

The Influence of Different Designs, Materials and Cements on the Success and Survival Rate of Endocrowns. A Systematic Review

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ABSTRACT

The aim is to evaluate the success and survival rate of endocrowns and the influence of design, material and cements. A search of clinical trials of endocrowns was performed using three databases (Medline/PubMed, Scopus, CochraneLibrary), complemented by a manual search. The search resulted in 2,718 studies, six of which were included for analysis. The follow-up times were 2-12 years. Feldspathic porcelain was the material of choice cemented with different adhesive resin cement systems. Designs varied significantly. In total, the six studies represented 471 endocrowns. Thirty-six of these failed. Most common failures were loss of retention and fracture. Due to insufficient information on timing of events and drop-out, no statistical analysis was performed. No conclusive correlation between design, material, cement and success or survival of endocrowns could be established. Signs of differences in survival rates between molar and premolar endocrowns were noted, with a tendency towards higher survival rates for molar endocrowns. Feldspathic ceramic endocrowns with adhesive cementation demonstrate promising clinical performance. These conclusions are however based on a limited number of studies of comparatively low quality. Further studies are thus needed to verify the conclusions and to provide guidance in the clinical decision on best choice of materials, design and cements.

INTRODUCTION

Restoring endodontically treated teeth is important in order to provide sealing and restore function, esthetics and patient satisfaction.^{1,2} Compared to restoration of vital teeth, restoration of non-vital teeth is more challenging since more tooth substance is often removed to gain access and perform proper cleaning and root canal treatment.² Some authors suggest there may be structural differences in non-vital teeth compared to vital teeth, e.g. that dentin becomes more brittle after elimination of the pulp.³ This particular statement has however been challenged in other studies.⁴

Several treatment options exist to restore the endodontically treated tooth, each with their specific advantages and limitations. Direct restorations, such as composite fillings, may be sufficient if tooth substance loss is partial. However, indirect restorations in the form of crowns have

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higher short- and medium-term (5 and 10 year) survival rates than direct restorations.⁵ Teeth restored with a direct restoration after root canal treatment need replacement more frequently compared with indirectly restored teeth, 30.3% and 6.4% respectively after 5 years.⁶ When loss of tooth substance is extensive, a post and core in combination with a crown is a common treatment. Although this type of restoration has been proven to be successful in restoring tooth function and esthetics, there is a major drawback which is further removal of tooth substance. In addition, endodontically treated teeth which are restored with posts show increased risk of catastrophic failures.⁷ Risk of root fracture may be reduced with non-metal fiber-posts but these rely on bonding to the tooth substance which may be problematic.⁸ To avoid posts and their inherent risks, there is a need for something that can replace the significant macromechanical retention that the post provides.

In restorative dentistry, there are three main types of retention; macromechanical, micromechanical and chemical. Macromechanical retention can be achieved by preparation, e.g. box, pins and posts. Micromechanical retention can be created with adhesive cement locking into etched dentinal tubules and chemical retention can be achieved by a cement that creates a middle layer, an interface with boundaries between the tooth structure and the restoration.⁹ With the aid of adhesive dentistry, a shift in treatment alternatives toward more conservative modalities is possible, and the need for conventional post and cores could be reduced. Ceramic inlays, onlays, and endocrowns have been presented as alternative restorations for endodontically treated teeth, depending on the residual tooth structure.⁵

The endocrown technique was initially proposed by Pissis in 1995.¹⁰ The term endocrown was however, first described by Bindl and Mörmann in 1999, and was described as porcelain crowns fixed to internal surfaces of the pulp chamber of non-vital teeth by adhesive cementation.¹¹ Endocrowns thus obtain macromechanical retention by anchoring to the available axial walls of the pulp chamber and the use of adhesive resin cement will add micromechanical and chemical retention.^{11,12} The depth of the central cavity and the width of the central margins varies between studies. It is not known however, which design is preferable.

It has been reported that stresses accumulated at the interfaces of different materials with different elasticity moduli, may cause increased risk of root fracture.¹³ This risk could be reduced in endocrown restorations as endocrowns are suggested to be made of ceramic materials which have lower elastic moduli than the metals normally used for post and cores.¹⁴ Etchable porcelains and glass-ceramics are favored materials for endocrowns.¹⁵ However, it is not known whether porcelains or glass-ceramics show different long-term results. The success of endocrowns may also be affected by the type of bonding agent and cement.¹⁵

Endocrowns are suggested as a conservative alternative to restore root-canal treated teeth. However, the influence of factors such as different designs, materials and cements used, are not yet clear. To provide answers on the influence of these factors on success, survival and complication rates of restorations as well as teeth, a systematic review is warranted. The aim of this study is to systematically review the literature on endocrowns and evaluate their success and survival rate and how different designs, materials and cements affect the success of endocrowns.

MATERIAL AND METHODS

The addressed questions for the current review were:

1. What is the success and survival rate of endocrowns?
2. How does different designs, materials and cements affect the success of endocrowns?

DEFINITIONS

Endocrown: a crown fixed to the internal surface of the pulp chamber of nonvital teeth.¹¹

Success: the restoration has remained in function without any need of repair/adjustment during the observation period.

Survival: the crown remaining in situ with modification during the observation period.

Failure: The restoration has been removed.

SEARCH STRATEGY

Three bibliographic databases; PubMed (MEDLINE), Cochrane and Scopus, were used. Furthermore, the reference sections of included studies identified in the search of bibliographic databases were hand-searched, and reference lists of related meta-analyses and reviews were screened. The search strategy based on PICO with search terms and inclusion- and exclusion criteria are shown in Table 1.

