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LETHICIA GOMES DE ARAÚJO PIAZZI

DESEMPENHO BIOMECÂNICODE MATERIAIS CERÂMICOS E RESINOSOS PARA CONFECÇÃO DE RESTAURAÇÕES ENDOCROWN: REVISÃO SISTEMÁTICA E META-ANÁLISE

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Dissertação apresentada ao Programa de Pós-Graduação em Clínica Odontológica, da Faculdade de Odontologia da Universidade Federal de Juiz de Fora, como requisito parcial para obtenção do título de Mestre. Área de concentração em Clínica Odontológica.

Orientadora: Profa. Dra. Fabíola Galbiatti de Carvalho

Co-orientador: Prof. Dr. Bruno Salles Sotto-Maior

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Aprovada em: __/___/_____

BANCA EXAMINADORA

____

Profa. Dra. Fabíola Galbiatti de Carvalho (Orientadora)
Departamento de Odontologia
Faculdade de Odontologia/UFJF – Campus Governador Valadares

____

Prof. Dr. Hugo Lemes Carlo
Departamento de Odontologia
Faculdade de Odontologia/UFJF – Campus Governador Valadares

____

Profa. Dra. Carolina Castro Martins
Departamento de Odontopediatria e Ortodontia
Faculdade de Odontologia/UFMG

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DEDICATÓRIA

Dedico este trabalho à minha mãe, Rita de Cássia. Sem seu apoio e confiança em mim, com certeza nada disso seria possível.

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RESUMO

Esta revisão sistemática foi realizada para avaliar qual material, cerâmico ou resinoso, possui melhor desempenho biomecânico para restaurações endocrown. A busca dos artigos foi realizada até março de 2018 em cinco bases de dados: PubMed, Web of Science, Cochrane Library, Clinical Trials e Scopus. Foram incluídos apenas estudos que compararam diferentes materiais para restaurações endocrown. Um total de 436 estudos foram obtidos, dos quais 11 estudos *in vitro* foram incluídos na revisão. A meta-análise foi realizada para os valores de resistência à fratura de oito estudos. Foi realizada uma comparação de efeito sumário final entre endocrowns cerâmicas e resinosas, com modelos de efeitos aleatórios a um nível de significância de p< 0,05. Análises de subgrupos foram realizadas para analisar a resistência à fratura de endocrowns cerâmicas em comparação com aqueles de resinas, considerando a posição dos dentes (anterior / posterior) e a profundidade de preparo das endocrowns na câmara pulpar (curta / longa). As endocrowns cerâmicas apresentaram maior resistência à fratura comparadas as resinosas (p< 0,0001) na análise global e na análise de subgrupo para os dentes anteriores (p= 0,0007). Não houve diferença significante na resistência à fratura entre endocrowns cerâmicas e resinosas com relação à profundidade de preparo (curta: p= 0,37 / longo: p= 0,05). A literatura *in vitro* parece sugerir que o uso de materiais cerâmicos pode proporcionar melhor desempenho que os resinosos em relação à resistência à fratura de endocrowns, no entanto, o modo de falha das restaurações deve ser considerado na interpretação dos resultados. Os materiais resinosos forneceram melhor ajuste interno e adaptação marginal em comparação à cerâmica. O desempenho biomecânico das restaurações endocrowns cerâmicas e resinosas foi dependente da composição do material e ambos mostraram resistência à fratura, ajuste interno e adaptação marginaladequados. No entanto, ensaios clínicos devem ser conduzidos para esclarecer qual material seria o mais indicadopara confecção de restaurações endocrown.

ABSTRACT

This systematic review was conducted to evaluate which material, ceramic or composite, has better biomechanical performance for endocrown restorations. The search for the studies was performed and updated in March 2018in five databases: PubMed, Web of Science, Cochrane Library, Clinical Trials and Scopus. Only studies that compared different materials for endocrown restorations were included. 436 articles were selected by 2 independent reviewers, in which 11 in vitro studies were included in thereview. The meta-analysis was performed for the fracture strength values of 8 studies. A overall comparison was performed between ceramic and composite endocrowns, with random-effects models at a significance level of $p < 0.05$*. Subgroupanalyses were performed to analyze the fracture strength of ceramic endocrowns compared with those of compositeconsidering the position of teeth (anterior/posterior) and the depth of endocrown preparations in the pulp chamber (short/long). The ceramic endocrowns had higher fracture strength than composite types (*$p<0.0001$*) in the overall analysis and in the subgroup analysis for anterior teeth (*$p=0.0007$*). There was no significant difference in the fracture strength between ceramic and composite endocrowns, irrespective of the preparation depth (short:* $p=0.37$*/long:* $p=0.05$*). The use of ceramic materials may provide better performance than composites relative tothe fracture strength of endocrowns, however, the failure mode of restorations should be considered wheninterpreting the results. The composite materials provided better internal fit and marginal adaptation compared to with ceramics. The biomechanical performance of ceramic and composite endocrowns was dependent on material composition and both showed adequate fracture strength, internal fit and marginal adaptation. However, clinical trials should be conducted to select which material would be more suitable for endocrown restorations.*

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1 INTRODUÇÃO

A restauração de dentes tratados endodonticamente com perda extensa da porção coronária geralmente é realizada por confecção de coroas totais suportadas em núcleos metálicos fundidos ou pinos de fibra de vidro (BIACCHI e BASTING, 2012). Diante do sucesso clínico alcançado com o uso de retentores intrarradiculares (SEDREZ-PORTO et al., 2016), acreditava-se que esta retenção intracanal providenciasse maior reforço à estrutura dentária (HIRSCHFELD e STERN, 1972). Contudo, já foi demonstrado que o uso de retentor intrarradicular promove perda de tecido dentário hígido durante a preparação, retenção apenas da coroa protética e pode afetar todo o comportamento biomecânico do dente restaurado (FORBERGER e GÖHRING, 2008; BIACCHI e BASTING, 2012; EL-DAMANHOURY et al., 2015; SEDREZ-PORTO et al., 2016).

Com o avanço da odontologia adesiva e para evitar as desvantagens mencionadas do uso de retentores intrarradiculares, as restaurações adesivas do tipo endocrown surgiram como alternativa (FORBERGER e GÖHRING, 2008; SEVİMLİ et al., 2015; GRESNIGT et al., 2016). Estas são especialmente indicadas em casos com coroa clínica curta, espaço interoclusal insuficiente e perda extensa de tecido dentário que não permitam um preparo para coroa total convencional (EL-DAMANHOURY et al., 2015).

O precursor da técnica da endocrown foi Pissis, em 1995, descrevendo-a como a "técnica de porcelana monobloco". Em 1999, Bindl e Mörmann utilizaram pela primeira vez o termo “endocrown”, definindo-a como coroas adesivas endodônticas e coroas de porcelana total fixadas aos dentes posteriores tratados endodonticamente. As endocrowns são restaurações que não utilizam retentores intrarradiculares e a câmara pulpar é utilizada para a construção da coroa e núcleo em única unidade (LIN et al., 2010), sendo ancoradas nas paredes internas da câmara e nas margens da cavidade, obtendo estabilidade e retenção macro e micromecânica proporcionada pelas paredes pulpares e cimentação adesiva, respectivamente (SEDREZ-PORTO et al., 2016).

Entretanto, não há ainda uma padronização das características de preparo dentário para restaurações endocrown, particularmente em relação a profundidade de preparo na câmara pulpar e quantidade de tecido dentário residual (AKTAS et al., 2016; LISE et al., 2017; BELLEFLAMME et al., 2017), existindo variação entre os trabalhos encontrados na literatura. Pissis (1995) ao descrever as restaurações endocrown pela primeira vez determinou que as mesmas teriam 5mm profundidade. Entretanto, Bindl e Mörmann (1999) reportaram que a profundidade da cavidade na câmara pulparnão é padronizada, podendo variar entre 1 e 4mm. Kanat-Ertürk et al. (2018) encontraram que a profundidade de preparo só afetou a resistência à fratura de restaurações endocrown realizadas quando a cerâmica feldspática foi utilizada. Segundo Lise et al. (2017) não há evidências de que uma retenção mais profunda de 5 mm melhoraria a resistência à fratura e inclusive, uma preparação superficial poderia ser interessante, uma vez que diminui o risco de perfuração acidental da raiz e evita a remoção adicional do tecido dentário sadio que enfraqueceria o complexo raiz-coroa.

As restaurações endocrown podem ser confeccionadas em diferentes materiais, principalmente blocosde resina ou cerâmica para a tecnologia CAD/CAM (FORBERGER e GÖHRING, 2008; AKTAS et al., 2016; ROCCA et al., 2016; SEDREZ-PORTO et al., 2016; SKALSKYI et al., 2018). Tecnologia esta que oferece ainda a possibilidade de desenho e fabricação da restauração em consultório, atendendo ao modelo “*chair-side*” (EL-DAMANHOURY et al., 2015). Tanto as restaurações cerâmicas como as de resina composta reestabelecem a função mecânica e biológica, proporcionando estética com desgaste mínimo de estrutura dentária (SEVİMLİ et al., 2015). Dependendo do material escolhido, o sistema pode tornar-se mais rígido comparado à estrutura dentária (no caso de cerâmica) ou biomecanicamente semelhante (no caso de resina composta) (GRESNIGT et al. 2016; SEDREZ-PORTO et al., 2016).

Dentre os materiais cerâmicos, os mais utilizados para confecção de restaurações endocrownsão as cerâmicasde dissilicato de lítio, de zircônia, feldspática, infiltrada por leucita, e de silicato de alumina(RAMÍREZ-SEBASTIÀ et al., 2013; RAMÍREZ-SEBASTIÀ et al., 2014; EL-DAMANHOURY et al., 2015; AKTAS et al., 2016; GRESNIGT et al., 2016; BANKOĞLU GÜNGÖR et al., 2017; LISE et al, 2017). As resinas compostas empregadas são confeccionadas com tecnologia CAD/CAM e geralmente contendo partículas de carga cerâmicas ou nanocerâmicas de zircônia ou partículas agregadas de zircônia e sílica dispersas na matriz polimérica(EL-DAMANHOURY et al., 2015; RAMÍREZ-SEBASTIÀ et al., 2013; SEVİMLİ et al., 2015; ROCCA et al., 2013).

Em 2016, Sedrez-Porto et al. realizaram uma revisão sistemática para comparar a longevidade clínica e a resistência à fratura (estudos *in vitro*) das restaurações endocrown com as convencionais (retentores intrarradiculares, resina composta direta, inlays/onlays), de modo que foi encontrado similaridade ou melhor desempenho para as restaurações endocrown. Entretanto, o tipo de material empregado na restauraçãopode influenciar na resistência e no seu desempenho clínico (FORBERGER e GÖHRING, 2008; AKTAS et al., 2016; ROCCA et al., 2016; SEDREZ-PORTO et al., 2016), afinal as propriedades físicas, mecânicas e de ultraestrutura dos materiais disponíveis variam amplamente e, consequentemente, espera-se que o comportamento biomecânico do complexo dente-restauração também possua variação (EL-DAMANHOURY et al., 2015).

