Direct and Indirect Restorations for Endodontically Treated Teeth: A Systematic Review and Meta-analysis, IAAD 2017 Consensus Conference Paper

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**Purpose:** The primary objective of this systematic review was to compare treatment outcomes of direct and indirect permanent restorations in endodontically treated teeth, and provide clinical suggestions for restoring teeth after endodontic treatment.

**Materials and Methods:** Electronic databases (Medline, EMBASE, CENTRAL) and gray literature were screened for articles in English that reported on prospective and retrospective clinical studies of direct or indirect restorations after endodontic treatment with an observation period of at least 3 years. Primary outcomes were determined to be short-term (≤ 5 years) and medium-term (> 5 and ≤ 10 years) survival. Secondary outcomes included restorative and endodontic success of restored teeth. The quality of included studies and risk of bias were assessed using Cochrane Collaboration’s tool for RCTs (randomized controlled trials), the Newcastle-Ottawa Scale for cohort studies, and the Agency for Healthcare Research and Quality (AHRQ) methodology checklist for cross-sectional studies. The GRADE system was used for assessing collective strength of the overall body of evidence.

**Results:** Of 2547 screened articles, only 9 (2 RCTs, 3 retrospective cohort studies, 3 cross-sectional studies) met the inclusion criteria, and 8 studies were used in the meta-analysis. In general, indirect restorations (mostly full crowns) showed higher 5-year survival (OR 0.28, 95% CI 0.19-0.43, p < 0.00001) and 10-year survival (OR 0.20, 95% CI 0.12-0.31, p < 0.00001) than direct restorations. However, there was no statistical difference in short-term (≤ 5 years) restorative success (OR 0.32, 95% CI 0.05-2.12, p = 0.24) and endodontic success (OR 0.88, 95% CI 0.72-1.08, p = 0.22).

**Conclusions:** Based on current evidence, there is a weak recommendation for indirect restorations to restore endodontically treated teeth, especially for teeth with extensive coronal damage. Indirect restorations using mostly crowns have higher short-term (5-year) and medium-term (10-year) survival than do direct restorations using composite or amalgam (GRADE quality of evidence: low to moderate), but no difference in short-term (≤ 5 years) restorative success (low quality) and endodontic success (very low quality). There is a need for high-quality clinical trials, especially well-designed RCTs.

**Keywords:** endodontic treatment, direct restorations, indirect restorations, survival rates, success rates, apical periodontitis.

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Endodontically treated teeth (ETT) are more susceptible to biomechanical failure compared to vital teeth, mostly due to the amount of internal tooth structure that is removed during endodontic treatment and the loss of coronal hard tissue. The prognosis of ETT depends not only on the quality of endodontic treatment, but also on the subsequent restorative techniques. Reported reasons for extraction of teeth after endodontic treatment include endodontic failures, prosthodontic complications, coronal and root fracture, caries, or periodontal disease.

The best way to restore ETT has been extensively discussed but is still controversial concerning the best type of final restoration. Conventional restoration modality involves fabricating a full-coverage crown with or without a post, as this was believed to provide better protection and reinforcement of the remaining tooth structure. However, complete crown restoration usually also requires extensive tooth preparation and new occlusal schemes. In addition, the loss of anatomic structures such as cusps, ridges, and the pulp chamber roof may decrease the strength of the remaining tooth.

Although direct amalgam and composite restorations were recommended in 2003 as conservative restorative techniques with 10-year survival rates of 82.4% and 85.2%, respectively, more recent studies of large numbers of patients treated by general dentists give a median longevity of direct posterior composite restorations between 5 and 8 years. Maximum preservation of healthy tooth structure is the main goal of restorative dentistry. Therefore, with recent advances in bonding technologies, adhesively bonded ceramic inlay or onlay restorations have been suggested in several in vitro studies. Some indicate that only complete coverage can provide sufficient protection and ensure the longevity of the tooth-restoration complex, while others claim the decision to place full-coverages crowns or onlays should depend on the amount of remaining tooth structure.

Many clinicians prefer using direct composite restorations to restore ETT due to their good esthetic properties, relatively low cost, ease of handling, and preservation of dental structures. Some laboratory studies indicate that there is no significant difference in the load required to fracture ETT that have received direct or indirect restorations. However, it was later reported that indirect ceramic restorations may pose a higher risk of catastrophic tooth fracture.