The screening was done by two independent reviewers (WH, EP). Publications were selected based on the inclusion and exclusion criteria (Table 1) through the titles and, when at least one author found one study interesting, it was read in abstract. Abstracts where reviewers grading differed, were discussed and were either selected for full-text reading or excluded. Articles that did not have an abstract available went directly to full-text. The full-texts were read independently and disagreements regarding inclusion and exclusion were resolved through discussion, based on the set criteria. In the case of articles where content was unclear, the corresponding authors were contacted. Depending on the information acquired, the article was reevaluated and a decision was made on whether to include or exclude. In case of articles with repeated follow-up data, only the most recent publication was included.

Table 1. Search strategy and inclusion and exclusion criteria

Search strategy	((((endocrown) OR endo crown) OR endodontic crown) OR adhesive endodontic crown) OR ("Tooth, Nonvital"[Mesh]) AND "Crowns"[Mesh])
Population	Endodontically treated teeth
Intervention	Endocrown
Comparison	Design, material of endocrown and cement
Outcome	Success and survival rate
Inclusion criteria	English Clinical trial Treatment with endocrown Minimum follow-up time of 1 year Studies with a minimum of 10 patients Types of endocrown material and cements clearly stated
Exclusion criteria	In vitro studies Case reports Restoring endodontically treated teeth with other than endocrown

RESULTS

STUDY SELECTION

The search of databases resulted in 3,472 potential articles. After removing duplicates, 2,718 articles were left. Out of those articles, 170 relevant abstracts were identified. Based on abstract reading, 71 potentially relevant articles were identified for full-text reading. After application of inclusion and exclusion criteria, 64 articles were excluded for different reasons, leaving 7 articles for analysis. Appendix 1.

One study was excluded at this stage as full-text analysis revealed that the same sample was used in another included study from the same author.¹⁶ Consequently, 6 studies were included for final analysis.^{11,17-21} (Figure 1.)

DESCRIPTIVE ANALYSIS

Study set-up

No randomized clinical trials were identified, although three studies had a control group (no matched groups).¹⁹⁻²¹ Three of the included studies were prospective and three were retrospective. Three of the included studies were conducted in a university setting, two in a private dental office, one study lacked information on setting. The publication dates ranged from 1999 to 2017. A total of 471 endocrowns were reported. All endocrowns were placed on molars and premolars except one study (Belleflamme *et al*) that included canine crowns in 2 cases.¹⁷ Follow-up time ranged from 2 to 12 years. (Table 2.)

Design

The designs of endocrowns were mainly with pulp chamber extension but with varying depth. Two studies (Bernhart *et al* and Fages *et al*) mentioned a minimum depth of internal cavity axial walls of 2 mm and a circular butt margin (shoulder) width of 2 mm.^{18,20} One study (Bindl and Mörmann) made the axial wall depth 1-4 mm and the shoulder 1-1.2 mm.¹¹ The other studies did not mention specific measurements. (Table 2.)

Materials

Four studies used milled feldspathic ceramic blocks. Bindl and Mörmann used other ceramic materials in addition to feldspathic ceramic; In-Ceram Alumina and In-Ceram Spinell.¹¹ Belleflamme *et al* used three different materials; lithium disilicate glass-ceramic in a majority of the cases, some polymer-infiltrated ceramic network and a few restorations of indirect composite.¹⁷ (Table 2.)

Cements

All six included studies used adhesive resin cements. Three studies (Belleflamme *et al*, Bernhart *et al* and Otto *et al*)^{17,18,21} used dual-curing adhesive resin cements, while three studies (Bindl and Mörmann, Bindl *et al* and Fages *et al*) used light-curing adhesive resin cements.^{11,19,20} With the In-Ceram Alumina and Spinell endocrowns, a self-curing adhesive resin cement was used.¹¹ (Table 2.)

OUTCOME

Thirty-six out of the 471 endocrowns were lost, i.e. 7.6%. The most common failure among the included studies was loss of retention of the endocrown. Eighteen (6 premolar and 12 molars) out of 471 endocrowns (3.8%) lost retention. In most cases, debonding occurred between the resin luting material and dentin. Seven endocrowns out of 471 (1.5%) fractured; four feldspathic porcelain endocrowns, and three cases where the material was not stated. Two of the fractures were minor chipping, the others were complete crown fractures. Biological failure happened in eight cases (1.7%). Five cases were periodontitis, two recurrent caries and one osteitis. In addition, two vertical root fractures occurred. (Table 2.)

Success and survival rate as reported in the different studies

The reported survival rate of endocrowns ranged from 68.8% to 99.9%. This wide range is largely due to a difference between molars and premolars in two studies.^{19,21} In one study premolar and molar survival rate was 68.8% and 87.1% respectively, after 5 years follow-up.¹⁹ In another study, the molar survival rate was 90.5% while premolars survival rate decreases to 75% after 12 years follow-up.²¹ Success rates were only presented in two studies (Belleflamme *et al* and Fages *et al*) as 89.9% and 99.8% respectively.^{17,20} (Table 2.)