A maioria dos ensaios clínicos avaliaram o desempenho das restaurações endocrown com um tipo de material (BINDL e MÖRMANN, 1999; OTTO et al., 2004; BINDL et al., 2005; BERNHART et al., 2010; ZIMMERLI et al., 2012;DECERLE et al., 2014; OTTO et al., 2015) não avaliando o desempenho clínico entre os diferentes materiais que podem ser empregados.Com relação aos estudos *in vitro,* os ensaios de termociclagem e fadiga mecânica são os métodos mais utilizados para simular o envelhecimento e as tensões na interface adesiva analisando microinfiltração, adaptação marginal e resistência à fratura de restaurações endocrown, com o objetivo de avaliar a durabilidade das mesmas (EL-DAMANHOURY et al., 2015; BANKOĞLU GÜNGÖR et al., 2017). Porém, poucos estudos na literatura avaliaram aresistência à fratura e a adaptação marginal entre os materiais cerâmicos e os resinosos utilizados neste tipo de restaurações(RAMÍREZ-SEBASTIÀ et al, 2013; EL-DAMANHOURY et al., 2015; AKTAS et al., 2016; GRESNIGT et al., 2016; BANKOĞLU GÜNGÖR et al., 2017; LISE et al., 2017).

Com o aumento da popularidade das restaurações endocrown associado à ampla variedade de materiais para sua confecção, a escolha do material com melhor desempenho para estas restaurações torna-se difícil para os clínicos, permanecendo a dúvida de qual material seria o mais indicado para confecção de restaurações endocrown. Assim, a presente revisão sistemática foi conduzida para avaliar qual material (cerâmica ou resina) possui melhor desempenho clínico e biomecânico em restaurações endocrown.

2 PROPOSIÇÃO

O objetivo deste trabalho foi revisar sistematicamente a literatura para avaliar qual material, cerâmico ou resinoso, possui melhor desempenho clínico e biomecânico em restaurações endocrown.

3 MATERIAL E MÉTODOS

Esta revisão sistemática foi registrada no banco de dados PROSPERO (https://www.crd.york.ac.uk/PROSPERO/)com o número de protocolo CRD 42017060000 e foi organizada de acordo com o PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses - http://www.prisma-statement.org) (MOHER et al., 2009).

3.1 Estratégia de busca

Uma pesquisa computadorizada sistemática foi realizada para busca dos artigos científicos até 20 de março de 2018. Seis bases de dados eletrônicos foram selecionados:Pubmed (https://www.ncbi.nlm.nih.gov/pubmed/), Web of Science (http://www.webofknowledge.com/), Cochrane Library (http://www.cochranelibrary.com/), Clinical Trials (https://clinicaltrials.gov/ct2/home), Lilacs (http://lilacs.bvsalud.org/) e Scopus (https://www.scopus.com/home.uri). Os seguintes descritores foram utilizados nas bases de dados Pubmed, Web of Science, Scopus e Cochrane: (“endocrown” OR “endocrowns” OR "endo crowns" OR "endo crown" OR “depulped restoration” OR “adhesive endodontic crown” OR “adhesive endodontic crowns”). Para as bases Clinical Trials e Lilacs a estratégia de busca foi realizada por meio da combinação das palavras (“endocrown”, “endocrowns”, “endo crown”, “adhesive endodontic crown”). A busca manual foi realizada avaliando a lista de referências de todos os estudos incluídos. A busca na literatura cinzenta foi realizada também no *Google Scholar* procurando teses, monografias e resumos apresentados em congressos. Não houve restrições de idioma e de ano de publicação. Para definir a busca foi estabelecida a pergunta de pesquisa (“*PICO question*”): dentes com restaurações endocrown (paciente); materiais cerâmicos ou resinosos (intervenção); longevidade, resistência à fratura e adaptação marginal (resultado).

3.2 Seleção dos estudos

Para seleção dos artigos científicos, os critérios de inclusão foram: estudos epidemiológicos (randomizados, não randomizados, caso-controle, coorte); estudos observacionais sobre restaurações endocrown e com comparação de diferentes materiais para confecção dessas restaurações; estudos *in vitro* que avaliaram a resistência à fratura e/ou adaptação marginal de diferentes materiais.

Dessa forma, os critérios de exclusão foram: estudos que avaliaram apenas entre as restaurações endocrown e as restaurações com retentores intrarradiculares; estudos com restaurações não endocrown; estudos de restaurações endocrown sem a comparação do desempenho dos materiais empregados para sua confecção; estudos com apenas análise de elementos finitos; estudos que analisaram somente agentes de cimentação; estudos em animais; relatos de caso; cartas ao editor; revisões de literatura e estudos não relacionados à área de Odontologia.

O *software* de referências EndNote X7.5® (Clarivate Analytics, Philadelphia, PA, USA) foi usado para organizar a lista de artigos. Os resultados duplicados foram removidos após a identificação. O processo de seleção dos artigos foi realizado em duas fases. Na primeira, dois examinadores revisaram de forma independente a lista de títulos e resumos para inclusão. Os examinadores foram calibrados para a determinação do acordo dos critérios de elegibilidade utilizando 10% dos estudos. Caso o resumo fosse julgado com informação insuficiente para uma decisão de inclusão ou de exclusão, o texto completo foi obtido e revisado. A discrepância entre os dois examinadores para inclusão ou exclusão dos artigos foi discutida até o alcance do consenso para seleção. Ao final, a concordância entre os examinadores foi considerada adequada (Kappa= 0.92). Ao final, os revisores deram prosseguimento ao processo de seleção.

Após a seleção dos artigos pelo título e resumo, os artigos completos foram obtidos para a segunda fase da revisão, a qual constou da leitura na íntegra dos artigos selecionados pelos dois examinadores. A fase seguinte consistiu na extração, de forma independente, dos dados dos artigos que atendiam aos critérios de inclusão. Qualquer discordância foi discutida e reexaminada até que o consenso fosse alcançado. Quando foram necessárias informações adicionais, os autores dos artigos foram contatados por *e-mail*.

3.3 Extração dos dados

Os dados extraídos dos artigos foram organizados em uma tabela no software Microsoft Office Excel 2016 (Microsoft Corporation, Redmond, WA, EUA), especificamente projetada para esta revisão. Para cada estudo, dois revisores coletaram, independentemente, dados quantitativos e qualitativos: país, autor, ano de publicação, tipo de estudo, tamanho da amostra, dente restaurado, resultados encontrados, métodos de envelhecimento e de avaliação da resistência à fratura e adaptação marginal, grupos avaliados, presença de férula, profundidade de preparo na câmara pulpar, valores de resistência à fratura e adaptação marginal.

3.4 Avaliação da qualidade metodológica

Dois examinadores conduziram de forma independentea avaliação da qualidade metodológica de cada estudo *in vitro*incluído, como previamente descrito (SEDREZ-PORTO et al., 2016) de acordo com a descrição dos seguintes parâmetros:aleatorização dos dentes, preparo padronizado pelo mesmo operador, dentes com morfologia similar, cálculo amostral, análise do preparo por operadores cegos, padronização do desenho da restauração, informação da profundidade do preparo endocrown na câmarapulpar, simulação do ligamento periodontal e presença de grupo controle. Se os estudos apresentaram o parâmetro, o artigo recebeu um "sim"; se não foi possível encontrar a informação, o artigo recebeu um "não". Os artigos que relataram risco de viés em até três itensforam classificados como tendo um baixo risco de viés, entre quatro eseisitens como um risco médio de viés e em mais de seis itens como um alto risco de viés. Para a classificação final de risco de viés, qualquer discordância entre os revisores foi discutida até o consenso.

3.5 Análise estatística

As análises estatísticas foram realizadas usando o Review Manager (RevMan) Computer Program versão 5.3 (The Nordic Cochrane Center, The Cochrane Collaboration, Copenhague, Dinamarca, 2014)com o objetivo de realizar a meta-análise. Os resultados nos quais a meta-análise não pôde ser aplicada foram avaliados descritivamente.

A meta-análise foi utilizada para os dados de resistência à fratura, realizando a análise global com o modelo de efeito aleatório comparando-se a média de resistência à fratura entre os grupos de restaurações endocrown cerâmicas e os grupos de restaurações endocrown resinosas. Um valor de $p<0,05$ foi considerado estatisticamente significante. Vários grupos do mesmo estudo foram analisados de acordo com o “*guideline*” Cochrane para a combinação de grupos (HIGGINS e GREEN, 2008). Análises subgrupos foram realizadas para avaliar a resistência à fratura de endocrowns cerâmicas comparadas às de materiais resinosos levando-se em conta a posição dos dentes (anteriores e posteriores) e a profundidade do preparo das endocrowns na câmara pulpar (preparo curto e longo). O preparo foi considerado curto quando a profundidade foi de até 5mm no interior da câmara, e longo quando a profundidade foi igual ou maior que 5mm. A heterogeneidade estatística do efeito do tratamento entre os estudos foi avaliada usando o teste Q de Cochran e o teste de inconsistência I^2, no qual valores maiores que 50% foram considerados como indicativos de substancial heterogeneidade.

4 ARTIGO

Artigo submetido para publicação no Periódico Journal of Dentistry

Biomechanical performance of ceramic and composite materials for endocrown restorations: a systematic review and meta-analysis

ABSTRACT

Objectives: This systematic review was conducted to evaluate which material, ceramic or composite, has better biomechanical performance for endocrown restorations.

Data: This report followed the PRISMA statement.

Sources: Searches were performed up to March2018 in five databases: PubMed, Web of Science, Cochrane Library, Clinical Trials and Scopus.

Study selection: Only studies that compared different materials for endocrown restorations were included. The eligibility criteria were applied to a total of 436 identified studies of which, 11 *in vitro* studies were included in this review. The meta-analysis was performed for the fracture strength values of 8 studies. A global comparison was performed between ceramic and composite endocrowns, with random-effects models at a significance level of $p< 0.05$. Subgroup analyses were performed to analyze the fracture strength of ceramic endocrowns compared with those of resins considering the position of teeth (anterior/posterior) and the depth of endocrown preparations in the pulp chamber (short/long).

*Results:*The ceramic endocrowns had higher fracture strength than composite types ($p<0.0001$) in the global analysis and in subgroup analysis for anterior teeth ($p=0.0007$). There was no significant difference in fracture strength between ceramic and composite endocrowns, irrespective of the preparation depth (short: $p=0.37$/long: $p=0.05$).

Conclusions: The *in vitro* literature seemed to suggest that the use of ceramic materials may provide better performance than composites relative to the fracture strength of endocrowns, however, the failure mode of restorations should be considered when interpreting the results. The composite materials provided better internal fit and marginal adaptation compared to with ceramics.

Clinical Significance: The biomechanical performance of ceramic and composite endocrowns was dependent on material composition and both showed adequate fracture strength, internal fit and marginal adaptation. However, clinical trials should be conducted to select which material would be more suitable for endocrown restorations.

*Keywords:*endodontically treated teeth, ceramics, composite resins

1. Introduction

The advancement of adhesive dentistry has led to the appearance of endocrown restorations as an alternative for the rehabilitation of endodontically treated teeth [1,2]. Endocrowns are restorations that not use the intracanal retainers and the pulp chamber is used for crown and core construction as a single unit [3]. The restoration is anchored to the internal portion of the pulp chamber and on the cavity margins, thereby resulting in both macro- and micro-mechanical retention provided by the pulpal walls and the adhesive cementation, respectively [4].

