et al.* Micro-CT evaluation of voids using two root filling techniques in the placement of MTA in mesial root canals of Vertucci type II configuration. **Clinical Oral Investigations**, [*s. l.*], v. 22, n. 5, p. 1907–1913, 2017. Disponível em: https://doi.org/10.1007/s00784-017-2282-0. Acesso em: 22 mar. 2021.

KELEŞ, A.; KESKIN, C. Presence of voids after warm vertical compaction and single-cone obturation in band-shaped isthmuses using micro-computed tomography: A phantom study. **Microscopy Research and Technique**, [*s. l.*], v. 83, n. 4, p. 370–374, 2019. Disponível em: https://doi.org/10.1002/jemt.23423. Acesso em: 22 mar. 2021.

KIERKLO, A. *et al.* A Microcomputed Tomography-Based Comparison of Root Canal Filling Quality following Different Instrumentation and Obturation Techniques. **Medical Principles and Practice**, [*s. l.*], v. 24, n. 1, p. 84–91, 2014. Disponível em: https://doi.org/10.1159/000368307. Acesso em: 22 mar. 2021.

KIERKLO, A. *et al.* Application of microcomputed tomography for quantitative analysis of dental root canal obturations. **Postepy Higieny I Medycyny Doswiadczalnej (Online)**, [*s. l.*], v. 68, p. 310–315, 2014. Disponível em: https://doi.org/10.5604/17322693.1095271. Acesso em: 06 abr. 2021.

KIM, J.-A. *et al.* Root Canal Filling Quality of a Premixed Calcium Silicate Endodontic Sealer Applied Using Gutta-percha Cone-mediated Ultrasonic Activation. **Journal of Endodontics**, [*s. l.*], v. 44, n. 1, p. 133–138, 2018. Disponível em: https://doi.org/10.1016/j.joen.2017.07.023. Acesso em: 06 abr. 2021.

KIRKEVANG, L.-L.; HØRSTED-BINDSLEV, P. Technical aspects of treatment in relation to treatment outcome: Technical aspects. **Endodontic Topics**, [*s. l.*], v. 2, n. 1, p. 89–102,

2002. Disponível em: https://doi.org/10.1034/j.1601-1546.2002.20106.x. Acesso em: 06 abr. 2021.

KO, S.-Y. *et al.* Main and Accessory Canal Filling Quality of a Premixed Calcium Silicate Endodontic Sealer According to Different Obturation Techniques. **Materials**, [*s. l.*], v. 13, n. 19, p. 4389, 2020. Disponível em: https://doi.org/10.3390/ma13194389. Acesso em: 22 mar. 2021.

LEONG, D. J. X. *et al.* Outcomes of endodontically treated cracked teeth: a systematic review and meta-analysis. **Clinical Oral Investigations**, [*s. l.*], v. 24, n. 1, p. 465–473, 2020. Disponível em: https://doi.org/10.1007/s00784-019-03139-w. Acesso em: 22 mar. 2021.

LI, G. *et al.* Quality of obturation achieved by an endodontic core-carrier system with crosslinked gutta-percha carrier in single-rooted canals. **Journal of Dentistry**, [*s. l.*], v. 42, n. 9, p. 1124–1134, 2014. Disponível em: https://doi.org/10.1016/j.jdent.2014.04.008. Acesso em: 22 mar. 2021.

LI, J. *et al.* Micro-computed tomography evaluation of root canal filling quality with apical negative pressure. **Journal of Dentistry**, [*s. l.*], v. 100, p. 103431, 2020. Disponível em: https://doi.org/10.1016/j.jdent.2020.103431. Acesso em: 22 mar. 2021.

MARCIANO, J.; MICHAILESCO, P. M. Dental gutta-percha: Chemical composition, X-ray identification, enthalpic studies, and clinical implications. **Journal of Endodontics**, [*s. l.*], v. 15, n. 4, p. 149–153, 1989. Disponível em: https://doi.org/10.1016/S0099-2399(89)80251-1. Acesso em: 06 abr. 2021.