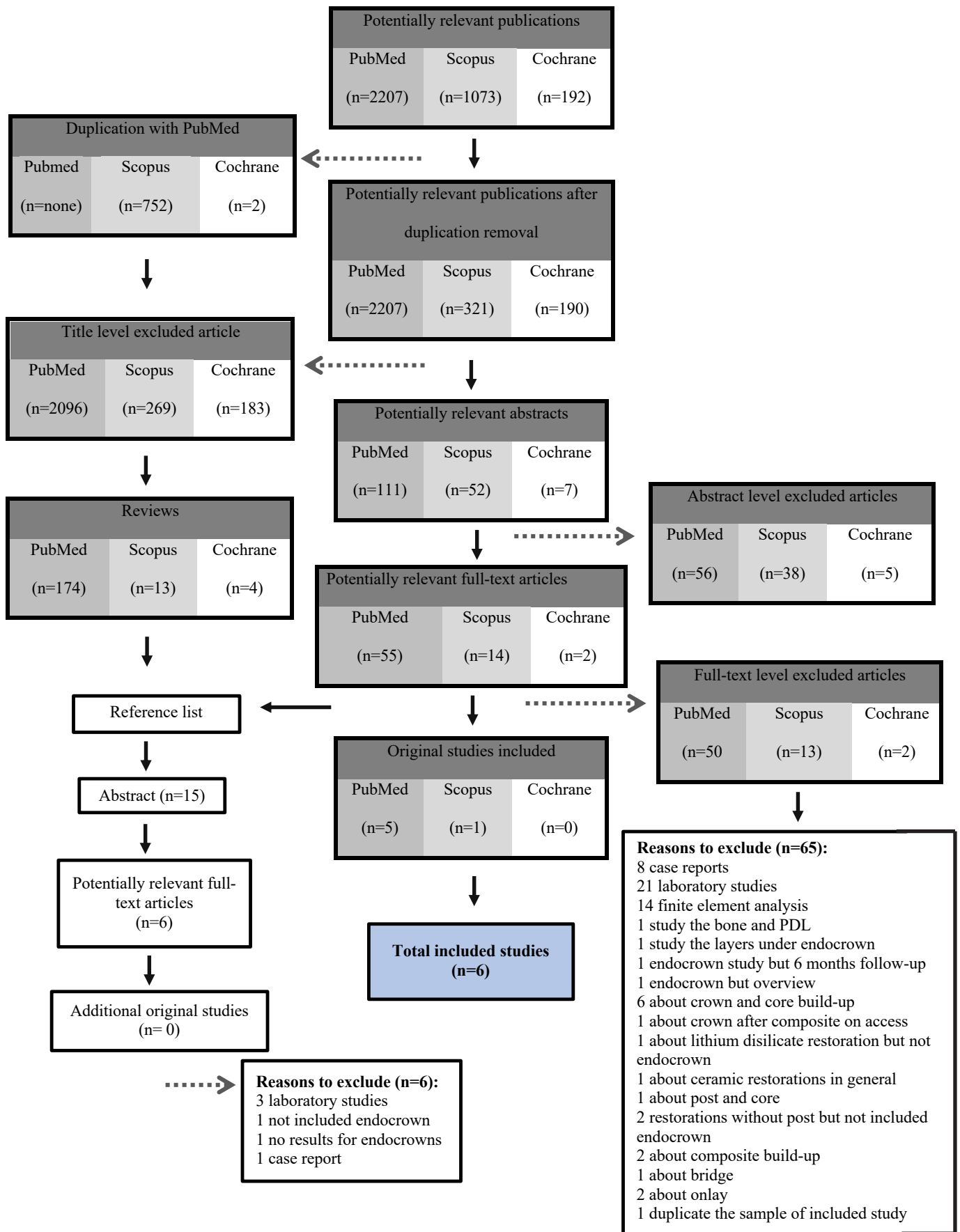


Figure 1: Flow-chart of search and study selection

Design, material and cementation

This analysis is based on five papers as one paper did not provide enough information to answer the research question: Belleflamme *et al* investigated three different materials and did not clarify in which material each failure occurred.¹⁷

When it comes to the design of endocrowns, some included studies recommend the retentive cavity depth and the shoulder width to be minimum 2 mm each.^{18,20} However, there was no mention of whether different depths affected the outcome. Most restorations were made of feldspathic ceramic (Vitablocks Mark II, Vita Zahnfabrik, Bad Säckingen, Germany) with CAD/CAM system. One study used glass infiltrated alumina (In-ceram Alumina and In-Ceram Spinell).¹¹ No failures occurred in this group of six restorations. Adhesive resin cements was the bonding material for all included studies. Debonding occurred between the cement and the tooth substance.

DISCUSSION

DISCUSSION ON METHODOLOGY

The search strategy was selected to be broad to include all possible relevant articles. Three databases were used. The language restriction may however have prevented finding some eligible studies. Considering the limited amount of studies identified, inclusion of case reports could have added data. On the other hand, the fact that two reviewers independently searched and applied the inclusion and exclusion criteria is a strength that may minimize selection bias.²² The minimum follow-up time was set as one year since shorter follow-up is less likely to reliably assess clinical outcome. Most reviews perform a quality assessment of the included studies. No such assessment was performed in the present review as only few studies with a large degree of heterogeneity were identified. Strict assessment with high quality demands would have resulted in no included studies. No statistical analysis was performed due to the heterogeneity of the studies. The present paper should thus be viewed as a descriptive review.

DISCUSSION ON RESULTS

As a limited number of studies with a large degree of heterogeneity were included, the results should be interpreted carefully.

Loss of retention

Loss of retention occurred in 3.8% of endocrowns. This is high when compared to single crowns after 5-years. Sailer *et al* found a loss of retention rate among feldspathic crowns to be 0.6%, and 0.2% among lithium-disilicate crowns which was similar to metal-ceramic crowns (0,1%).²³ In most cases, debonding occurred between the cement and dentin which suggests that the weak part was the luting agent/dentin

interface. Bonding to dentin has known limitations.²⁴ In addition, high modulus of elasticity of a ceramic material could transfer uncushioned chewing loads to the interface between luting cement and dentin, producing detrimental stress.²⁵ The debonding could also be explained by insufficient macroretention. Stabilization through the pulpal chamber walls was less than 2 mm in some studies, while the depth of the cavity has been advocated to extend to at least 3 mm.²⁶ A laboratory study showed that under oblique loading, molar endocrowns provided higher fracture resistance than glass fiber post-retained conventional crowns.²⁷ The height of retentive part of the endocrowns in that study was between 3.7 and 5mm.