However, as yet, there is no standardization of tooth preparation characteristics for endocrown restorations, particularly relative to the depth of preparation in the pulp chamber and the amount of residual dental tissue [5–7].These factors are extremely important because they are related to the adhesion and biomechanical performance of restorations, which may interfere on their durability over time [5,8].

Endocrown restorations can be performed using different materials, mainly composite and ceramics blocks by means of CAD/CAM technology [1,4,7,9,10], which provides the possibility for chair-side design and fabrication [11]. Among the ceramic materials, the most used for endocrown restorations are lithium disilicate, zirconia, feldspathic, leucite glass-ceramic and alumina silicate [2,5,7,11–14]. In addition, the most used composite materials are nanoceramics and polymer-infiltrated hybrid ceramics (PICNs) [11,12,15].The type of material used for endocrown restorations may influence their fracture strength, marginal adaptation and clinical performance, since the composition and physical-mechanical properties of the materials vary widely and can affect the biomechanics of the tooth-restoration complex [6,7,9,11,16].

Despite the increasing popularity and wide variety of materials used for endocrown restorations, the scientific literature revealed a lack of studies to compare the clinical performance of different materials used for endocrowns[18–24]. In this sense, the question that remains is which would be the best material for clinicians to perform endocrown restorations. Thus, the aim of this study was to systematically review the literature to evaluate which material (ceramic or composite) have the best clinical and *in vitro* performance for endocrown restorations. The hypothesis tested was that ceramic endocrowns would have similar clinical and biomechanical performance when compared with resin endocrowns.

2. Materials and methods

This systematic review was registered on the PROSPERO database (http://www.crd.york.ac.uk/PROSPERO/) under number CRD 42017060000 and was performed in accordance with the Preferred Reporting Items for Systematic Reviews and Meta-analyses (PRISMA) statement.

2.1. Search strategies

A systematic computerized search was performed from November 2016 to March 2018 in six electronic databases: Pubmed (https://www.ncbi.nlm.nih.gov/pubmed/), Web of Science (http://www.webofknowledge.com/), Cochrane Library (http://www.cochranelibrary.com/), Clinical Trials (https://clinicaltrials.gov/ct2/home), Lilacs (http://lilacs.bvsalud.org/) and Scopus (https://www.scopus.com/home.uri). The following terms were used in Pubmed, Web of Science, Scopus and Cochrane: “endocrown” OR “endocrowns” OR "endo crowns" OR "endo crown" OR “depulped restoration” OR “adhesive endodontic crown” OR “adhesive endodontic crowns”. For the databases Clinical Trials and Lilacs, the search strategy was performed with words combinations of “endocrown”, “endocrowns”, “endo crown”, “adhesive endodontic crown”. A manual search was conducted from a reference list of included studies. Grey literature was also searched using thesis, monographies and abstracts recently presented in meetings. There were no restrictions on language or on year of publication. To define the search the following research question was established ("*PICO question*"): teeth with endocrown restorations (patient); ceramic and composite materials (intervention); fracture strength and marginal adaptation (outcome).

2.2. Study selection

The studies were analyzed according to the following inclusion criteria: epidemiological studies (randomized, non-randomized, case-control, cohort); observational studies on endocrown restorations that compared different materials used for these restorations; *in vitro* studies that evaluated the fracture strength and/or marginal adaptation of different materials.

The exclusion criteria included: clinical trials or *in vitro* studies that made comparisons only between endocrown restorations and intraradicular restorations; clinical trials or *in vitro* studies with non-endocrown restorations; clinical trials or *in vitro* studies of endocrown restorations without comparing the performance of the materials; studies with only finite element analysis; studies that analyzed only cements; animal studies; case reports; letters to the editor; literature review or studies that were not related to dentistry research.

The EndNote X7.5® (Thomson Reuters, Philadelphia, PA, USA) was used to organize the list of studies. Duplicate results were removed upon identification. The review process was carried out in two stages. In the first stage, two researchers independently reviewed the list of titles and abstracts for inclusion. The reviewers were calibrated to determine the level of agreement about inclusion of the articles according to the eligibility criteria, by using 10% of the studies. If the abstract was judged to contain insufficient information for a decision about inclusion or exclusion, the full text was obtained and reviewed before a final decision was made. The discrepancies in inclusion of the articles between researchers were addressed through discussion until consensus was reached. In the end, agreement between the examiners was considered adequate (Kappa= 0.92). After selection of the articles by title and abstract, the eligibility criteria were independently applied to the full text analysis by the two researchers. Any disagreement regarding the eligibility of included studies was discussed until consensus was reached. When additional information was needed, the authors of the articles were contacted by e-mail.

The search strategy and studies selection were organized according the flow diagram - PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses - http://www.prisma-statement.org) [24].

2.3. Data extraction

The data were extracted using a standardized spreadsheet in Microsoft Office Excel 2016 software (Microsoft Corporation, Redmond, WA, EUA), specifically designed for this review. For each study two reviewers independently collected the qualitative and quantitative data of the eligible studies: aging, testing methods of fracture resistance / internal and marginal adaptation, endocrown material/groups, number of teeth (per group), presence of ferrule, preparation depth, fracture strength, internal and marginal adaptation.

2.4. Quality assessment

Two reviewers independently assessed the methodological quality of each included study, as previously described [4] accordingly the following parameters: randomization of teeth, standard tooth preparation by the same researcher, presence of control group, teeth with similar morphology, sample size calculation, blind analysis of tooth preparation independently by two researchers, standard design of endocrowns, preparation depths of endocrowns and artificial periodontal ligament. If the studies presented the parameter, the article had a “Yes” for that specific parameter; if it was not possible to find the information, the article received a “No”. Articles that reported risk of bias in up to three items were classified as having a low risk of bias; between four and six items, as medium risk of bias; and in more than six items, as having a high risk of bias. For the final classification of risk of bias, disagreements between the reviewers were solved by consensus.

2.5. Statistical analysis

The analyses of the *in vitro* studies were performed using the Review Manager (RevMan) Computer Program version 5.3 (The Nordic Cochrane Center, The Cochrane Collaboration, Copenhagen, Denmark, 2014). Results that did not make it possible to perform the meta-analysis were evaluated descriptively.

The global analysis was carried out using a random effect model, and pooled-effect estimates were obtained by comparing the mean of fracture strength between the groups of ceramic endocrowns and composite endocrown restorations. A p value < 0.05 was considered statistically significant. Multiple groups from the same study were analyzed according to Cochrane guidelines formula for combining groups [25]. Subgroup analyses were performed to analyze the fracture strength between ceramic and composite endocrowns considering the position of teeth (anterior or posterior) and the depth of preparation in the pulp chamber (short and long preparation). The preparation was considered short when the depth was up to 5 mm inside the chamber, and long when the depth was equal to or greater than 5 mm. Statistical heterogeneity of the treatment effect among studies was assessed using Cochran's Q test and the inconsistency I^2 test, and values higher than 50% were considered indicative of substantial heterogeneity [25].

3. Results

3.1. Search strategy

With the search strategy used, 436 potentially relevant records, excluding duplicates were identified. Figure 1 summarizes the article selection process according to the PRISMA Statement [24]. After examining the titles and abstracts, 384 studies were excluded because they did not meet the eligibility criteria (Appendix 1). Of the 52 studies retained for detailed review, 41 studies were excluded for the following reasons: 4 studies compared endocrowns with conventional treatments (intraradicular posts); 4 studies with only finite element analysis; 2 studies analyzed only cements; 29 studiesdid not compare different materials for endocrowns; 2studies were case reports (Appendix 2). Two restropective clinical studies were found, but they were excluded after full text analysis[6,27]. Thus, 11 *in vitro* studies were included in the review [2,5,7,8,10–14,16,26].

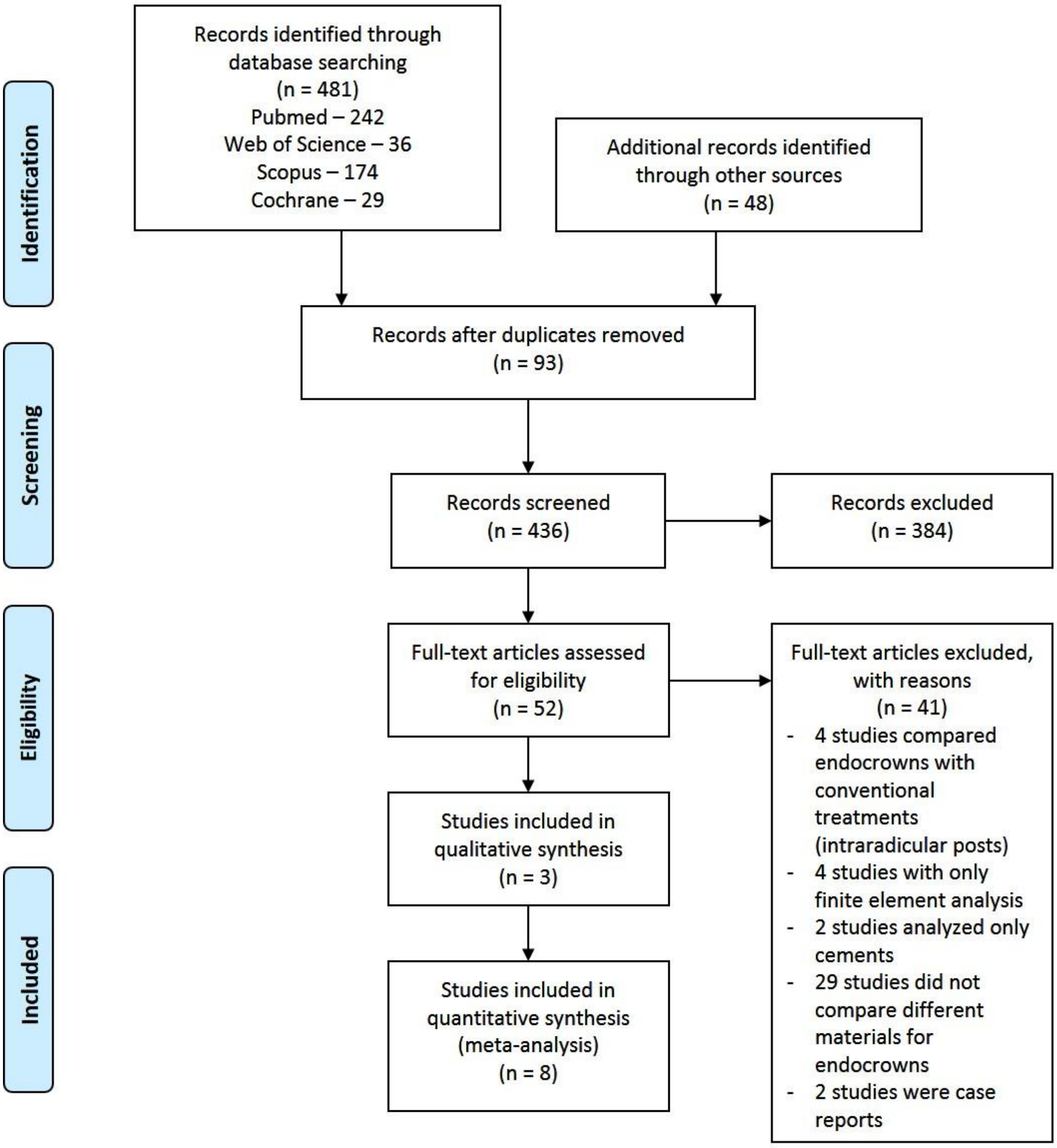

Fig. 1. Search flow as described in the PRISMA statement [24].