Results of thermomechanical loading indicated that ceramic restorations behave similarly to direct restorations when the same cavity preparations were used, and it was concluded that small conservative endodontic access cavities can be safely and simply restored with direct adhesive restorations and composite.

Therefore, the aim of this systematic review was to evaluate treatment outcomes of direct and indirect restorations to provide clinical recommendations for restoring endodontically treated teeth.

MATERIALS AND METHODS

**Literature Search and Study Selection**

An electronic search of published English literature in Medline via Pubmed, EMBASE (Excerpt Medica Database) via OVID, and CENTRAL (Cochrane Central Register of Controlled Trials) via OVID databases up to March 2017 was conducted. Search strategies are detailed in appendix 1. Utilizing ClinicalTrials.gov, Open Grey, and Google Scholar, gray literature was searched for potentially suitable unpublished clinical trials, including conference abstracts, unpublished and ongoing studies, nationally and internationally registered trials, doctoral dissertations. Hand searching was also conducted for relevant references.

All titles and abstracts were screened based on the following inclusion criteria:

- Patients and teeth (P): adult and adolescent patients with endodontically treated permanent teeth. There were no restrictions by gender or position of tooth.
- Intervention (I): indirect restorations including full-coverage (any type of complete crown or endocrown) and partial-coverage (any type of inlay, onlay, and partial crown) restorations with or without posts, using permanent materials.
- Control (C): direct restorations using permanent material (including composite and amalgam), with or without posts.
- Outcomes (O): only studies with a follow-up of at least 3 years were included, and the follow-up periods were classified as short-term (≥ 3 and ≤ 5 years), medium-term (> 5 and ≤ 10 years), and long-term (> 10 years).
- Primary outcomes: survival of restored teeth. The survival criterion used in this study was defined as the tooth-restoration complex being in situ.
- Secondary outcomes: restorative and endodontic success of restored teeth. Restorative success was defined as tooth and restoration present and clinically acceptable, no repair needed. Endodontic success referred to no signs or symptoms of pulpal or apical pathology according to clinical and radiological examinations, no endodontic intervention needed.
- Study design (S): randomized and nonrandomized controlled clinical trials, observational study designs including cohort (prospective and retrospective), case-control, and cross-sectional.

A full text was obtained of all relevant and potentially relevant studies. Two review authors independently assessed the full-text papers, and disagreements between the two reviewers were resolved by direct discussion, or by a third reviewer if no agreement could be reached. For missing or unclear information in the articles obtained, the corresponding authors were contacted by e-mail to confirm the ambiguous data. For the same clinical trial with multiple publications, only the latest was included in the analysis.

**Data Extraction**

Two reviewers independently scrutinized the full text of included studies. A data extraction table was employed to extract detailed information on: author(s), year of publication,
tion, study design, participants, follow-up time, sample size of each group, type, material and brand (if available) of the restoration as well as the post (if used), and the outcomes of each study.

When collecting the survival rate data, information provided in the publication was used directly. For outcomes expressed as Kaplan-Meier survival curves, data were extracted using the freeware software Engauge Digitizer (ver. 5.1 http://markummitchell.github.io/engauge-digitizer). The Engauge Digitizer software accepts image files (eg, PNG, JPEG, and TIFF) containing graphs, and recovers the data points from those graphs. For consistent studies, the extracted data were deemed precise enough to be included in the meta-analysis, while for inconsistent studies with no reply from the author, data were excluded from quantitative analysis. Other initial data were obtained by contacting the authors.

Due to national differences and writing styles, the terminology used in included studies varies. For standardization, confirmatory e-mails were sent to the authors to ascertain the restoration types and materials; further, descriptions were adjusted accordingly in the data extraction table. For authors who did not reply, the original text was used.

**Risk of Bias**

Two reviewers independently evaluated the methodological qualities of included studies according to the guidance provided by the Journal of Evidence-based Medicine.  

Cochrane Collaboration’s tool (http://handbook-5.1.cochrane.org/) was used to assess the risk of bias of RCTs. The domains of sequence generation, allocation concealment, and selective outcome reporting were addressed in the tool.