Fracture

The fractures that occurred could be due to limitations in physical properties of the ceramic material, and/or the design of the preparation, e.g. inadequate ceramics layer thickness, unfavorable stress orientation or intensity.²⁸ Framework fracture has been shown to be a common failure among feldspathic single crowns. A 5-year fracture rate of 6.7% has been reported, compared to 0.03% for metal-ceramic crowns in the same study.²³ The reason could also be related to the cementation. If there is insufficient adhesion between restoration and dentin/enamel the brittle ceramic will not be properly supported with increased risk of mechanical failure.^{29,30} One *in-vitro* study concludes that bonded ceramic endocrowns exhibit a significantly greater fracture resistance than the classic crown supported with posts and cores.³¹

Biological failures

Varying types of biological failures were reported. Biological complications are generally multifactorial and patient-related factors are likely to be more important than whether the restoration is a classic crown design or endocrown design.

Outcome

The clinical performance of endocrowns is comparable to other ceramic single tooth restorations. A study by Sailer *et al*, calculated a 5-year survival rate of feldspathic/silica-based ceramic single crown of 90.7%.²³ The higher failure rate of endocrowns on premolars than on molars could be due to the smaller surface area available for chemical and micro-mechanical retention in premolars. No conclusive correlation between the design, material, cement and the failures and success rate of endocrown could however be established, as no randomized controlled clinical trials comparing designs, materials and/or cements were identified.

Endocrowns have the advantage of less need for removal of sound tissue compared to other techniques, in addition to reduced chair time and dental laboratory work needed when post-and-core is excluded.¹⁵ However, due to the limited number of trials with a large degree of heterogeneity, the optimal design, choice of material and cement could

Table 2. Summary of all included studies

Author/ Design/ Setting	Patients (originally) ^a	Endocrowns (originally) ¹	Localization (n)	Control group	Follow-up (mean)	Design (n)	Endocrown Material (n)	Bonding material	Results	Failure reason (localization)	Success rate (ScR)/ Survival rate (SrR) ^b												
Belleflamme M et al. 2017^c	64 (94)	99 (137)	molars (56) premolars (41) canine (2)	-	10 years (44.7 ± 34.6 months)	Class 1: at least two cuspal walls superior to the half of their original height. (16) Class 2: maximum one cuspal wall superior to the half of its original height. (8) Class 3: all cuspal walls are reduced more than the half of their original height. (76) Pulp chamber anchorage (69) Ferrule (54)	Lithium disilicate glass-ceramic (IPS Empress2 or IPS e.max Press, Ivoclar Vivadent, Schaan, Liechtenstein) (84) Polymer-Infiltrated Ceramic Network (Enamic, VITA Zahnfabrik H. Rauter GmbH & Co. KG, Bad Sackingen, Germany) (12) Artisanal indirect composite (3)	Variolink 2 (Ivoclar Vivadent, Schaan, Liechtenstein) Dual cure	10 failures	Biological: 3 periodontitis (molar) 2 caries (molar) Technical: 2 loss of retention (molars) 3 fractures: 1 complete, 2 chipping (2 molars, 1 premolar)	ScR: 89.9% SrR: 99.0% Cumulative ScR: 54.9% Cumulative SrR: 98.8%												
												Retrospective	no information	235 (235)	molars (235): 122 maxilla, 113 mandible)	212 conv. crowns	7 years	minimum 2 mm axial direction and wall thickness - minimum occlusal thickness 1.5mm Crowns fabrication: all direct	Feldspathic ceramic (Vitablocks Mark II, VITA Zahnfabrik H. Rauter GmbH & Co. KG, Bad Sackingen, Germany)	Relyx Unicem (3M Espe Dental Division, Germany) Light cured	1 failure	Biological: none reported Technical: 1 fracture (molar)	ScR: 99.8% SrR: 99.9%
Private																							
Otto T et al 2015	no information	25 (25)	20 molars 5 premolars	8 conv. crowns and 32 "reduced prep" crowns	12 years (10 years, 8 months)	Prepare the internal walls of the pulp for retention, epigingival level walls Crowns fabrication: all direct	Feldspathic ceramic (Vitablocks Mark II, VITA Zahnfabrik H. Rauter GmbH & Co. KG)	Duo Cement Plus (Coltène/Whaledent AG, Altstätten, Suisse) Dual cured	3 failures (1 molar, 1 premolar) 1 complete fracture (molar)	Biological: none reported Technical: 2 loss of retention (1 molar, 1 premolar) 1 complete fracture (molar)	Cumulative SrR Overall: 85.7% Molar: 90.5% Premolar: 75%												
Prospective Private																							

Table 2 continued overleaf...

<p>Bernhart J et al 2010 Prospective No Information available</p>	<p>18 (18)</p> <p>20 (20)</p> <p>molars (15 maxilla, 5 mandible)</p> <p>2 years (24 ± 2 months)</p> <p>Central cavity in pulp cavity: 2-4mm depth, 4mm width, 5mm orofacial</p> <p>Circular shoulder 2mm- occlusal reduction at least 2mm.</p> <p>Crowns fabrication: indirect</p> <p>Feldspathic ceramic (Vitablocks Mark II, VITA Zahnfabrik H. Rauter GmbH & Co. KG)</p> <p>Panavia™ F 2.0 (Kuraray Medical, Osaka, Japan)</p> <p>Dual cured</p> <p>2 failures</p> <p>Biological: none reported</p> <p>Technical: 1 tooth and restoration fractures (molar) 1 complete fracture (molar)</p> <p>SrR: 90%</p>
<p>Bindl A et al 2005 Retrospective University of Zürich</p>	<p>70 conv. crowns and 52 "reduced prep" crowns</p> <p>86</p> <p>70 molars 16 premolars</p> <p>5 years (52 ± 15 months)</p> <p>Pulp chamber retention cavity</p> <p>Crowns fabrication: 39 direct 47 indirect</p> <p>Feldspathic ceramic (Vitablocks Mark II, VITA Zahnfabrik H. Rauter GmbH & Co. KG)</p> <p>Tetric (Ivoclar Vivadent, Schaan, Liechtenstein)</p> <p>Light cured</p> <p>Biological: 1 osteitis (molar) 2 periodontitis (molars)</p> <p>Technical: 14 loss of retention (9 molars, 5 premolars)</p> <p>Other: 2 vertical root fracture (molars)</p> <p>Cumulative SrR: Molar: 87.1% Premolar: 68.8%</p>
<p>Bindl and Mörmann 1999 Retrospective University of Zürich</p>	<p>13 (33)</p> <p>19</p> <p>15 molars 4 premolars</p> <p>2 years (26 ± 6 months)</p> <p>Central retention cavity of the entire pulp chamber (depth 1-4mm) circular equigingival butt margin (width 1-1.2 mm)</p> <p>Crowns fabrication: 5 direct 14 indirect</p> <p>Feldspathic ceramic (Vitablocks Mark II, VITA Zahnfabrik H. Rauter GmbH & Co. KG) (13)</p> <p>In-Ceram Alumina (VITA Zahnfabrik H. Rauter GmbH & Co. KG) (3)</p> <p>Mark II ceramic: Tetric (Ivoclar Vivadent, Schaan, Liechtenstein)</p> <p>Light cured</p> <p>In-Ceram: Panavia 21 TC (Kuraray Medical, Osaka, Japan)</p> <p>Dual cured</p> <p>1 failure</p> <p>Biological: 1 caries - (molar in material Mark II)</p> <p>Technical: none reported</p> <p>SrR: 95%</p>