3.2. Descriptive analysis

The demographic data of the included studies are described in the Table 1. Among the eleven studies, six evaluated the fracture strength and failure modes of endocrown restorations made of different materials [2,5,7,8,13,14]; one evaluated marginal adaptation [12]; two evaluated internal fit [16,26]; one assessed fracture strength using acoustic emission method [10], and one evaluated fractures strength, failure modes and microleakage [11] (Table 2). No study reported the sample size calculation, and the number of teeth *per* group ranged from 8 to 12 teeth. Four studies analyzed endocrowns in anterior teeth [8,12–14], while the other seven studies analyzed them in posterior teeth [2,5,7,10,11,16,26]. Relative to the type of restorative material, all studies compared at least one type of ceramic material with a type of composite. The materials investigated were: feldspathic, lithium disilicate, monoblock zirconia, leucite glass-ceramic, metal ceramic, PICNs and nanoceramic resin. The lithium disilicate ceramic and nanoceramic resin were the materials most investigated and compared (Table 2).

The results of marginal adaptation and internal fit varied widely among the studies (Table 2): percentage of continuous margins at the interfaces, internal and marginal fit accuracy measurements (μm) and dye penetration at tooth/luting interface (mm). In the majority of the studies the composite material showed better marginal adaptation and internal fit when compared with ceramic [12,16,26]. The ceramic endocrowns showed the lowest values only in the microleakage analysis [11].

Only three studies performed 2 mm ferrule preparations [12–14]. Among the studies, there was variation in the depth of endocrown preparations, ranging from 2 to 6 mm deep in the pulp chamber; and four studies did not inform the depth of the preparation performed [2,7,10,12]. Only two studies compared the depth of preparation (2.5 and 5 mm / 3 and 6 mm) between ceramic and composite endocrowns [5,8].

As regards the quality and risk of bias of the studies, three (27%) showed high risk of bias. Only two showed low risk of bias (18%), while the majority (55%) had medium risk of bias. The results are described in Table 3.

Table 1
Demographic data of the included studies.

Author	Year	Type of Study	Country	Number of teeth (per group)	Type of teeth	Outcomes
Aktas [7]	2016	*in vitro*	Turkey	36 (12)	mandibular molars	Fracture strength, failure modes and stiffness with thermal cycling
Bankoğlu Güngör [14]	2017	*in vitro*	Turkey	60 (10)	maxillary central incisors	Fracture strength and failure modes
Darwish [26]	2017	*in vitro*	Egipty	40 (5)	maxillary first premolars	Internal fit
El-Damanhoury [11]	2015	*in vitro*	United Arab Emirates	30 (10)	maxillary molars	Fracture strength and microleakage with thermal cycling
Gresnigt [2]	2016	*in vitro*	The Netherlands	60 (10)	mandibular molar	Fracture strength and failure modes with thermal cycling
Kanat-Ertürk [8]	2018	*in vitro*	Turkey	100 (10)	maxillary central incisors	Fracture strength and failure modes with thermal cycling
Lise [5]	2017	*in vitro*	Belgium	48 (8)	single-rooted premolars	Fracture strength and failure modes with fatigue aging
Ramírez-Sebastià [12]	2013	*in vitro*	Spain	48 (8)	maxillary central incisors	Marginal adaption with thermal cycling and fatigue aging
Ramírez-Sebastià [13]	2014	*in vitro*	Spain	48 (8)	maxillary central incisors	Fracture strength and failure modes with thermal cycling and fatigue aging
Skalskyi [10]	2018	*in vitro*	Ukraine	25 (5)	maxillary and mandibular molars	Fracture strength and failure modes by means of acoustic emission analysis
Zimmermann [16]	2018	*in vitro*	Switzerland	30 (10)	maxillary first molar on typondont	Internal fit

Table 2
Data of fracture strength and marginal adaptation of the studies included in the review.

Study	Aging	Testing methods of fracture resistance / internal and marginal adaptation	Endocrown material/Groups	Number of teeth (per group)	Ferrule	Depth of preparation	Fracture strength (N) Mean (± SD)	Internal and Marginal adaptation
Aktas [7]	Thermocycling (5,000 cycles 5º a 55ºC)	Universal testing machine with a sphere at 45° at a cross-head speed of 0.5 mm/s	- Feldspatic ceramic Vitablocs Mark II®	12	no	not informed	1035.08 ± 155.24	not applicable
			- Zirconia-reinforced glass ceramic Suprinity®				1058.33 ± 172.49	
			- Polymer-infiltrated hybrid ceramic Enamic®				1025.00 ± 134.26	
Bankoğlu Güngör [14]	not applicable	Universal testing machine with a sphere at 45° at a cross-head speed of 1 mm/min	-Resin nano ceramic Lava Ultimate®	10	2 mm	5 mm	869.04 ± 247.77	not applicable
			-Lithium dissilicate IPS e-max CAD®				915.91 ± 182.06	
Darwish [26]	not applicable	Internal fit was tested using cone beam computed tomography imaging before and after adaptation	- Lithium dissilicate IPS e.max CAD® – short preparation / 6°	5	no	short (3 mm) or long (5 mm) preparation / 6° or 10° of axial wall divergence	not applicable	not informed*
			- Lithium dissilicate IPS e.max CAD® – short preparation / 10°					not informed*
			- Lithium dissilicate IPS e.max CAD® – long preparation / 6°					not informed*
			- Lithium dissilicate IPS e.max CAD® – long preparation / 10°					489.2 ± 41.52 µm
			- Resin nano ceramic Lava Ultimate® - short preparation / 6°					not informed*
			- Resin nano ceramic Lava Ultimate® - short preparation / 10°					394.8 ± 21.17 µm
			- Resin nano ceramic Lava Ultimate® - long preparation / 6°					not informed*
			- Resin nano ceramic Lava Ultimate® - long preparation / 10°					not informed*

El-Damanhoury [11]	Thermocycling (5,000 cycles 5º a 55ºC)	Universal testing machine with a sphere at 45° at a cross-head speed of 0.5 mm/min and dye penetration (mm)	- Feldspatic ceramic Cerec Blocks®	10	no	2 mm	1340.92 ± 97.80	1.11 ± 0.18 mm
			- Lithium dissilicate IPS e-max CAD®				1368.77 ± 237.34	1.91 ± 0.14 mm
			- Resin nano ceramic Lava Ultimate®				1583.28 ± 170.55	2.80 ± 0.19 mm
Gresnigt [2]	Thermocycling (10,000 cycles 5º a 55ºC)	Universal testing machine with a sphere applied perpendicular to the occlusal plane (axial loading) and on the interface tooth-endocrown (lateral loading)	- Lithium dissilicate IPS e-max CAD®	10	no	not informed	Axial 2428 ± 566 Lateral 1118 ± 173	not applicable
			- Resin nano ceramic Lava Ultimate®				Axial 2675 ± 588 Lateral 838 ± 169	
Kanat-Ertürk [8]	Thermocycling (5,000 cycles 5º a 55ºC)	Universal testing machine with a sphere at 45° at a cross-head speed of 1 mm/min	- Feldspatic ceramic Vita Mark II® – short	10	no	short (3 mm) or long preparation (6 mm)	47.29 ± 14.79	not applicable
			- Feldspatic ceramic Vita Mark II® - long				71.38 ± 23.56	
			- Lithium dissilicate IPS e-max CAD® - short				244.11 ± 119.77	
			- Lithium dissilicate IPS e-max CAD®) – long				225.08 ± 125.36	
			- Resin nano ceramic Lava Ultimate® – short				81.49 ± 37.47	
			- Resin nano ceramic Lava Ultimate® – long				99.80 ± 33.62	
			- Polymer-infiltrated hybrid ceramic Vita Enamic® – short				172.12 ± 135.64	
			- Polymer-infiltrated hybrid ceramic Vita Enamic® – long				182.38 ± 106.52	
			- Monoblock zirconia inCoris TZI® – short				533.61 ± 189.05	
			- Monoblock zirconia inCoris TZI® – long				610.54 ± 214.04	

Lise [5]	Fatigue loading (1,200,000 cycles)	Universal testing machine with a sphere at 45° at a cross-head speed of 0.5 mm/min	- Composite resin CAD/CAM Cerasmart® – short - Composite resin CAD/CAM Cerasmart® – long - Lithium dissilicate IPS e-max CAD® – short - Lithium dissilicate IPS e-max CAD® – long	8	no	short (2.5 mm) or long preparation (5 mm)	216.9 ± 32.0 156.8 ± 41.9 136.1 ± 44.3 209.0 ± 28.2	not applicable
Ramírez-Sebastià [12]	Fatigue loading (600,000 cycles) and thermocycling (1,500 cycles 5º a 55ºC)	Percentage of continuous margins at interfaces by scanning electron microscopy analysis	- Leucite-glassceramic IPS Empress CAD® - Composite resin Paradigm MZ100®	8	2 mm	not informed	not applicable	68.4 ± 23.6% 80.9 ± 8.14%
Ramírez-Sebastià [13]	Fatigue loading (600,000 cycles) and thermocycling (1,500 cycles 5º a 55ºC)	Universal testing machine with a sphere at 45° at a cross-head speed of 1 mm/min	- Leucite glass-ceramic IPS Empress CAD® - Composite resin Paradigm MZ100®	8	2 mm	5 mm	628.22 ± 258.70 497.13 ± 264.89	not applicable
Skalskyi [10]	not applicable	Acoustic emission detection system associated to testing machine (SVR-5) with a sphere at a crosshead speed of 0.12 mm/min	- Lithium dissilicate IPS e.max Press® - Metal ceramic - Composite resin Nano Q® - Zirconium dioxidePrettau zirconia®	5	no	not informed	2726 ± 226 3320 ± 423 1533 ± 211 3082 ± 305	not applicable
Zimmermann [16]	not applicable	Fitting accuracy measurements of margin, axial and occlusal areas by 3D digital technique analysis	- Zirconia-reinforces lithium dissilicate ceramic Cetra Duo® - Leucite glass-ceramic IPS Empress CAD® - Resin nano ceramic Lava Ultimate®	10	no	2 mm	not applicable	131 ± 26.5 µm 88.9 ± 7.7 µm 99.6 ± 23.7 µm

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*data requested but not informed.