The Newcastle-Ottawa Scale (http://www.ohri.ca/programs/clinical_epidemiology/oxford.asp) was applied for assessing cohort studies. Using the tool, each study was judged on 8 items, categorized into 3 groups: the selection, comparability, and outcome of exposed and non-exposed cohort. Stars were awarded for each study (up to 9 stars) for quick visual assessment. Studies awarded with 6 or more stars were regarded as high-quality studies.

For cross-sectional studies, the Agency for Healthcare Research and Quality (AHRQ) methodology checklist (https://www.ncbi.nlm.nih.gov/books/NBK35156/) was applied. This is a methodological quality assessment tool using an 11-item checklist, and the AHRQ recommends it for assessment of cross-sectional studies. An item would be scored “0” if it was answered “NO” or “UNCLEAR”; if it was answered “YES”, then the item was given a score of “1”. Article quality was assessed as follows: low quality = 0–3; moderate quality = 4–7; high quality = 8–11.

For every outcome of meta-analysis, the quality of the evidence was assessed using the GRADE (Grading of Recommendations, Assessment, Development and Evaluations) approach by GRADEprofiler (Ver 3.6). The GRADE approach was used for collective grading of the overall body of evidence in this review, as the study designs vary; moreover, it is also a systematic and explicit approach to making judgements about quality of evidence and strength of recommendations.

All studies, regardless of the risk of bias and methodological quality, were included in the quantitative synthesis.

**Statistical Analysis and Heterogeneity**

Pooled data of all the outcomes were subjected to meta-analysis to estimate the odds ratio (OR) and 95% confidence intervals (CI) using the Cochrane Collaboration Review Manager (Ver. 5.3). To test the reliability of evidence, outcomes of fixed-effect models and random-effect models were compared, but considering the unexplained heterogeneity between studies, only random-effect estimates were reported, to be more conservative.

Cochran’s Q test was applied for analyzing the heterogeneity between included studies, and no heterogeneity was determined if the p-value was higher than 0.1. Otherwise, the I^2 statistic was used to quantify the statistical heterogeneity, and the threshold was determined as Cochrane recommended, ie, 0% to 40%: might not be important; 30% to 60%: may represent moderate heterogeneity; 50% to 90%: may represent substantial heterogeneity; 75% to 100%: considerable heterogeneity. For outcomes with substantial or considerable heterogeneity, sensitivity analysis was carried out by comparing the fixed and random-effect estimates, considering subgroup analysis, and testing for excess of studies with significant results.

**RESULTS**

The initial electronic search yielded 3497 records (1358 in Medline, 1379 in OVID, 758 in Central, and 2 from hand-searching and gray literature), and 2547 records were found after removing the duplicates. From these 2547 records, 49 potentially pertinent records were selected after screening the titles and abstracts. Full-text articles were retrieved for eligibility assessment, and 40 articles were excluded with reasons (different definition of survival rates: n = 1; insufficient follow-up time: n = 2; only indirect restorations were used: n = 19; insufficient follow-up time: n = 2; only indirect restorations were used: n = 18; 44,78 only indirect restorations were used: n = 18; 24,11,20,26,29,34,35,38,45,47,50,55,63,64,75,81). Ultimately, only 9 articles met the inclusion criteria, and all included studies had a parallel design. Some of the included studies provided specific data in their publications, including the studies by: Aquilino et al\(^7\) and Pratt et al\(^56\) in short-term (5 years) survival analyses, Aquilino et al\(^7\) and Dammasschke et al\(^16\) in medium-term (10 years) analyses, Skupien et al\(^70\) and Mannocci et al\(^46\) in short-term (≤5 years) restorative success assessments. Frisk et al\(^28\), Hommes et al\(^36\) and Dawson et al\(^18\) in endodontic success assessments. Their information was used directly. For studies with Kaplan-Meier survival curves,\(^56,73\) data extracted from Engauge Digitizer were compared with the available information in the text to test the precision of the figure. For consistent studies,\(^56\) the extracted data were deemed precise enough to be included in the meta-analysis; while for
inconsistent studies with no reply from the author,73 data were excluded from quantitative analysis.

Therefore, 8 studies were included in the meta-analyses. Three retrospective cohort studies were selected for analysis of short-term and medium-term survival, 2 RCTs were included for evaluation of restorative success, and 3 cross-sectional studies were subjected to endodontic success assessment. The process of searching and study selection is outlined in Fig 1. The characteristics of included studies are detailed in Table 1.