MARCIANO, J.; MICHAILESCO, P. M. Dental gutta-percha: Chemical composition, X-ray identification, enthalpic studies, and clinical implications. **Journal of Endodontics**, [*s. l.*], v. 15, n. 4, p. 149–153, 1989. Disponível em: https://doi.org/10.1016/S0099-2399(89)80251-1. Acesso em: 06 abr. 2021.

MARLIN, J.; SCHILDER, H. Physical properties of gutta-percha when subjected to heat and vertical condensation. **Oral Surgery, Oral Medicine, Oral Pathology**, [*s. l.*], v. 36, n. 6, p. 872–879, 1973. Disponível em: https://doi.org/10.1016/0030-4220(73)90339-3. Acesso em: 06 abr. 2021.

MARTINS, S. C. *et al.* Comparação da obturação endodôntica pelas técnicas de condensação lateral, híbrida de Tagger e Thermafil: estudo piloto com Micro-tomografia computorizada. **Revista Portuguesa de Estomatología, Medicina Dentária e Cirugia Maxilofacial**, [*s. l.*],

v. 52, n. 2, p. 59–69, 2011. Disponível em: https://doi.org/10.1016/S1646-2890(11)70013-9. Acesso em: 22 mar. 2021.

MIRFENDERESKI, M. *et al.* Technique Acquisition in the Use of Two Thermoplasticized Root Filling Methods by Inexperienced Dental Students: A Microcomputed Tomography Analysis. **Journal of Endodontics**, [*s. l.*], v. 35, n. 11, p. 1512–1517, 2009. Disponível em: https://doi.org/10.1016/j.joen.2009.07.027. Acesso em: 22 mar. 2021.

MOELLER, L. *et al.* Quality of root fillings performed with two root filling techniques. An in vitro study using micro-CT. **Acta Odontologica Scandinavica**, [*s. l.*], v. 71, n. 3–4, p. 689–696, 2013. Disponível em: https://doi.org/10.3109/00016357.2012.715192. Acesso em: 22 mar. 2021.

MOHER, D. *et al.* Preferred reporting items for systematic review and meta-analysis protocols (PRISMA-P) 2015 statement. **Systematic Reviews**, [*s. l.*], v. 4, n. 1, p. 1, 2015. Disponível em: https://doi.org/10.1186/2046-4053-4-1. Acesso em: 22 mar. 2021.

MOINZADEH, A. T. *et al.* Porosity distribution in root canals filled with gutta percha and calcium silicate cement. **Dental Materials**, [*s. l.*], v. 31, n. 9, p. 1100–1108, 2015. Disponível em: https://doi.org/10.1016/j.dental.2015.06.009. Acesso em: 22 mar. 2021.

NASERI, M. *et al.* Evaluation of the quality of four root canal obturation techniques using micro-computed tomography. **Iranian Endodontic Journal**, [*s. l.*], v. 8, n. 3, p. 89–93, 2013. Acesso em: 22 mar. 2021.

NG, Y.-L. *et al.* Outcome of primary root canal treatment: systematic review of the literature – Part 2. Influence of clinical factors. **International Endodontic Journal**, [*s. l.*], v. 41, n. 1, p. 6–31, 2007. Disponível em: https://doi.org/10.1111/j.1365-2591.2007.01323.x. Acesso em: 06 abr. 2021.

NHATA, J. *et al.* Micro-computed tomography and bond strength analysis of different root canal filling techniques. **Indian Journal of Dental Research**, [*s. l.*], v. 25, n. 6, p. 698, 2014. Disponível em: https://doi.org/10.4103/0970-9290.152164. Acesso em: 22 mar. 2021.