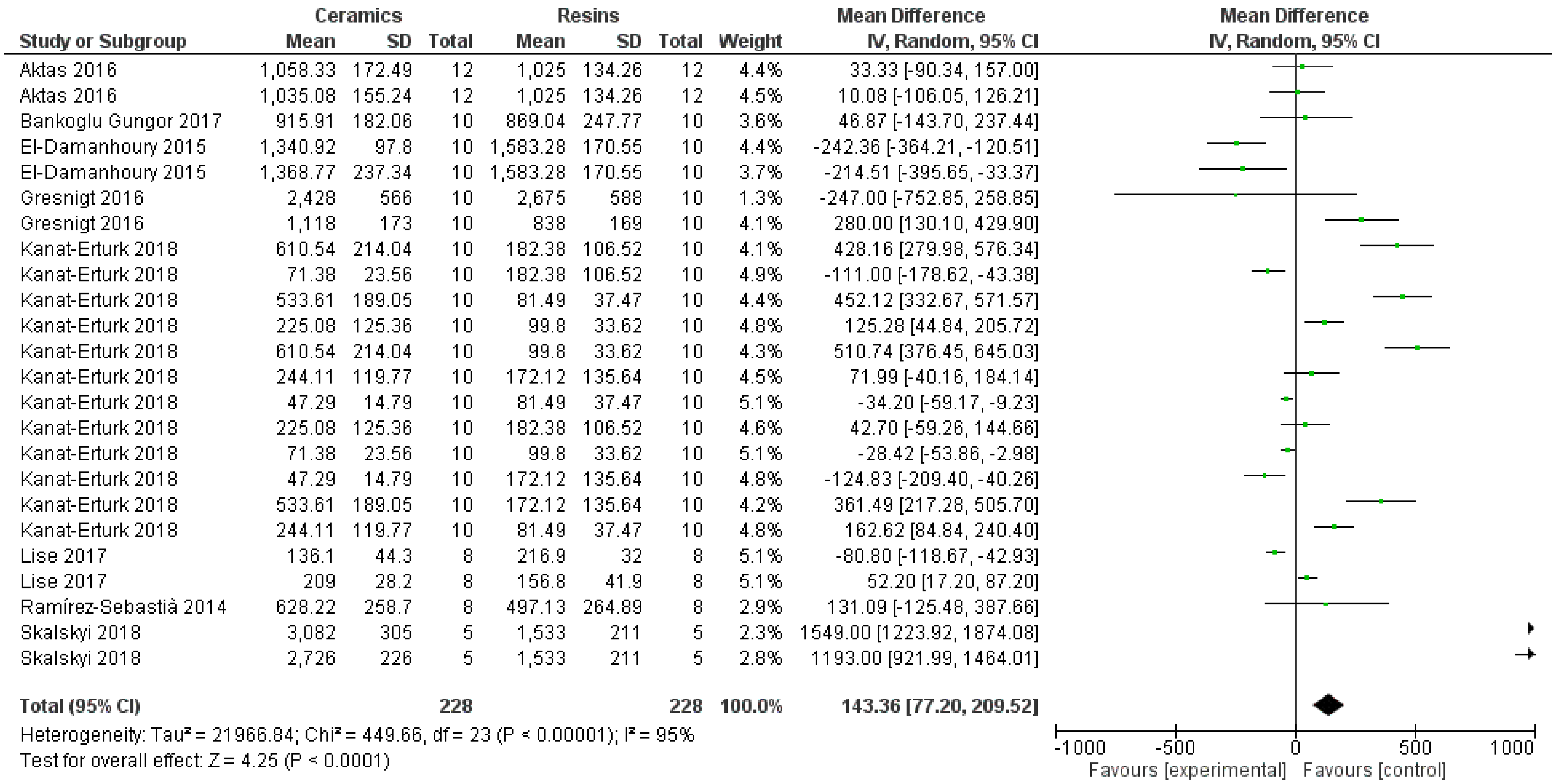
Table 3
Risk of bias of the studies considering parameters reported in Materials and Methods section.

	Randomization of teeth	Standard tooth preparation by the same researcher	Presence of control group	Teeth with similar morphology	Sample size calculation	Blind analysis of tooth preparation by two independently researchers	Standard design of endocrowns	Preparation depths of endocrowns	Artificial periodontal ligament	Risk of Bias
Aktas [7]	Yes	Yes	Yes	Yes	No	Yes	No	No	No	**Medium**
Bankoğlu Güngör [14]	Yes	No	Yes	Yes	No	No	Yes	Yes	No	**Medium**
Darwish [26]	No	No	No	Yes	No	No	No	Yes	No	**High**
El-Damanhoury [11]	Yes	No	Yes	Yes	No	No	Yes	Yes	No	**Medium**
Gresnigt [2]	Yes	No	Yes	Yes	No	No	No	No	No	**Medium**
Kanat-Ertürk [8]	Yes	Yes	Yes	Yes	No	No	Yes	Yes	Yes	**Low**
Lise [5]	Yes	No	Yes	Yes	No	No	Yes	Yes	No	**Medium**
Ramírez-Sebastià [12]	Yes	No	No	Yes	No	No	No	No	No	**High**
Ramírez-Sebastià [13]	Yes	No	No	Yes	No	No	No	Yes	No	**Medium**
Skalskyi [10]	No	No	Yes	Yes	No	No	No	No	No	**High**
Zimmermann [16]	-	-	Yes	-	No	-	Yes	Yes	-	**Low**

3.4. Meta-analysis

The meta-analysis was performed with eight *in vitro* studies (95% CI). The global fracture strength analysis showed statistically significant differences ($p<0.0001$) between ceramic endocrowns when compared with composite endocrowns, favoring the ceramic group (Fig. 2). The value of the I^2 test was 95%.

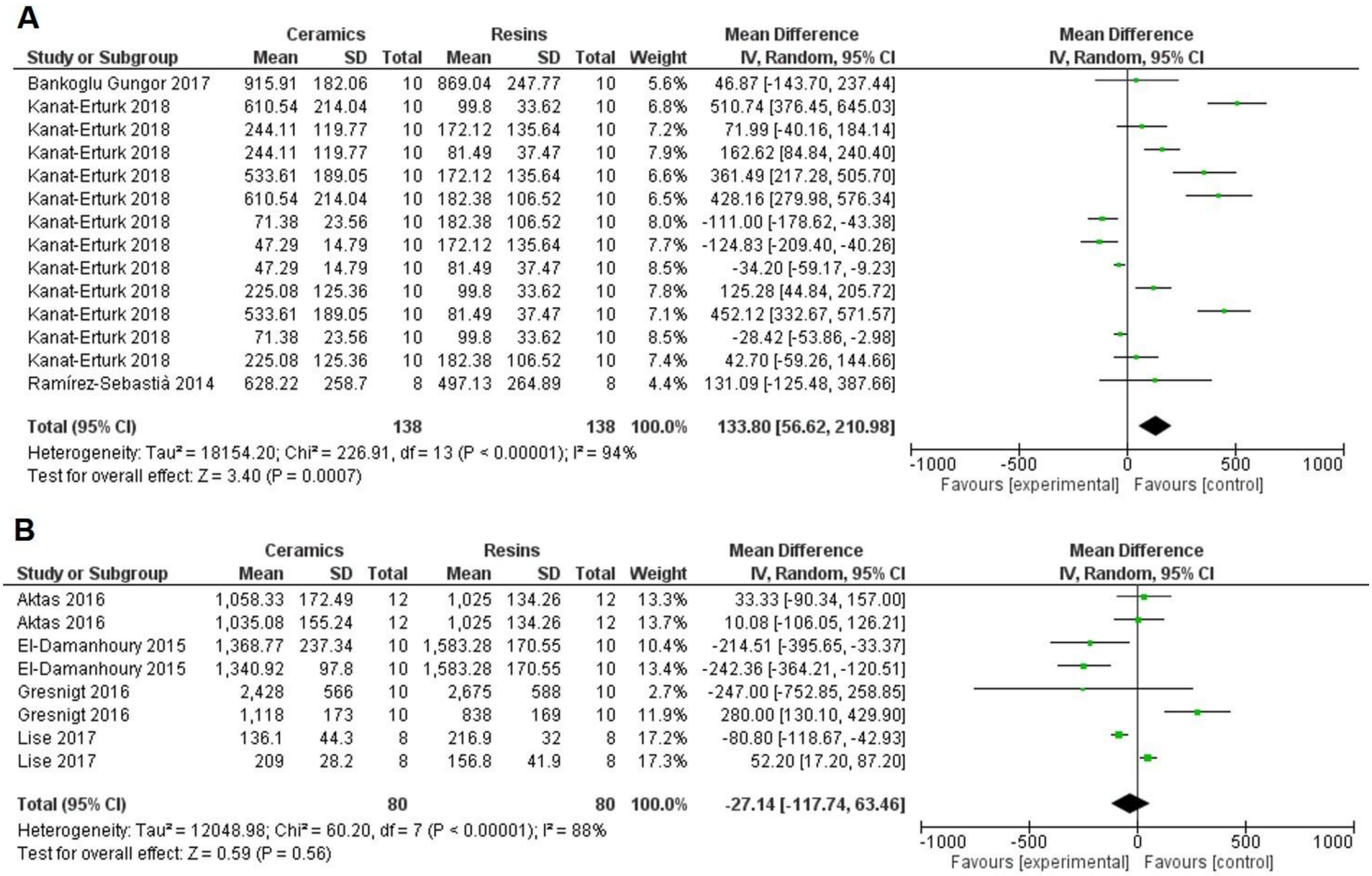
In the first subgroup analysis comparing fracture strength between ceramic and composite endocrowns in anterior teeth, there was a significant difference ($p= 0.0007$; $I^2= 94\%$) favoring the ceramic material (Fig. 3A). Whereas, there was no statistically significant difference of fracture strength between ceramic and composite materials for posterior teeth ($p= 0.56$; $I^2= 88\%$) (Fig. 3B). In the second subgroup analysis, there was no significant difference in fracture strength between ceramic and composite endocrowns, irrespective of the preparation depth (short preparation: $p= 0.37$; $I^2= 100\%$ and long preparation: $p= 0.05$; $I^2= 97\%$) (Fig. 4A and 4B).