^a Before the drop-out

^b The success and survival rate mentioned just like the original studies

^c Belleflamme was excluded from the analysis to answer research question 2.

not be determined. Randomized clinical trials comparing endocrowns of different designs, materials and cements as well as comparing endocrowns with conventional crowns and post and core treatment are needed. The presence of control groups, and randomization between groups, is preferable as it limits the risk of selection bias. In the meantime, using a design with a minimum of 2 mm retentive pulp cavity design, etchable glass-based ceramics and an adhesive resin cement system is recommended.

CONCLUSION

The main finding of this review is the limited number of available trials evaluating endocrowns – as well as the limited quality and high risk of bias in the available papers. Within the limitations of this systematic review, some preliminary conclusions of possible relevance for the dental community may be suggested:

- endocrown restorations made from feldspathic ceramic, with a retentive cavity depth into the pulp chamber of 1-4 mm and a shoulder preparation width of 1-2 mm, cemented with adhesive resin cement, shows potential as a treatment alternative to restore endodontically treated teeth.
- a higher survival rate is found for molar than premolar endocrowns.

Further studies are needed to verify these findings and to provide guidance in the clinical decision on best choice of materials, design and cements.

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29. Mörmann, W.H., Bindl, A., Lüthy, H. and Rathke, A. Effects of preparation and luting system on all-ceramic computer-generated crowns. *Int. J. Prosthodont.*, 1998; **11**:333-399.

30. Fleming, G.J.P. and Addison, O. Adhesive Cementation and the Strengthening of All-Ceramic Dental Restorations. *J. Adhes. Sci. Technol.*, 2009; **23**:945-959.

31. Chang, C.Y., Kuo, J.S., Lin, Y. and Chang, Y.H. Fracture resistance and failure modes of CEREC endo-crowns and conventional post and core-supported CEREC crowns. *J. Dent. Sci.*, 2009; **4**:110-117.

APPENDICES

Appendix 1. List of excluded articles and the reasons for exclusion.

	Article	Reason for exclusion
1	Aversa R, Apicella D, Perillo L, et al. Non-linear elastic three-dimensional finite element analysis on the effect of endocrown material rigidity on alveolar bone remodeling process. <i>Dent Mater.</i> , 2009; 25 :678-690.	Study the bone and PDL
2	Barkhordar R.A, Plesh O, Curtis DA, Watanabe L. and Parisi R.G. Fracture resistance of endodontically treated teeth restored with bonded amalgam and full crowns. <i>Gen Dent.</i> , 1999; 47 :404-407.	Crown and core build-up
3	Beier U.S, Kapferer I. and Dumfahrt H. Clinical long-term evaluation and failure characteristics of 1,335 all-ceramic restorations. <i>Int J Prosthodont.</i> , 2012; 25 :70-78.	Ceramic restoration in general
4	Bitter K, Meyer-Lueckel H, Fotiadis N, et al. Influence of endodontic treatment, post insertion, and ceramic restoration on the fracture resistance of maxillary premolars. <i>Int Endod J.</i> , 2010; 43 :469-477.	Crown after composite on access
5	Bitter K, Noetzel J, Stamm O, et al. Randomized clinical trial comparing the effects of post placement on failure rate of postendodontic restorations: preliminary results of a mean period of 32 months. <i>J Endod.</i> , 2009; 35 :1477-1482.	No post, Crown and core build-up
6	Bompolaki D, Kontogiorgos E, Wilson J.B. and Nagy W.W. Fracture resistance of lithium disilicate restorations after endodontic access preparation: An <i>in vitro</i> study. <i>J Prosthet Dent.</i> , 2015; 114 :580-586.	Lithium disilicate restoration but not endocrown
7	Daoudi M.F. A single-appointment, definitive post-crown restoration: a case report. <i>Dent Update.</i> , 2002; 29 :303-305.	Post and core
8	Fokkinga W.A, Kreulen C.M, Bronkhorst E.M. and Creugers N.H. Composite resin core-crown reconstructions: an up to 17-year follow-up of a controlled clinical trial. <i>Int J Prosthodont.</i> , 2008; 21 :109-115.	Composite build-up
9	Grobecker-Karl T, Christian M. and Karl M. Effect of endodontic access cavity preparation on monolithic and ceramic veneered zirconia restorations. <i>Quintessence Int.</i> , 2016; 47 :725-729.	Study on bridges
10	Guzy G.E. and Nicholls J.I. <i>In vitro</i> comparison of intact endodontically treated teeth with and without endo-post reinforcement. <i>J Prosthet Dent.</i> , 1979; 42 :39-44.	No endocrown
11	Rocca G.T, Saratti C.M, Cattani-Lorente M, Feilzer A.J, Scherrer S. and Krejci I. The effect of a fiber reinforced cavity configuration on load bearing capacity and failure mode of endodontically treated molars restored with CAD/CAM resin composite overlay restorations. <i>J Dent.</i> , 2015; 43 :1106-1115.	Study the layers under an endocrown
12	Salameh Z, Ounsi H.F, Aboushelib M.N, Al-Hamdan R, Sadig W. and Ferrari M. Effect of different onlay systems on fracture resistance and failure pattern of endodontically treated mandibular molars restored with and without glass fiber posts. <i>Am J Dent.</i> , 2010; 23 :81-86.	Onlay
13	Salameh Z, Sorrentino R, Ounsi HF, et al. Effect of different all-ceramic crown system on fracture resistance and failure pattern of endodontically treated maxillary premolars restored with and without glass fiber posts. <i>J Endod.</i> , 2007; 33 :848-851.	No endocrown