OI, T.; SAKA, H.; IDE, Y. Three-dimensional observation of pulp cavities in the maxillary first premolar tooth using micro-CT. **International Endodontic Journal**, [*s. l.*], v. 37, n. 1, p. 46–51, 2004. Disponível em: https://doi.org/10.1111/j.1365-2591.2004.00757.x. Acesso em: 23 abr. 2021.

ÖZOK, A. R. *et al.* Sealing Ability of a New Polydimethylsiloxane-based Root Canal Filling Material. **Journal of Endodontics**, [*s. l.*], v. 34, n. 2, p. 204–207, 2008. Disponível em: https://doi.org/10.1016/j.joen.2007.11.005. Acesso em: 06 abr. 2021.

PENG, L. *et al.* Outcome of Root Canal Obturation by Warm Gutta-Percha versus Cold Lateral Condensation: A Meta-analysis. **Journal of Endodontics**, [*s. l.*], v. 33, n. 2, p. 106–109, 2007. Disponível em: https://doi.org/10.1016/j.joen.2006.09.010. Acesso em: 06 abr. 2021.

PÉREZ-GONZÁLEZ, F. *et al.* Assessment of clinical outcomes and histomorphometric findings in alveolar ridge augmentation procedures with allogeneic bone block grafts: A systematic review and meta-analysis. **Medicina Oral Patología Oral y Cirugia Bucal**, [*s. l.*], p. 291-298, 2020. Disponível em: https://doi.org/10.4317/medoral.23353. Acesso em: 22 mar. 2021.

PETERS, O. A. et al. ProTaper rotary root canal preparation: assessment of torque and force in relation to canal anatomy: ProTaper: effect of canal geometry on torques and forces. International Endodontic Journal, [s. l.], v. 36, n. 2, p. 93–99, 2003. Disponível em: https://doi.org/10.1046/j.1365-2591.2003.00628.x. Acesso em: 23 abr. 2021.

PETERS, O. A. et al. Three-dimensional Analysis of Root Canal Geometry by High-resolution Computed Tomography. Journal of Dental Research, [s. l.], v. 79, n. 6, p. 1405–1409, 2000. Disponível em: https://doi.org/10.1177/00220345000790060901. Acesso em: 23 abr. 2021.

RODRIGUES, F. P. et al. Sequential software processing of micro-XCT dental-images for 3D-FE analysis. Dental Materials, [s. l.], v. 25, n. 6, p. e47–e55, 2009. Disponível em: https://doi.org/10.1016/j.dental.2009.02.007. Acesso em: 23 abr. 2021.

ROIZENBLIT, R. N. *et al.* Root canal filling quality of mandibular molars with EndoSequence BC and AH Plus sealers: A micro- CT study. **Australian Endodontic Journal**, [*s. l.*], v. 46, n. 1, p. 82–87, 2019. Disponível em: https://doi.org/10.1111/aej.12373. Acesso em: 22 mar. 2021.

SELEM, L. C. *et al.* Quality of Obturation Achieved by a Non–gutta-percha–based Root Filling System in Single-rooted Canals. **Journal of Endodontics**, [*s. l.*], v. 40, n. 12, p. 2003–

2008, 2014. Disponível em: https://doi.org/10.1016/j.joen.2014.07.032. Acesso em: 22 mar. 2021.

SHEMESH, H.; WESSELINK, P. R.; WU, M.-K. Incidence of dentinal defects after root canal filling procedures: Dentinal defects after root canal filling. **International Endodontic Journal**, [*s. l.*], v. 43, n. 11, p. 995–1000, 2010. Disponível em: https://doi.org/10.1111/j.1365-2591.2010.01740.x. Acesso em: 06 abr. 2021.

SHIPPER, G. *et al.* An Evaluation of Microbial Leakage in Roots Filled with a Thermoplastic Synthetic Polymer-Based Root Canal Filling Material (Resilon). **Journal of Endodontics**, [*s. l.*], v. 30, n. 5, p. 342–347, 2004. Disponível em: https://doi.org/10.1097/00004770-200405000-00009. Acesso em: 06 abr. 2021.