Risk of bias and quality assessments are presented in Fig 2 (RCTs), Table 2 (cohort studies), and Table 3 (cross-sectional studies). For RCTs, the risk of performance bias and detection bias was high. The Newcastle-Ottawa scores of cohort studies ranged from 5 to 7 asterisks with half of the studies showing high-quality. The methodological qualities of included cross-sectional studies showed only 1 study had high quality.

**Survival of Tooth-Restoration Complex**

**Five-year survival (Fig 3)**

Two retrospective studies7,56 were included in the assessment of short-term (≤ 5-year) survival, both of which provided 5-year survival results. Meta-analysis showed that indirect restorations have a higher survival rate than do direct restorations (OR 0.28, 95% CI 0.19–0.43, p < 0.00001). No heterogeneity was detected between the studies (p = 0.55, I² = 0%).

**Ten-year Survival (Fig 4)**

In respect to medium-term (> 5 and ≤ 10 year survival), the 8-year survival results of Pratt et al56 were originally included in the meta-analysis, but it significantly increased the heterogeneity because of different follow-up times (Aquilino et al7 and Dammaschke et al16 were both 10 years), and was therefore ultimately excluded from meta-analysis. Higher survival rates for indirect restorations were observed in 10-year assessment (OR 0.20, 95% CI 0.12–0.31, p < 0.00001), and no heterogeneity was detected (p = 0.94, I² = 0%).

**Restorative Success (Fig 5)**

Two RCTs reported the ≤ 5-year success rates, and meta-analysis indicated that direct and indirect restorations do not differ significantly in success rates (OR 0.32, 95% CI 0.05–2.12, p = 0.24). Moderate to substantial heterogeneity was introduced into the combined ORs. Meta-analysis showed a lower success rate for indirect restorations compared to direct restorations (OR 0.32, 95% CI 0.21–0.47, p < 0.00001). No heterogeneity was detected between the studies (p = 0.39, I² = 0%).

**Table 1 Characteristics of included studies**

<table>
<thead>
<tr>
<th>Author (year)</th>
<th>Study design</th>
<th>Follow-up</th>
<th>Age in years</th>
<th>Teeth</th>
<th>Indirect restorations (n*)</th>
<th>Direct restorations (n*)</th>
<th>Outcomes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Skupien70 (2016)</td>
<td>RCT</td>
<td>5 years</td>
<td></td>
<td></td>
<td>Endodontically treated teeth with extensive coronal damage</td>
<td>Porcelain fused-to-metal crowns bonded with composite cement, with fiber posts (n = 27)</td>
<td>Composite fillings with fiber posts (n = 30)</td>
</tr>
<tr>
<td>Mannocci46 (2002)</td>
<td>RCT</td>
<td>3 years</td>
<td></td>
<td></td>
<td>Endodontically treated premolars with class II lesions</td>
<td>Porcelain fused-to-metal crowns bonded with Zinc phosphate cement, with fiber posts (n = 57)</td>
<td>Composite fillings with fiber posts (n = 60)</td>
</tr>
<tr>
<td>Pratt56 (2016)</td>
<td>Retrospective cohort</td>
<td>8 years</td>
<td>Mean 46</td>
<td></td>
<td>Endodontically treated posterior teeth</td>
<td>Crowns (n = 441)</td>
<td>Amalgam or composite fillings (n = 198)</td>
</tr>
<tr>
<td>Dammaschke16 (2012)</td>
<td>Retrospective cohort</td>
<td>10 years</td>
<td>18–76</td>
<td></td>
<td>Endodontically treated posterior teeth</td>
<td>Crowns or partial crowns (n = 441)</td>
<td>Amalgam or composite fillings (n = 135)</td>
</tr>
<tr>
<td>Tickle73 (2008)</td>
<td>Retrospective cohort</td>
<td>7.7 years</td>
<td>20–60, 49.2±10.3</td>
<td></td>
<td>Endodontically treated mandibular first molar</td>
<td>Crowns (n = 67)</td>
<td>Composite fillings (n = 107)</td>
</tr>
<tr>
<td>Aquilino7 (2002)</td>
<td>Retrospective cohort</td>
<td>10 years</td>
<td>54.1±15.2</td>
<td></td>
<td>Endodontically treated teeth</td>
<td>Crowns (n = 129)</td>
<td>Amalgam or composite fillings (n = 74)</td>
</tr>
<tr>
<td>Dawson18 (2016)</td>
<td>Cross-sectional</td>
<td>/</td>
<td>20–89</td>
<td></td>
<td>Endodontically treated teeth</td>
<td>Crowns with posts (n = 275)</td>
<td>Amalgam or composite fillings with posts (n = 179)</td>
</tr>
<tr>
<td>Frisk28 (2015)</td>
<td>Cross-sectional</td>
<td>/</td>
<td>20–70</td>
<td></td>
<td>Endodontically treated teeth</td>
<td>Crowns or inlays (n = 1475)</td>
<td>Amalgam or composite resin fillings (n = 1159)</td>
</tr>
<tr>
<td>Hommes36 (2002)</td>
<td>Cross-sectional</td>
<td>/</td>
<td>Not mentioned</td>
<td></td>
<td>Endodontically treated teeth</td>
<td>Crowns (n = 305)</td>
<td>Amalgam or composite fillings (n = 413)</td>
</tr>
</tbody>
</table>