14	Salameh Z, Sorrentino R, Papacchini F, et al. Fracture resistance and failure patterns of endodontically treated mandibular molars restored using resin composite with or without translucent glass fiber posts. <i>J Endod.</i> , 2006; 32 :752-755.	Composite build-up
15	Yu W, Guo K, Zhang B. and Weng W. Fracture resistance of endodontically treated premolars restored with lithium disilicate CAD/CAM crowns or onlays and luted with two luting agents. <i>Dent Mater J.</i> , 2014; 33 :349-354.	Onlay
16	Biacchi G.R, Mello B. and Basting R.T. The endocrown: an alternative approach for restoring extensively damaged molars. <i>J Esthet Restor Dent.</i> , 2013; 25 :383-390.	Case report
17	Bilgin M.S, Erdem A. and Tanriver M. CAD/CAM Endocrown Fabrication from a Polymer-Infiltrated Ceramic Network Block for Primary Molar: A Case Report. <i>J Clin Pediatr Dent.</i> , 2016; 40 :264-268.	Case report
18	da Cunha L.F, Gonzaga C.C, Pissaia J.F. and Correr G.M. Lithium silicate endocrown fabricated with a CAD-CAM system: A functional and esthetic protocol. <i>J Prosthet Dent.</i> , 2017; 118 : 131-134.	Case report
19	da Cunha L.F, Mondelli J, Auersvald C.M, et al. Endocrown with Leucite-Reinforced Ceramic: Case of Restoration of Endodontically Treated Teeth. <i>Case Rep Dent.</i> , 2015; 2015 :750313.	Case report
20	Göhring T.N. and Peters O.A. Restoration of endodontically treated teeth without posts. <i>Am J Dent.</i> , 2003; 16 :313-317.	Case report
21	Lander E. and Dietschi D. Endocrowns: a clinical report. <i>Quintessence Int.</i> , 2008; 39:99-106.	Case report
22	Rocca G.T, Rizcalla N. and Krejci I. Fiber-reinforced resin coating for endocrown preparations: a technical report. <i>Oper Dent.</i> , 2013; 38 :242-248.	Case report
23	Zoidis P, Bakiri E. and Polyzois G. Using modified polyetheretherketone (PEEK) as an alternative material for endocrown restorations: A short-term clinical report. <i>J Prosthet Dent.</i> , 2017; 117 :335-339.	Case report
24	Aktas G, Yerlikaya H. and Akca K. Mechanical Failure of Endocrowns Manufactured with Different Ceramic Materials: An <i>In vitro</i> Biomechanical Study. <i>J Prosthodont.</i> , 2018 27 :340-346.	<i>In vitro</i> Laboratory
25	Atash R, Arab M, Duterme H. and Cetik S. Comparison of resistance to fracture between three types of permanent restorations subjected to shear force: An <i>in vitro</i> study. <i>J Indian Prosthodont Soc.</i> , 2017; 17 :239-249.	<i>In vitro</i> Laboratory
26	Bankoğlu Güngör M, Turhan Bal B, Yilmaz H, Aydin C. and Karakoca Nemli S. Fracture strength of CAD/CAM fabricated lithium disilicate and resin nano ceramic restorations used for endodontically treated teeth. <i>Dent Mater J.</i> , 2017; 36 :135-141.	<i>In vitro</i> Laboratory
27	Biacchi G.R. and Basting R.T. Comparison of fracture strength of endocrowns and glass fiber post-retained conventional crowns. <i>Oper Dent.</i> 2012; 37 :130-136.	<i>In vitro</i> Laboratory
28	Carvalho A.O, Bruzi G, Anderson R.E, Maia H.P, Giannini M. and Magne P. Influence of Adhesive Core Buildup Designs on the Resistance of Endodontically Treated Molars Restored With Lithium Disilicate CAD/CAM Crowns. <i>Oper Dent.</i> , 2016; 41 :76-82.	<i>In vitro</i> Laboratory
29	Einhorn M, DuVall N, Wajdowicz M, Brewster J. and Roberts H. Preparation Ferrule Design Effect on Endocrown Failure Resistance. <i>J Prosthodont.</i> , 2019; 28 :e237-e242.	<i>In vitro</i> Laboratory
30	El-Damanhoury H.M. and Gaintantzopoulou M. The effect of nadimmediate dentin sealing and optical powder removal method on the fracture resistance of CAD/CAM-fabricated endocrowns. <i>Int J Comput Dent.</i> , 2016; 19 :135-151.	<i>In vitro</i> Laboratory
31	El-Damanhoury H.M, Haj-Ali R.N. and Platt J.A. Fracture resistance and microleakage of endocrowns utilizing three CAD-CAM blocks. <i>Oper Dent.</i> , 2015; 40 :201-210.	<i>In vitro</i> Laboratory
32	Gaintantzopoulou M.D. and El-Damanhoury H.M. Effect of Preparation Depth on the Marginal and Internal Adaptation of Computer-aided Design/Computer-assisted Manufacture Endocrowns. <i>Oper Dent.</i> , 2016; 41 :607-616.	<i>In vitro</i> Laboratory
33	Gregor L, Bouillaguet S, Onisor I, Ardu S, Krejci I. and Rocca G.T. Microhardness of light- and dual-polymerizable luting resins polymerized through 7.5-mm-thick endocrowns. <i>J Prosthet Dent.</i> , 2014; 112 :942-948.	<i>In vitro</i> Laboratory