SILVA, E. J. N. L. *et al.* Impact of contracted endodontic cavities on fracture resistance of endodontically treated teeth: a systematic review of in vitro studies. **Clinical Oral Investigations**, [*s. l.*], v. 22, n. 1, p. 109–118, 2018. Disponível em: https://doi.org/10.1007/s00784-017-2268-y. Acesso em: 22 mar. 2021.

SIMSEK, N. *et al.* 3D Micro-CT Analysis of Void and Gap Formation in Curved Root Canals. **European Endodontic Journal**, [*s. l.*], v. 2, n. 1, 2017. Disponível em: https://doi.org/10.5152/eej.2017.17004. Acesso em: 16 mar. 2021. Acesso em: 22 mar. 2021.

SOMMA, F. *et al.* Quality of thermoplasticized and single point root fillings assessed by micro-computed tomography: µCT analysis of root fillings. **International Endodontic Journal**, [*s. l.*], v. 44, n. 4, p. 362–369, 2011. Disponível em: https://doi.org/10.1111/j.1365-2591.2010.01840.x. Acesso em: 22 mar. 2021.

SOUSA-NETO, M. D. de *et al.* Root canal preparation using micro-computed tomography analysis: a literature review. **Brazilian Oral Research**, [*s. l.*], v. 32, n. suppl 1, 2018. Disponível em: https://doi.org/10.1590/1807-3107bor-2018.vol32.0066. Acesso em: 06 abr. 2021.

SUASSUNA, F. C. M. *et al.* Comparison of microtomography and optical coherence tomography on apical endodontic filling analysis. **Dentomaxillofacial Radiology**, [*s. l.*], v. 47, n. 2, p. 20170174, 2018. Disponível em: https://doi.org/10.1259/dmfr.20170174. Acesso em: 22 mar. 2021.

TAGGER, M. *et al.* Evaluation of the apical seal produced by a hybrid root canal filling method, combining lateral condensation and thermatic compaction. **Journal of Endodontics**, [*s. l.*], v. 10, n. 7, p. 299–303, 1984. Disponível em: https://doi.org/10.1016/S0099-2399(84)80183-1. Acesso em: 06 abr. 2021.

TANOMARU-FILHO, M. *et al.* Effect of compression load and temperature on thermomechanical tests for gutta-percha and Resilon®: Thermomechanical tests for gutta-percha and Resilon®. **International Endodontic Journal**, [*s. l.*], v. 44, n. 11, p. 1019–1023, 2011. Disponível em: https://doi.org/10.1111/j.1365-2591.2011.01910.x. Acesso em: 06 abr. 2021.

TAVARES, P. B. L. *et al.* Prevalence of Apical Periodontitis in Root Canal–Treated Teeth From an Urban French Population: Influence of the Quality of Root Canal Fillings and Coronal Restorations. **Journal of Endodontics**, [*s. l.*], v. 35, n. 6, p. 810–813, 2009. Disponível em: https://doi.org/10.1016/j.joen.2009.03.048. Acesso em: 22 mar. 2021.

VENTURI, M.; DI LENARDA, R.; BRESCHI, L. An ex vivo comparison of three different gutta-percha cones when compacted at different temperatures: rheological considerations in relation to the filling of lateral canals. **International Endodontic Journal**, [*s. l.*], v. 39, n. 8, p. 648–656, 2006. Disponível em: https://doi.org/10.1111/j.1365-2591.2006.01133.x. Acesso em: 06 abr. 2021.

VERSIANI, M. A.; PÉCORA, J. D.; DE SOUSA-NETO, M. D. Root and Root Canal Morphology of Four-rooted Maxillary Second Molars: A Micro–Computed Tomography Study. **Journal of Endodontics**, [*s. l.*], v. 38, n. 7, p. 977–982, 2012. Disponível em: https://doi.org/10.1016/j.joen.2012.03.026. Acesso em: 06 abr. 2021.