*n: number of teeth. **Clinical performance refers to assessment of each restoration’s esthetic, functional and biological properties, according to FDI criteria.
ity was detected between the 2 studies, but this was not statistically significant (p = 0.15, I^2 = 52%). The main reasons for failure were restoration fractures, secondary caries in direct groups, and post debonding; marginal gaps were revealed by radiographs in both groups.

**Endodontic Success (Fig 6)**

Three cross-sectional studies investigated the periapical status (endodontic success) of directly vs indirectly restored teeth and composite vs amalgam restorations.

Meta-analysis showed no difference in the incidence of apical periodontitis (AP) for direct or indirect restorations (OR 0.88, 95% CI 0.72-1.08, p = 0.22) with statistically nonsignificant moderate heterogeneity (p = 0.21, I^2 = 36%). The results for periapical status of ETT with composite or amalgam fillings are different. Hommes et al\(^{36}\) found the rate of AP to be significantly higher (p < 0.01) in composite (40.5%) than amalgam (28.4%) restorations, as supported by Frisk et al\(^{28}\) who found that composite restorations were associated with the occurrence of AP. However, Dawson et

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**Table 2  Quality assessment of cohort studies with the Newcastle-Ottawa Scale**

<table>
<thead>
<tr>
<th>Selection</th>
<th>Pratt et al(^{56})</th>
<th>Tickle et al(^{7})</th>
<th>Dammaschke et al(^{15})</th>
<th>Aquilino et al(^{7})</th>
</tr>
</thead>
<tbody>
<tr>
<td>1) Representativeness of the exposed cohort</td>
<td>c</td>
<td>b *</td>
<td>c</td>
<td>b *</td>
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<tr>
<td>2) Selection of the non-exposed cohort</td>
<td>a *</td>
<td>a *</td>
<td>a *</td>
<td>a *</td>
</tr>
<tr>
<td>3) Ascertainment of exposure</td>
<td>a *</td>
<td>a *</td>
<td>a *</td>
<td>a *</td>
</tr>
<tr>
<td>4) Demonstration that outcome of interest was not present at start of study</td>
<td>a *</td>
<td>a *</td>
<td>a *</td>
<td>a *</td>
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</table>

**Comparability**

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<tbody>
<tr>
<td>1) Comparability of cohorts on the basis of the design or analysis</td>
<td>a *</td>
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</table>

**Outcome**

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</thead>
<tbody>
<tr>
<td>1) Ascertainment of outcome</td>
<td>b *</td>
</tr>
<tr>
<td>2) Was follow-up long enough for outcomes to occur?</td>
<td>a *</td>
</tr>
<tr>
<td>3) Adequacy of follow up of cohorts</td>
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**Total scale**

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* Studies with 6 or more asterisks were regarded as high-quality studies.