34	Gresnigt M.M, Özcan M, van den Houten M.L, Schipper L. and Cune MS. Fracture strength, failure type and Weibull characteristics of lithium disilicate and multiphase resin composite endocrowns under axial and lateral forces. <i>Dent Mater.</i> , 2016; 32 :607-614.	<i>In vitro</i> Laboratory
35	Hayes A, Duvall N, Wajdowicz M and Roberts H. Effect of Endocrown Pulp Chamber Extension Depth on Molar Fracture Resistance. <i>Oper Dent.</i> , 2017; 42 :327-334.	<i>In vitro</i> Laboratory
36	Guo J, Wang Z, Li X, Sun C, Gao E. and Li H. A comparison of the fracture resistances of endodontically treated mandibular premolars restored with endocrowns and glass fiber post-core retained conventional crowns. <i>J Adv Prosthodont.</i> , 2016; 8 :489-493.	<i>In vitro</i> Laboratory
37	Kanat-Ertürk B, Saridağ S, Köseleler E, Helvacioğlu-Yiğit D, Avcu E. and Yildiran-Avcu Y. Fracture strengths of endocrown restorations fabricated with different preparation depths and CAD/CAM materials. <i>Dent Mater J.</i> , 2018; 37 :256-265.	<i>In vitro</i> Laboratory
38	Ramírez-Sebastià A, Bortolotto T, Roig M. and Krejci I. Composite vs ceramic computer-aided design/computer-assisted manufacturing crowns in endodontically treated teeth: analysis of marginal adaptation. <i>Oper Dent.</i> , 2013; 38 :663-673.	<i>In vitro</i> Laboratory
39	Rocca G.T, Daher R, Saratti C.M, et al. Restoration of severely damaged endodontically treated premolars: The influence of the endo-core length on marginal integrity and fatigue resistance of lithium disilicate CAD-CAM ceramic endocrowns. <i>J Dent.</i> , 2018; 68 :41-50.	<i>In vitro</i> Laboratory
40	Rocca G.T, Saratti C.M, Poncet A, Feilzer A.J. and Krejci I. The influence of FRCs reinforcement on marginal adaptation of CAD/CAM composite resin endocrowns after simulated fatigue loading. <i>Odontology.</i> , 2016; 104 :220-232.	<i>In vitro</i> Laboratory
41	Rocca G.T, Sedlakova P, Saratti C.M, et al. Fatigue behavior of resin-modified monolithic CAD-CAM RNC crowns and endocrowns. <i>Dent Mater.</i> , 2016; 32 :338-350.	<i>In vitro</i> Laboratory
42	Shin Y, Park S, Park J.W, Kim K.M, Park Y.B. and Roh B.D. Evaluation of the marginal and internal discrepancies of CAD-CAM endocrowns with different cavity depths: An in vitro study. <i>J Prosthet Dent.</i> , 2017; 117 :109-115.	<i>In vitro</i> Laboratory
43	Taha D, Spintzyk S, Schille C, et al. Fracture resistance and failure modes of polymer infiltrated ceramic endocrown restorations with variations in margin design and occlusal thickness. <i>J Prosthodont Res.</i> , 2018; 62 :293-297.	<i>In vitro</i> Laboratory
44	Dejak B. and Młotkowski A. Strength comparison of anterior teeth restored with ceramic endocrowns vs custom-made post and cores. <i>J Prosthodont Res.</i> , 2018; 62 :171-176.	<i>In vitro</i> Finite element analysis
45	Dejak B. and Młotkowski A. 3D-Finite element analysis of molars restored with endocrowns and posts during masticatory simulation. <i>Dent Mater.</i> , 2013; 29 :309-317.	<i>In vitro</i> Finite element analysis
46	Gulec L. and Ulusoy N. Effect of Endocrown Restorations with Different CAD/CAM Materials: 3D Finite Element and Weibull Analyses. <i>Biomed Res Int.</i> , 2017; 2017 :5638683.	<i>In vitro</i> Finite element analysis
47	Lin C.L, Chang Y.H, Chang C.Y, Pai C.A. and Huang S.F. Finite element and Weibull analyses to estimate failure risks in the ceramic endocrown and classical crown for endodontically treated maxillary premolar. <i>Eur J Oral Sci.</i> , 2010; 118 :87-93.	<i>In vitro</i> Finite element analysis
48	Zarone F, Sorrentino R, Apicella D, et al. Evaluation of the biomechanical behavior of maxillary central incisors restored by means of endocrowns compared to a natural tooth: a 3D static linear finite elements analysis. <i>Dent Mater.</i> , 2006; 22 :1035-1044.	<i>In vitro</i> Finite element analysis
49	Helal M.A. and Wang Z. Biomechanical Assessment of Restored Mandibular Molar by Endocrown in Comparison to a Glass Fiber Post-Retained Conventional Crown: 3D Finite Element Analysis. <i>J Prosthodont.</i> , 2017; 25 :1-9 .	<i>In vitro</i> Finite element analysis
50	Hasan I, Frentzen M, Utz K.H, Hoyer D, Langenbach A. and Bourauel C. Finite element analysis of adhesive endo-crowns of molars at different height levels of buccally applied load. <i>J Dent Biomech.</i> , 2012; 3 :1758736012455421.	<i>In vitro</i> Finite element analysis
51	Atash R, Arab M, Duterme H. and Cetik S. Comparison of resistance to fracture between three types of permanent restorations subjected to shear force: An invitro study. <i>J Indian Prosthodont Soc.</i> , 2017; 17 :239-249.	<i>In vitro</i> Finite element analysis
52	Bindl A. and Mörmann W.H. Survival rate of mono-ceramic and ceramic-core CAD/CAM-generated anterior crowns over 2-5 years. <i>European J Oral Sciences.</i> , 2004; 112 :197-204.	Crown and core build-up