WEIS, M. V.; PARASHOS, P.; MESSER, H. H. Effect of obturation technique on sealer cement thickness and dentinal tubule penetration. **International Endodontic Journal**, [*s. l.*], v. 37, n. 10, p. 653–663, 2004. Disponível em: https://doi.org/10.1111/j.1365-2591.2004.00839.x. Acesso em: 06 abr. 2021.

WU, M.-K. *et al.* Fluid movement along the coronal two-thirds of root fillings placed by three different gutta-percha techniques: Evaluation of three obturation techniques. **International Endodontic Journal**, [*s. l.*], v. 36, n. 8, p. 533–540, 2003. Disponível em: https://doi.org/10.1046/j.1365-2591.2003.00685.x. Acesso em: 06 abr. 2021.

YANG, G. *et al.* Effects of two nickel-titanium instrument systems, Mtwo versus ProTaper universal, on root canal geometry assessed by micro-computed tomography. **Journal of Endodontics**, [*s. l.*], v. 37, n. 10, p. 1412-1416, 2011. Disponível em: https://doi.org/10.1016/j.joen.2011.06.024. Acesso em: 06 abr. 2021.

ZOGHEIB, C. *et al.* Comparative micro-computed tomographic evaluation of two carrier-based obturation systems. **Clinical Oral Investigations**, [*s. l.*], v. 17, n. 8, p. 1879–1883, 2012. Disponível em: https://doi.org/10.1007/s00784-012-0875-1. Acesso em: 22 mar. 2021.

ANEXOS

ANEXO A – Parecer da COMPESQ

Sistema Pesquisa - Pesquisador: Natália Backa Abrahão

Retornar

Dados Gerais:

Projeto Nº:	40244	**Título:**	INFLUENCIA DA TECNICA OBTURADORA NA QUALIDADE DE OBTURACOES AVALIADAS POR MICRO-CT: UMA REVISAO SISTEMATICA		
Área de conhecimento:	Endodontia	**Início:**	03/02/2021	**Previsão de conclusão:**	30/08/2021
Situação:	Projeto em Andamento				
Origem:	Faculdade de Odontologia Programa de Pós-Graduação em Odontologia		**Projeto da linha de pesquisa:** BIOMATERIAIS E TÉCNICAS TERAPÊUTICAS EM ODONTOLOGIA		
Local de Realização:	não informado				

Não apresenta relação com Patrimônio Genético ou Conhecimento Tradicional Associado.

Objetivo:

Avaliar as evidências científicas disponíveis referentes as diferentes técnicas obturadoras e sua influência na qualidade de obturações avaliadas por Micro-CT.

Palavras Chave:

ENDODONTIA; OBTURAÇÃO DO CANAL RADICULAR;

Equipe UFRGS:

Nome: Ricardo Abreu da Rosa
Coordenador - Início: 03/02/2021 Previsão de término: 30/08/2021

Nome: GABRIEL BARCELOS SÓ
Ensino: mestrado - Início: 03/02/2021 Previsão de término: 30/08/2021

Nome: MARCUS VINICIUS REIS SO
Pesquisador - Início: 03/02/2021 Previsão de término: 30/08/2021

Nome: NATÁLIA BACKA ABRAHÃO
Técnico: Digitador - Início: 03/02/2021 Previsão de término: 30/08/2021

Nome: Theodoro Weissheimer
Ensino: mestrado - Início: 03/02/2021 Previsão de término: 30/08/2021

Avaliações:

Comissão de Pesquisa de Odontologia - Aprovado em 17/03/2021 Clique aqui para visualizar o parecer

Anexos:

Projeto Completo	**Data de Envio:** 04/03/2021
Outro	**Data de Envio:** 04/03/2021