**Table 3  Quality assessment of cross-sectional studies with ARHQ methodology checklist**

<table>
<thead>
<tr>
<th></th>
<th>Dawson et al(^{18})</th>
<th>Frisk et al(^{28})</th>
<th>Hommes et al(^{36})</th>
</tr>
</thead>
<tbody>
<tr>
<td>1) Define the source of information (survey, record review)</td>
<td>1</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>2) List inclusion and exclusion criteria for exposed and unexposed subjects (cases and controls) or refer to previous publications</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>3) Indicate time period used for identifying patients</td>
<td>1</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>4) Indicate whether or not subjects were consecutive if not population-based</td>
<td>0</td>
<td>0</td>
<td>0</td>
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<tr>
<td>5) Indicate if evaluators of subjective components of study were masked to other aspects of the status of the participants</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>6) Describe any assessments undertaken for quality assurance purposes (eg, test/retest of primary outcome measurements)</td>
<td>1</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>7) Explain any patient exclusions from analysis</td>
<td>1</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>8) Describe how confounding was assessed and/or controlled</td>
<td>1</td>
<td>0</td>
<td>1</td>
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<tr>
<td>9) If applicable, explain how missing data were handled in the analysis</td>
<td>1</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>10) Summarize patient response rates and completeness of data collection</td>
<td>1</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>11) Clarify what follow-up, if any, was expected and the percentage of patients for which incomplete data or follow-up was obtained</td>
<td>1</td>
<td>0</td>
<td>0</td>
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</table>

**Total scale**

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<tbody>
<tr>
<td></td>
<td>8</td>
<td>4</td>
<td>3</td>
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</tbody>
</table>

* Article quality was assessed as follows: low quality = 0–3; moderate quality = 4–7; high quality = 8–11.
al\textsuperscript{18} reported no difference in the frequency of AP between teeth restored with composite and amalgam filings.

**GRADE Assessment**

The SoF (summary of findings) table created by GRADE profiler is presented in Figs 7–9. Among the 4 outcomes analyzed in this review, survival (short-term and medium-term) and restorative success of restored teeth showed low to moderate quality, compared with very low quality of endodontic success.

**DISCUSSION**

The present systematic review and meta-analysis suggested that indirect restorations (mainly crowns) would provide increased short-term (5-year) and medium-term (10-year) survival for endodontically treated teeth compared with direct restorations (mainly composite and amalgam fillings). Indirect restorations also showed better esthetic, functional, and biological properties, but no difference in short-term (≤ 5 years) restorative success or endodontic success.

The search strategies for this systematic review covered both published studies and gray literature, but abstracts and articles published in languages other than English were not searched. Publication bias could not be assessed due to the limited number of studies. All of the outcomes showed satisfactory reliability.

Reasons for extraction of ETT are mainly nonrestorable carious destruction, endodontic issues, and tooth fracture.\textsuperscript{16,78} Crowns are expected to provide a better coronal seal to prevent bacterial recontamination of residual tooth tissue.\textsuperscript{13} Studies showed that 85% of extracted ETT were not crowned, due to the presence of more nonrestorable caries compared with crowned teeth.\textsuperscript{78} Crowns may also serve to protect the tooth from the risk of fracture,\textsuperscript{13} as crowned ETT demonstrated a significantly lower fracture rate than teeth provided with a filling.\textsuperscript{16}

Traditionally, most clinicians prefer to use posts followed by crown restorations for ETT;\textsuperscript{14} however, full-coverage crowns may not be necessary. A retrospective study investigated 189 posterior ETT restored with indirect composite onlays, and suggested this method can be a viable option for the restoration of posterior ETT (tooth survival 100%, restoration survival 96.8%, with median follow-up time of 37 months).\textsuperscript{14} Another study also showed that gold partial crowns displayed a comparable fracture rate compared with full-coverage crowns for ETT.\textsuperscript{16} However, the decision on whether to place a crown or a partial-coverage restoration should also depend on functional requirements and the amount of remaining tooth structure.\textsuperscript{10,17,54} According to some studies in vital teeth, the risk of failure has been showed to increase by 30% to 40% for every extra missing wall.\textsuperscript{54} An occlusal cavity preparation could reduce tooth stiffness by 20%, compared to 63% for a MOD (mesial-occlusal-distal) cavity.\textsuperscript{14} Therefore, crowns are still crucial to provide enough coronal protection, if ETT have been extensively damaged by caries or endodontic treatment.\textsuperscript{32,78}