	Ceramics			Resins				Mean Difference
Study or Subgroup	**Mean**	**SD**	**Total**	**Mean**	**SD**	**Total**	**Weight**	**IV, Random, 95% CI**
Aktas 2016	1,058.33	172.49	12	1,025	134.26	12	4.4%	33.33 [-90.34, 157.00]
Aktas 2016	1,035.08	155.24	12	1,025	134.26	12	4.5%	10.08 [-106.05, 126.21]
Bankoglu Gungor 2017	915.91	182.06	10	869.04	247.77	10	3.6%	46.87 [-143.70, 237.44]
El-Damanhoury 2015	1,340.92	97.8	10	1,583.28	170.55	10	4.4%	-242.36 [-364.21, -120.51]
El-Damanhoury 2015	1,368.77	237.34	10	1,583.28	170.55	10	3.7%	-214.51 [-395.65, -33.37]
Gresnigt 2016	2,428	566	10	2,675	588	10	1.3%	-247.00 [-752.85, 258.85]
Gresnigt 2016	1,118	173	10	838	169	10	4.1%	280.00 [130.10, 429.90]
Kanat-Erturk 2018	610.54	214.04	10	182.38	106.52	10	4.1%	428.16 [279.98, 576.34]
Kanat-Erturk 2018	71.38	23.56	10	182.38	106.52	10	4.9%	-111.00 [-178.62, -43.38]
Kanat-Erturk 2018	533.61	189.05	10	81.49	37.47	10	4.4%	452.12 [332.67, 571.57]
Kanat-Erturk 2018	225.08	125.36	10	99.8	33.62	10	4.8%	125.28 [44.84, 205.72]
Kanat-Erturk 2018	610.54	214.04	10	99.8	33.62	10	4.3%	510.74 [376.45, 645.03]
Kanat-Erturk 2018	244.11	119.77	10	172.12	135.64	10	4.5%	71.99 [-40.16, 184.14]
Kanat-Erturk 2018	47.29	14.79	10	81.49	37.47	10	5.1%	-34.20 [-59.17, -9.23]
Kanat-Erturk 2018	225.08	125.36	10	182.38	106.52	10	4.6%	42.70 [-59.26, 144.66]
Kanat-Erturk 2018	71.38	23.56	10	99.8	33.62	10	5.1%	-28.42 [-53.86, -2.98]
Kanat-Erturk 2018	47.29	14.79	10	172.12	135.64	10	4.8%	-124.83 [-209.40, -40.26]
Kanat-Erturk 2018	533.61	189.05	10	172.12	135.64	10	4.2%	361.49 [217.28, 505.70]
Kanat-Erturk 2018	244.11	119.77	10	81.49	37.47	10	4.8%	162.62 [84.84, 240.40]
Lise 2017	136.1	44.3	8	216.9	32	8	5.1%	-80.80 [-118.67, -42.93]
Lise 2017	209	28.2	8	156.8	41.9	8	5.1%	52.20 [17.20, 87.20]
Ramírez-Sebastià 2014	628.22	258.7	8	497.13	264.89	8	2.9%	131.09 [-125.48, 387.66]
Skalskyi 2018	3,082	305	5	1,533	211	5	2.3%	1549.00 [1223.92, 1874.08]
Skalskyi 2018	2,726	226	5	1,533	211	5	2.8%	1193.00 [921.99, 1464.01]
Total (95% CI)			**228**			**228**	**100.0%**	**143.36 [77.20, 209.52]**

Heterogeneity: Tau^2 = 21966.84; Chi^2 = 449.66, df = 23 ($P < 0.00001$); I^2 = 95%
Test for overall effect: Z = 4.25 ($P < 0.0001$)

Fig. 2. Results for the global analysis of the fracture strength of endocrowns for comparison between ceramics and composite materials using random-effects models.



A

Study or Subgroup	Ceramics Mean	Ceramics SD	Ceramics Total	Resins Mean	Resins SD	Resins Total	Weight	Mean Difference IV, Random, 95% CI
Bankoglu Gungor 2017	915.91	182.06	10	869.04	247.77	10	5.6%	46.87 [-143.70, 237.44]
Kanat-Erturk 2018	610.54	214.04	10	99.8	33.62	10	6.8%	510.74 [376.45, 645.03]
Kanat-Erturk 2018	244.11	119.77	10	172.12	135.64	10	7.2%	71.99 [-40.16, 184.14]
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Kanat-Erturk 2018	533.61	189.05	10	172.12	135.64	10	6.6%	361.49 [217.28, 505.70]
Kanat-Erturk 2018	610.54	214.04	10	182.38	106.52	10	6.5%	428.16 [279.98, 576.34]
Kanat-Erturk 2018	71.38	23.56	10	182.38	106.52	10	8.0%	-111.00 [-178.62, -43.38]
Kanat-Erturk 2018	47.29	14.79	10	172.12	135.64	10	7.7%	-124.83 [-209.40, -40.26]
Kanat-Erturk 2018	47.29	14.79	10	81.49	37.47	10	8.5%	-34.20 [-59.17, -9.23]
Kanat-Erturk 2018	225.08	125.36	10	99.8	33.62	10	7.8%	125.28 [44.84, 205.72]
Kanat-Erturk 2018	533.61	189.05	10	81.49	37.47	10	7.1%	452.12 [332.67, 571.57]
Kanat-Erturk 2018	71.38	23.56	10	99.8	33.62	10	8.5%	-28.42 [-53.86, -2.98]
Kanat-Erturk 2018	225.08	125.36	10	182.38	106.52	10	7.4%	42.70 [-59.26, 144.66]
Ramírez-Sebastià 2014	628.22	258.7	8	497.13	264.89	8	4.4%	131.09 [-125.48, 387.66]
Total (95% CI)			**138**			**138**	**100.0%**	**133.80 [56.62, 210.98]**

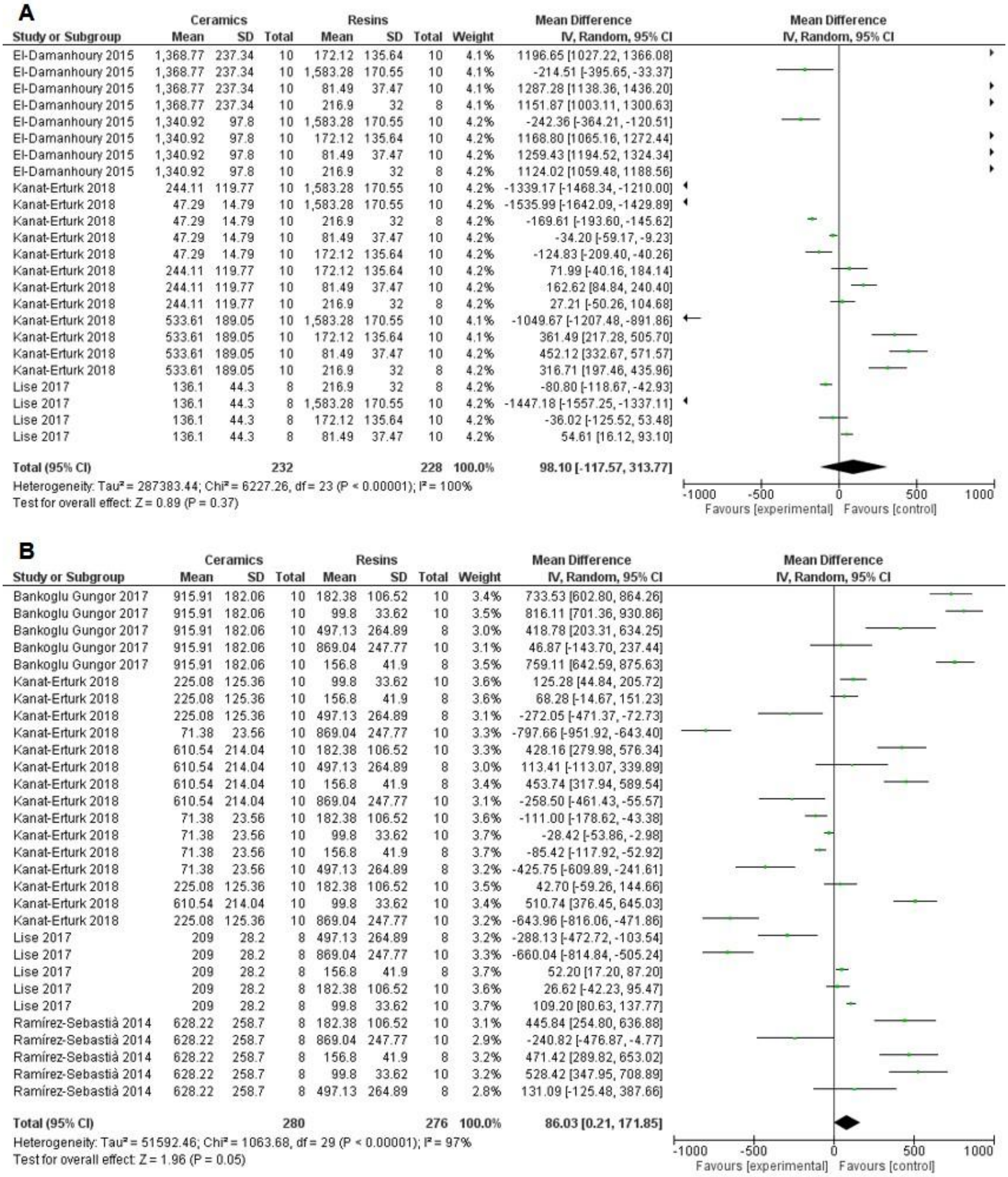
Heterogeneity: Tau² = 18154.20; Chi² = 226.91, df = 13 (P < 0.00001); I² = 94%
Test for overall effect: Z = 3.40 (P = 0.0007)

B

Study or Subgroup	Ceramics Mean	Ceramics SD	Ceramics Total	Resins Mean	Resins SD	Resins Total	Weight	Mean Difference IV, Random, 95% CI
Aktas 2016	1,058.33	172.49	12	1,025	134.26	12	13.3%	33.33 [-90.34, 157.00]
Aktas 2016	1,035.08	155.24	12	1,025	134.26	12	13.7%	10.08 [-106.05, 126.21]
El-Damanhoury 2015	1,368.77	237.34	10	1,583.28	170.55	10	10.4%	-214.51 [-395.65, -33.37]
El-Damanhoury 2015	1,340.92	97.8	10	1,583.28	170.55	10	13.4%	-242.36 [-364.21, -120.51]
Gresnigt 2016	2,428	566	10	2,675	588	10	2.7%	-247.00 [-752.85, 258.85]
Gresnigt 2016	1,118	173	10	838	169	10	11.9%	280.00 [130.10, 429.90]
Lise 2017	136.1	44.3	8	216.9	32	8	17.2%	-80.80 [-118.67, -42.93]
Lise 2017	209	28.2	8	156.8	41.9	8	17.3%	52.20 [17.20, 87.20]
Total (95% CI)			**80**			**80**	**100.0%**	**-27.14 [-117.74, 63.46]**

Heterogeneity: Tau² = 12048.98; Chi² = 60.20, df = 7 (P < 0.00001); I² = 88%
Test for overall effect: Z = 0.59 (P = 0.56)

Fig. 3. Results for subgroups analysis of fracture strength of endocrowns in anterior teeth (A) and posterior teeth (B) for comparison between ceramics and composite materials