53	Bindl A. and Mörmann W.H. An up to 5-Year Clinical Evaluation of Posterior In-Ceram CAD/CAM Core Crowns. <i>Int J Prosthodont.</i> , 2002; 15 :451-456.	Crown and core build-up
54	Decerle N, Bessadet M, Munoz-Sanchez M.L, Eschevins C, Veyrune J. and Nicolas E. Evaluation of Cerec endocrowns: a preliminary cohort study. <i>European J Prosthodont and Restor Dent.</i> , 2014; 22 :89-95.	Endocrown but 6 months follow-up
55	Lia Mondelli R.F, Ishikiriama S.K, De Oliveira Filho O. and Mondelli J. Fracture resistance of weakened teeth restored with condensable resin with and without cusp coverage. <i>J Appl Oral Science.</i> , 2009; 17 :161-165.	Crown and core build-up
56	Rocca G.T. and Krejci I. Crown and post-free adhesive restorations for endodontically treated posterior teeth: from direct composite to endocrowns. <i>European J Esthetic Dent.</i> , 2013; 8 :156-179.	Overview
57	Van Dijken J.W.V, Hasselrot L, Örmín A. and Olofsson A.L. Restorations with extensive dentin/enamel-bonded ceramic coverage. A 5-year follow-up. <i>European J Oral Sciences.</i> , 2001; 109 :222-229.	Crown and core build-up
58	Li H.B, Liu L, Li X.S, Wang X.Y, Gao Y.X. and Jing, G. Influence of Three Pattern Materials on the Marginal Adaption of Co-Cr Alloy Inner Crown of PFM Endocrown. <i>Advanc Mater Res.</i> , 2014; 887-888 :407-410.	In vitro Laboratory
59	Chang C.Y, Kuo J.S, Lin Y.S. and Chang Y.H. Fracture resistance and failure modes of CEREC endocrowns and conventional post and core-supported CEREC crowns. <i>J Dent Sciences.</i> , 2009; 4 :110-117.	In vitro Finite element analysis
60	Chen B, Ma Y, Wu K, et al. Influence of various materials on biomechanical behavior of endocrown-restored, endodontically-treated mandibular first molar: A 3D-finite element analysis. <i>J Wuhan University of Technology, Mater Science Edition.</i> , 2015; 30 :643-648.	In vitro Finite element analysis
61	Lin C.L. and Pai C.A. Numerical investigation of failure risk of cad/cam ceramic restoration for an endodontically treated maxillary premolar with no preparation. <i>Biomed Engineering - Appl, Basis and Commun.</i> , 2010; 22 :327-335.	In vitro Finite element analysis
62	Lin C.L, Chang Y.H. and Pa C.A. Estimation of the Risk of Failure for an Endodontically Treated Maxillary Premolar With MODP Preparation and CAD/CAM Ceramic Restorations. <i>J Endodon.</i> , 2009; 35 :1391-1395.	In vitro Finite element analysis
63	Seow L.L, Toh C.G. and Wilson N.H.F. Strain measurements and fracture resistance of endodontically treated premolars restored with all-ceramic restorations. <i>J Dent.</i> , 2015; 43 :126-132.	In vitro Finite element analysis
64	Seow L.L, Toh C.G, Fok A.S.L. and Wilson N.H.F. A finite element analysis of ceramic restorations in endodontically treated premolars. <i>American J Dent.</i> , 2008; 21 :331-336.	In vitro Finite element analysis
65	Lin C.L, Chang Y.H. and Pai C.A. Evaluation of failure risks in ceramic restorations for endodontically treated premolar with MOD preparation. <i>Dent Mater.</i> , 2011; 27 :431-438.	In vitro Finite element analysis
66	Otto T. Computer-aided direct all-ceramic crowns: preliminary 1-year results of a prospective clinical study. <i>Int J Periodontics Restor Dent.</i> , 2004; 24 :446-55	Duplicated sample
67	Guo J, Wang Z, Li X, Sun C, Gao E. and Li H. A comparison of the fracture resistances of endodontically treated mandibular premolars restored with endocrowns and glass fiber post-core retained conventional crowns. <i>J Adv Prosthodont.</i> , 2016; 8 :489-493.	In vitro Laboratory
68	Oliveira Fde C, Denehy G.E. and Boyer D.B. Fracture resistance of endodontically repaired teeth using various restorative materials. <i>J Am Dent Assoc.</i> , 1987; 115 :57-60.	In vitro Laboratory
69	Mörmann W.H, Bindl A, Lüthy H. and Rathke A. Effect of preparation and luting system on all-ceramic computer-generated crowns. <i>Int J Prosthodont.</i> , 1998; 11 :333-339.	In vitro Laboratory
70	Reich S.M, Wichmann M, Rinne H. and Shortall A. Clinical performance of large all-ceramic CAD/CAM generated restorations after three years: a pilot study. <i>J Am Dent Assoc.</i> , 2004; 135 :605-612.	Not mention endocrown result separately
71	Pissis P. Fabrication of a metal-free ceramic restoration utilizing the monobloc technique. <i>Pract Periodontics Aesthet Dent.</i> , 1995; 7 :83-94.	Case report