As for ETT without extensive coronal destruction, direct composite restorations are mainly indicated for teeth with minimal or moderate tooth structure loss.\textsuperscript{10} Some evidence suggested that for similar cuspal coverage, direct and indirect methods showed similar outcomes, and decided that preference should be given to direct over indirect restorations because they are more time effective and less costly.\textsuperscript{6,19,24} However, the accuracy and skills of the practitioners could significantly influence decision to repair or replace direct restoration.\textsuperscript{45} For example, direct restorations are technique sensitive with greater risks of polymerization shrinkage, marginal discrepancies, microleakage, undesirable proximal contacts, and secondary caries.\textsuperscript{5,12}

On the other hand, indirect restorations (inlay/onlay) have a reduced composite shrinkage volume, limited to the resin luting layer, and therefore increase the marginal adaptation of restorations.\textsuperscript{37}

Failure of restorative treatment may be influenced by the position of the tooth. In a long-term study of ETT, mandibular premolars and maxillary and mandibular anterior teeth were reported to have longer survival times than other tooth types, and molars demonstrated the worst survival outcomes, possibly because of difficulties in endodontic treatment and the subsequent restoration.\textsuperscript{13} A large practice-based study analyzing direct restoration longevity showed a higher annual failure rate (AFR) of 5.2% in molars compared to anterior teeth (4.4%) and premolars (4.0%).\textsuperscript{45}

Another controversial issue is whether to place a post after endodontic treatment. In vitro studies showed that placement of fiber post could significantly improve the fracture resistance of ETT.\textsuperscript{1} A long-term clinical investigation (at least 5 years) found that the survival rate of teeth with a fiber post amounted to 94.3%, and for teeth without a post, it was 76.3% (p < 0.001).\textsuperscript{31} However, other investigators believe that preparation of a post space might increase the chance of root fracture,\textsuperscript{30} so that posts should only be used when other options were not available to retain a core.\textsuperscript{23}

In this review, indirect restorations (mainly crowns) had better outcomes in tooth-restoration complex survival, possibly because crowns could provide better protection in such a study pool of teeth with substantial tooth structure loss in areas of high masticatory forces. In addition, indirect restorations might serve as a more stable restoration technique in the long run, as the effect of 10-year results (OR 0.20) was larger than that of 5-year results (OR 0.28).

Meta-analysis of restorative success showed no statistical difference between the two restorations, probably because of limited sample size and observation time. However, a comparison of the two included studies showed that with the increase in observation time (from 3 years to 5 years), indirect restorations exhibited more favorable results.

In terms of endodontic success, results differed among studies, especially when comparing amalgam and composite fillings. Studies published in different years exhibited opposing outcomes, probably because the quality of composites was better in more recent studies as a result of
the development of materials, techniques and instruments for placement of filling materials. A systematic review suggested that composite restorations in the posterior region still have reduced longevity and a greater likelihood of secondary caries when compared to amalgam restorations. The quality of coronal restorations may have an impact on the periapical status by influencing coronal leakage.

A previous systematic review published in 2012 and updated in 2015 discussed a similar topic by comparing single crowns vs direct restorations for ETT, but included only one clinical trial; insufficient evidence was found to support either treatment option. However, our systematic review included 2 RCTs and 7 observational studies, and reached a conclusion in meta-analysis, which may be helpful for clinical practice. This is possibly because of more comprehensive search strategies in 3 databases, coverage of gray literature, and inclusion of observational studies. In addition, multiple and rigorous quality assessment was applied for different study designs. Use of a collective evidence grading system (GRADE) further improved the quality of this systematic review.

The present study also had some limitations, e.g., that most of the conclusions were drawn from retrospective cohort studies mostly including skilled operators, with materials available in the 1990s. Well-designed RCTs with large sample sizes are needed using today’s materials and general dentists, especially for endodontically treated teeth with minimal or moderate coronal tooth structure loss.

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**Fig 1** Flow diagram.

**Fig 2** Risk of bias summary (RCTs).
CONCLUSIONS

Based on current evidence, there is a weak recommendation for indirect restorations to restore endodontically treated teeth, especially for teeth with extensive coronal damage.