A

	Ceramics			Resins				Mean Difference
Study or Subgroup	Mean	SD	Total	Mean	SD	Total	Weight	IV, Random, 95% CI
El-Damanhoury 2015	1,368.77	237.34	10	172.12	135.64	10	4.1%	1196.65 [1027.22, 1366.08]
El-Damanhoury 2015	1,368.77	237.34	10	1,583.28	170.55	10	4.1%	-214.51 [-395.65, -33.37]
El-Damanhoury 2015	1,368.77	237.34	10	81.49	37.47	10	4.1%	1287.28 [1138.36, 1436.20]
El-Damanhoury 2015	1,368.77	237.34	10	216.9	32	8	4.1%	1151.87 [1003.11, 1300.63]
El-Damanhoury 2015	1,340.92	97.8	10	1,583.28	170.55	10	4.2%	-242.36 [-364.21, -120.51]
El-Damanhoury 2015	1,340.92	97.8	10	172.12	135.64	10	4.2%	1168.80 [1065.16, 1272.44]
El-Damanhoury 2015	1,340.92	97.8	10	81.49	37.47	10	4.2%	1259.43 [1194.52, 1324.34]
El-Damanhoury 2015	1,340.92	97.8	10	216.9	32	8	4.2%	1124.02 [1059.48, 1188.56]
Kanat-Erturk 2018	244.11	119.77	10	1,583.28	170.55	10	4.2%	-1339.17 [-1468.34, -1210.00]
Kanat-Erturk 2018	47.29	14.79	10	1,583.28	170.55	10	4.2%	-1535.99 [-1642.09, -1429.89]
Kanat-Erturk 2018	47.29	14.79	10	216.9	32	8	4.2%	-169.61 [-193.60, -145.62]
Kanat-Erturk 2018	47.29	14.79	10	81.49	37.47	10	4.2%	-34.20 [-59.17, -9.23]
Kanat-Erturk 2018	47.29	14.79	10	172.12	135.64	10	4.2%	-124.83 [-209.40, -40.26]
Kanat-Erturk 2018	244.11	119.77	10	172.12	135.64	10	4.2%	71.99 [-40.16, 184.14]
Kanat-Erturk 2018	244.11	119.77	10	81.49	37.47	10	4.2%	162.62 [84.84, 240.40]
Kanat-Erturk 2018	244.11	119.77	10	216.9	32	8	4.2%	27.21 [-50.26, 104.68]
Kanat-Erturk 2018	533.61	189.05	10	1,583.28	170.55	10	4.1%	-1049.67 [-1207.48, -891.86]
Kanat-Erturk 2018	533.61	189.05	10	172.12	135.64	10	4.1%	361.49 [217.28, 505.70]
Kanat-Erturk 2018	533.61	189.05	10	81.49	37.47	10	4.2%	452.12 [332.67, 571.57]
Kanat-Erturk 2018	533.61	189.05	10	216.9	32	8	4.2%	316.71 [197.46, 435.96]
Lise 2017	136.1	44.3	8	216.9	32	8	4.2%	-80.80 [-118.67, -42.93]
Lise 2017	136.1	44.3	8	1,583.28	170.55	10	4.2%	-1447.18 [-1557.25, -1337.11]
Lise 2017	136.1	44.3	8	172.12	135.64	10	4.2%	-36.02 [-125.52, 53.48]
Lise 2017	136.1	44.3	8	81.49	37.47	10	4.2%	54.61 [16.12, 93.10]
Total (95% CI)			**232**			**228**	**100.0%**	**98.10 [-117.57, 313.77]**

Heterogeneity: Tau^2 = 287383.44; Chi^2 = 6227.26, df = 23 ($P < 0.00001$); I^2 = 100%
Test for overall effect: Z = 0.89 (P = 0.37)

B

	Ceramics			Resins				Mean Difference
Study or Subgroup	Mean	SD	Total	Mean	SD	Total	Weight	IV, Random, 95% CI
Bankoglu Gungor 2017	915.91	182.06	10	182.38	106.52	10	3.4%	733.53 [602.80, 864.26]
Bankoglu Gungor 2017	915.91	182.06	10	99.8	33.62	10	3.5%	816.11 [701.36, 930.86]
Bankoglu Gungor 2017	915.91	182.06	10	497.13	264.89	8	3.0%	418.78 [203.31, 634.25]
Bankoglu Gungor 2017	915.91	182.06	10	869.04	247.77	10	3.1%	46.87 [-143.70, 237.44]
Bankoglu Gungor 2017	915.91	182.06	10	156.8	41.9	8	3.5%	759.11 [642.59, 875.63]
Kanat-Erturk 2018	225.08	125.36	10	99.8	33.62	10	3.6%	125.28 [44.84, 205.72]
Kanat-Erturk 2018	225.08	125.36	10	156.8	41.9	8	3.6%	68.28 [-14.67, 151.23]
Kanat-Erturk 2018	225.08	125.36	10	497.13	264.89	8	3.1%	-272.05 [-471.37, -72.73]
Kanat-Erturk 2018	71.38	23.56	10	869.04	247.77	10	3.3%	-797.66 [-951.92, -643.40]
Kanat-Erturk 2018	610.54	214.04	10	182.38	106.52	10	3.3%	428.16 [279.98, 576.34]
Kanat-Erturk 2018	610.54	214.04	10	497.13	264.89	8	3.0%	113.41 [-113.07, 339.89]
Kanat-Erturk 2018	610.54	214.04	10	156.8	41.9	8	3.4%	453.74 [317.94, 589.54]
Kanat-Erturk 2018	610.54	214.04	10	869.04	247.77	10	3.1%	-258.50 [-461.43, -55.57]
Kanat-Erturk 2018	71.38	23.56	10	182.38	106.52	10	3.6%	-111.00 [-178.62, -43.38]
Kanat-Erturk 2018	71.38	23.56	10	99.8	33.62	10	3.7%	-28.42 [-53.86, -2.98]
Kanat-Erturk 2018	71.38	23.56	10	156.8	41.9	8	3.7%	-85.42 [-117.92, -52.92]
Kanat-Erturk 2018	71.38	23.56	10	497.13	264.89	8	3.2%	-425.75 [-609.89, -241.61]
Kanat-Erturk 2018	225.08	125.36	10	182.38	106.52	10	3.5%	42.70 [-59.26, 144.66]
Kanat-Erturk 2018	610.54	214.04	10	99.8	33.62	10	3.4%	510.74 [376.45, 645.03]
Kanat-Erturk 2018	225.08	125.36	10	869.04	247.77	10	3.2%	-643.96 [-816.06, -471.86]
Lise 2017	209	28.2	8	497.13	264.89	8	3.2%	-288.13 [-472.72, -103.54]
Lise 2017	209	28.2	8	869.04	247.77	10	3.3%	-660.04 [-814.84, -505.24]
Lise 2017	209	28.2	8	156.8	41.9	8	3.7%	52.20 [17.20, 87.20]
Lise 2017	209	28.2	8	182.38	106.52	10	3.6%	26.62 [-42.23, 95.47]
Lise 2017	209	28.2	8	99.8	33.62	10	3.7%	109.20 [80.63, 137.77]
Ramírez-Sebastià 2014	628.22	258.7	8	182.38	106.52	10	3.1%	445.84 [254.80, 636.88]
Ramírez-Sebastià 2014	628.22	258.7	8	869.04	247.77	10	2.9%	-240.82 [-476.87, -4.77]
Ramírez-Sebastià 2014	628.22	258.7	8	156.8	41.9	8	3.2%	471.42 [289.82, 653.02]
Ramírez-Sebastià 2014	628.22	258.7	8	99.8	33.62	10	3.2%	528.42 [347.95, 708.89]
Ramírez-Sebastià 2014	628.22	258.7	8	497.13	264.89	8	2.8%	131.09 [-125.48, 387.66]
Total (95% CI)			**280**			**276**	**100.0%**	**86.03 [0.21, 171.85]**

Heterogeneity: Tau^2 = 51592.46; Chi^2 = 1063.68, df = 29 ($P < 0.00001$); I^2 = 97%
Test for overall effect: Z = 1.96 (P = 0.05)

Fig. 4. Results for subgroups analysis of fracture strength of short (A) and long (B) endocrowns for comparison between ceramics and resins materials.

4. Discussion

In the present review only*in vitro* studies were evaluated. According to the search strategies used, two retrospective clinical studies investigated the clinical performance of ceramic and composite endocrowns, buta low number of composite endocrowns evaluated did not allow the comparison between the materials [6,27].Furthermore, our search also revelead the clinical trials have evaluated the performance of endocrown restorations fabricated from only one type of ceramic material [18–24]. Thus, although clinical trials provide more scientific evidence, laboratory studies have been used as alternative evidence when testing the different materials for endocrown restorations, and when trying to select the most suitable material. The correlation between laboratory data and clinical outcomes for dental prostheses is difficult to predict [28]. However, the fracture strength test associated with aging by thermal-mechanical cycling and fractographic analysis could play a critical role in predicting clinical lifetimes of ceramic materials[28,29]. For that, this systematic review and meta-analysis evaluated these parameters to verify the pooled effect of data from *in vitro* studies that compared ceramic and composite materials for endocrown restorations.

The meta-analysis results of this review showed high heterogeneity values, which is frequently found in *in vitro* systematic reviews due to the wide methodological variability among studies[30–32]. The majority studies showed medium risk of bias (55% - Table 3) and variation in the following aspects: composition of the ceramic and resin materials investigated; thermo-mechanical aging parameters; type of tooth investigated (incisor, molar or premolar), and bonding strategies and surface treatment of the restorations(Table 2). The extensive variability of sample size could also have been an influence. It is relevant to consider that no study performed a sample size calculation. Future laboratory studies should take into consideration standardized methodological parameters related to: thermo-mechanical assays, sample size calculation, tooth and restoration preparation and their blinding analysis, and the presence of control group with the aim of reducing the risk of bias.Other variability found was related to the simulation of the periodontal ligament, performed in only one study [8]. This simulation of clinical conditions is necessary for *in vitro* tests and could change the results of fracture strength and failure mode positively, since the ligament could serve as a shock absorber[2,14].

With regard to fracture strength, the ceramic endocrowns seemed to perform better than the composite types, with a relevant Z value and $p < 0.0001$ despite the high heterogeneity found($I^2 = 95\%$) (Fig. 2). In fact, ceramic materials showed higher fracture strength values when compared with composite endocrowns [7,8,14], and the highest elasticity modulus and flexural strength values of ceramic materials were associated with this result [8,10,14]. As several factors are related to the mechanical behavior of the restoration/tooth system and its performance in the oral cavity (mainly the intrinsic strength and the ratios of elastic moduli of tooth, cement, restoration; the thickness of restorative material; and the quality of adhesive interface) [18,33,34], only the fracture strength values of materials should not be considered to decide which material would be a better choice for clinical applications.

The researchers observed that the failure mode and fracture strength values should always be evaluated, because they are directly associated with the elasticity modulus and have an influence on the susceptibility to fracture of cemented restorations [5,8,11,14]. Ceramic materials have higher elasticity modulus (Zirconia: 180-220 GPa/ Lithium disilicate: 81-95 GPa/ Leucite glass-ceramic: 62-65.4 GPa/ Feldspathic: 45-63 GPa) compared with composite materials (PICNs: 30 GPa/ resin nanoceramic: 11.7-13.7 GPa) and with dentin (5.5-19.3 GPa) [5,8,11,13]. Rigid materials with different elastic moduli compared with that of the tooth produce more stress concentration in the critical areas leading to catastrophic failures, while restorative materials with elastic moduli compatible with that of dentin tend to bend under load and distribute stresses more evenly[11]. In addition, more brittle materials tend to induce cohesive failure within the luting composite at lower load values[5]. This fact could explain why the failure modes of the ceramic endocrowns were more frequently non-repairable and catastrophic involving the tooth root portion [5,7,8,11], reaching 100% of non-repairable fractures for zirconia endocrowns [7,11], while the composite endocrowns showed more repairable failures[7,8,11]. Thus, from a clinical point of view the reduced risk of catastrophic failures of the endocrown/tooth system and the possibility of being able to restore the tooth after fracture are relevant biomechanical behaviors of endocrowns and must also be considered when selecting restorative materials.

As far as we know, there is no previous study comparing the performance of anterior and posterior endocrowns in the same standardized study, but some studies reported that the failure mode and the survival rate of endocrowns could differ between anterior and posterior teeth, because the bond area and the incidence of non-axial forces during oral function may differ between them [4,5,8,14,18]. Thus, the sub-group analysis to evaluate the fracture strength between ceramic and composite endocrowns was performed separately for posterior and anterior teeth. For posterior teeth, there was no statistically significant difference between ceramic and composite endocrowns related to fracture strength ($p= 0.56$; $I^2= 88\%$) (Fig. 3B), whereas in anterior teeth,ceramic endocrowns seemed to perform better than the composite type ($p= 0.0007$; $I^2= 94\%$) (Fig. 3A). However, the result for anterior teeth should be considered with caution, because the zirconia was investigated as ceramic material only in the study of Kanat-Ertürk [8], and significant difference was found between ceramic and composite endocrowns. The highest strength values of zirconia endocrowns probably affected the meta-analysis results, because when the zirconia data were removed from the analysis no significant difference was found between the materials ($p= 0.62$, $I^2= 83\%$). Furthermore, for the analysis of posterior teeth, the study of Skalsky [10] was not included, because this made the data less heterogeneous, considering that the acoustic emission methodology used to evaluate the fracture strength generated values very divergent from those of the other studies.

Ceramic and composite endocrowns seemed have similar performance for short ($p= 0.37$) and for long ($p= 0.05$) preparation depths (Figs. 4A e 4B). As stated before, it could be speculated that the stiffer ceramic would have better fracture strength than the more resilient composite and more root failure would be observed. For the long preparation there was a tendency ($p=0.05$) toward that speculation, but no difference was found (Fig. 4B). Furthermore, relevant to consider is that high values of heterogeneity were found (Figs. 4A e 4B), showing evidence of the lack of standardization among the studies relative to preparation depth in the pulp chamber and the methodological parameters previously discussed. The reference value of preparation depth (5 mm) used for this sub-group meta-analysis was based on the Pissis[35] study and on the depth values found among the studies (Table 2). In the present review, only two *in vitro* studies evaluated its influence on the fracture strength of ceramic and composite endocrowns, and the material type influenced the results[5,8]. Despite the divergent results found between the studies, the present meta-analysis demonstrated no significant difference between ceramic and composite endocrowns for short and long preparation. Thus, it would seem clinically reasonable to consider that a shallow preparation for endocrowns in the pulp chamber could be more interesting than a long type, because it decreases the risk of accidental root perforation and avoids additional removal of sound tooth tissue that would weaken the tooth-root complex[5].

The standardization and classification of endocrown preparations has become extremely necessary to make it possible to compare the results of studies, to reduce or avoid the variability and heterogeneity among them, and to conduct well-designed clinical studies, mainly relative to the following: the amount of residual tooth walls and peripheral butt margins; and the preparation depth and degree of axial wall divergence inside pulp chamber. Evaluation of the preservation of tissues and presence of a ferrule effect are also important, since they optimize the biomechanical behavior of tooth/restoration[36]. There was no previous report of comparison (in a single study) of the effect of the presence or absence of ferrule on the fracture strength of endocrowns

The marginal adaptation and adequate fit of endocrowns are indispensable prerequisites for long-term clinical success[12,16]. In the present review it was not possible to carry out the meta-analysis for marginal and internal fit, due to the variability of analysis type found among the studies (Table 2). Nevertheless, the composite endocrowns showed better marginal adaptation and internal fit when compared with ceramic[12,16,26]. The resilience of composite endocrowns also seemed to have an effect on the distribution of stress that is transferred to the marginal walls, showing better mechanical behavior compared with rigid ceramic materials[12].

An important fact observed in the present review was that the lithium disilicate ceramic was the material most used in the *in vitro* studies, in spite of the clinical trials having mostly evaluated the long-term and short-term performance of feldspathic endocrowns[17,20,21]. The excellent esthetic appearance and better mechanical strength of lithium disilicate ceramic compared with the feldspathic type could probably explain why this material has been extensively investigated in the last few years. According to the studies, no significant difference in fracture strength was found between lithium disilicate and composite endocrowns (nanoceramic and PICNs)[2,5,8,14]. Therefore, a meta-analysis was performed to compare the fracture strength of lithium disilicate ceramic with that of composites, and there also was no statistically significant difference ($p= 0.18$, $I^2= 87\%$) (Appendix 3). The composition of nanoceramic and PICNs contain over 80% by weight of ceramic, which could improve the mechanical properties of composites and explain their mechanical strength values similar to those of lithium disilicate ceramic; and without losing their resilience and modulus of elasticity similar to dentin.

According to the present findings the study hypothesis was not accepted, because ceramic materials performed better than composites relative to fracture strength of endocrowns, and the composite materials provided better internal fit and marginal adaptation compared with the ceramic types. This review indicated that there was no single *in vitro* test variable that could predict the clinical performance of restorations, and their failure mode was of great importance in order tomake a well-informed decision of the material choice for endocrown restorations, until clinical studies be conducted.The results of the present review should be interpreted with caution because laboratory studies have intrinsic limitations to simulating *in vivo* conditions, and the studies investigated showed moderate-high bias and variation of methodological parameters. Well-designed randomized controlled trials to compare ceramic and composite materials in posterior and anterior teeth, with long follow-up periods, are needed to provide the answer to which material would be best indicated for endocrown restorations.

5. Conclusion

Both ceramic and composite materials showed adequate fracture strength, internal fit and marginal adaptationfor endocrown restorations. For fracture strength, the *in vitro* literature seemed to suggest that the use of ceramic endocrowns may provide better performance than the composites types, however the composite materials provided better internal fit and marginal adaptation when compared with ceramics. In addition, the failure mode of restoration must also be considered when deciding which material would be the better choice for endocrowns.

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Appendix 1 - List of articles excluded in the titles and abstracts selection

1.	2013 4th International Conference on Advances in Materials and Manufacturing, ICAMMP 2013. Advanced Materials Research 2014.
2.	Aarts Johanna WM, Nieboer Theodoor E, Johnson N, Tavender E, Garry R, Mol Ben Willem J, et al. Surgical approach to hysterectomy for benign gynaecological disease. Cochrane Database of Systematic Reviews [Internet]. 2015; (8).
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Appendix 2 - Articles excluded after analysis of full texts with reasons

	References	Reasons*
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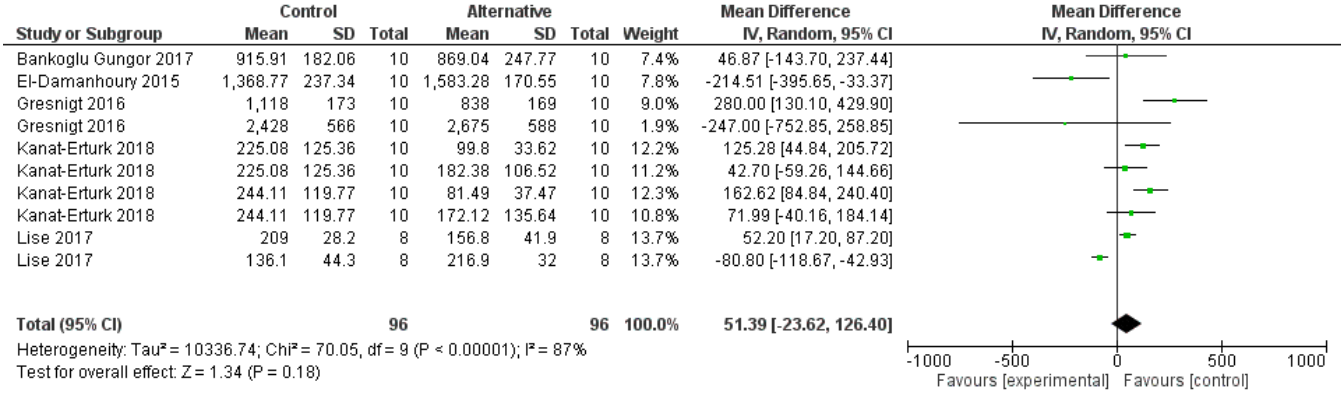
*** Abbreviations of the reasons for exclusion of each reference: EWC: endocrown restorations without the comparison of the performance of the materials used; EIP: evaluation only between endocrown restorations and restorations with intraradicular post; FEA: only finite element analysis; CR: case report; CA: only analysis of cements.**

Appendix 3 - Results for subgroups analysis of fracture strength of endocrowns of lithium disilicate ceramic compared to composite endocrowns



	Control			Alternative				Mean Difference	Mean Difference
Study or Subgroup	Mean	SD	Total	Mean	SD	Total	Weight	IV, Random, 95% CI	IV, Random, 95% CI
Bankoglu Gungor 2017	915.91	182.06	10	869.04	247.77	10	7.4%	46.87 [-143.70, 237.44]	
El-Damanhoury 2015	1,368.77	237.34	10	1,583.28	170.55	10	7.8%	-214.51 [-395.65, -33.37]	
Gresnigt 2016	1,118	173	10	838	169	10	9.0%	280.00 [130.10, 429.90]	
Gresnigt 2016	2,428	566	10	2,675	588	10	1.9%	-247.00 [-752.85, 258.85]	
Kanat-Erturk 2018	225.08	125.36	10	99.8	33.62	10	12.2%	125.28 [44.84, 205.72]	
Kanat-Erturk 2018	225.08	125.36	10	182.38	106.52	10	11.2%	42.70 [-59.26, 144.66]	
Kanat-Erturk 2018	244.11	119.77	10	81.49	37.47	10	12.3%	162.62 [84.84, 240.40]	
Kanat-Erturk 2018	244.11	119.77	10	172.12	135.64	10	10.8%	71.99 [-40.16, 184.14]	
Lise 2017	209	28.2	8	156.8	41.9	8	13.7%	52.20 [17.20, 87.20]	
Lise 2017	136.1	44.3	8	216.9	32	8	13.7%	-80.80 [-118.67, -42.93]	
Total (95% CI)			**96**			**96**	**100.0%**	**51.39 [-23.62, 126.40]**	

Heterogeneity: Tau² = 10336.74; Chi² = 70.05, df = 9 (P < 0.00001); I² = 87%

Test for overall effect: Z = 1.34 (P = 0.18)

5 CONSIDERAÇÕES FINAIS

De acordo com os achados desta revisão, os materiais cerâmicos parecem apresentar melhor desempenho para restaurações endocrown comparado aos resinosos com relação à resistência à fratura. Porém, quando o modo de falha das restaurações foi considerado, a maioria das falhas catastróficas ocorreram em restaurações endocrown cerâmicas. Já com relação ajuste interno e adaptação marginal, os materiais resinosos proporcionaram melhores resultados em relação aos cerâmicos. Assim, pode ser observado que não existiu um consenso entre os estudos *in vitro* sobre qual material seria o mais indicado para confeccionar restaurações endocrown, além da grande variabilidade metodológica e alta heterogeneidade encontrada entre eles. Desta forma, ensaios clínicos randomizados controlados e bem planejados para comparar materiais cerâmicos e resinosos, com longos períodos de acompanhamento, são necessários para fornecer qual material seria o mais indicado para restaurações de endocrown.

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