Indirect restorations consisting mostly of crowns have a higher short-term (5-year) and medium-term (10-year) survival than direct restorations using composite or amalgam, but no significant difference was found in short-term (≤ 5-year) restorative success. However, further research is likely to have an important impact on our confidence in the estimate of effect and may change the estimate, because the evidence is of low to moderate quality. Indirect and direct restorations showed no significant difference in end-

![Fig 3](image3.png)

**Fig 3** Forest plot of 5-year survival analysis.

![Fig 4](image4.png)

**Fig 4** Forest plot of 10-year survival analysis.

![Fig 5](image5.png)

**Fig 5** Forest plot of short-term restorative success.

![Fig 6](image6.png)

**Fig 6** Forest plot of endodontic success.
Survival of ETT with direct or indirect restorations

<table>
<thead>
<tr>
<th>Outcomes</th>
<th>Illustrative comparative risks* (95% CI)</th>
<th>Relative effect (95% CI)</th>
<th>No of Participants (studies)</th>
<th>Quality of the evidence (GRADE)</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>5-year survival Follow-up: 5 years</td>
<td>228 per 1000 (53 to 113)</td>
<td>OR 0.28 (0.19 to 0.43)</td>
<td>842 (2 studies)</td>
<td>low1,2,3</td>
<td>○○○○</td>
</tr>
<tr>
<td>10-year survival Follow-up: 10 years</td>
<td>287 per 1000 (46 to 111)</td>
<td>OR 0.20 (0.12 to 0.31)</td>
<td>726 (2 studies)</td>
<td>low1,2,3</td>
<td>○○○○</td>
</tr>
</tbody>
</table>

*The basis for the assumed risk (eg, the median control group risk across studies) is provided in footnotes. The corresponding risk (and its 95% confidence interval) is based on the assumed risk in the comparison group and the relative effect of the intervention (and its 95% CI).

CI: Confidence interval; OR: Odds ratio.

GRADE Working Group grades of evidence

<table>
<thead>
<tr>
<th>Quality of the evidence</th>
<th>Grade of recommendation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Low</td>
<td>Very uncertain about the estimate.</td>
</tr>
<tr>
<td>Moderate</td>
<td>Further research is likely to have an important impact on our confidence in the estimate of effect and may change the estimate.</td>
</tr>
<tr>
<td>High</td>
<td>Further research is very unlikely to change our confidence in the estimate of effect.</td>
</tr>
<tr>
<td>Very high</td>
<td>We are very uncertain about the estimate.</td>
</tr>
</tbody>
</table>

1 All studies are observational studies and thus would start with low quality rating.
2 Downgraded 1 level for high RoB in 2/3 studies (failure to adequately control confounding).
3 Upgraded 1 level for large effect based on observational studies without important risk of bias or other limitations showing an OR < 0.5 with at least consistent studies.
4 Downgraded 1 level for imprecise (data of Pratt’s study were extracted from the Kaplan-Meier survival curves).

Fig 7 GRADE SoF survival rate.

Restorative success of ETT with direct or indirect restorations

<table>
<thead>
<tr>
<th>Outcomes</th>
<th>Illustrative comparative risks* (95% CI)</th>
<th>Relative effect (95% CI)</th>
<th>No of Participants (studies)</th>
<th>Quality of the evidence (GRADE)</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>5-year survival Follow-up: 3 – 5 years</td>
<td>145 per 1000 (8 to 264)</td>
<td>OR 0.32 (0.05 to 2.12)</td>
<td>164 (2 studies)</td>
<td>low1,2,3</td>
<td>○○○○</td>
</tr>
</tbody>
</table>

*The basis for the assumed risk (eg, the median control group risk across studies) is provided in footnotes. The corresponding risk (and its 95% confidence interval) is based on the assumed risk in the comparison group and the relative effect of the intervention (and its 95% CI).

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<td>Very high</td>
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</tr>
</tbody>
</table>

1 Both studies are RCTs so would start with high quality rating.
2 Downgraded 1 level for imprecision (optimal information size n < 400 and wide CI).
3 Downgraded 1 level for high RoB in both studies (lack of concealment and lack of blinding).
4 Downgraded 1 level for moderate heterogeneity (52%).

Fig 8 GRADE SoF restorative success rate.

Endodontic success of ETT with direct or indirect restorations

<table>
<thead>
<tr>
<th>Outcomes</th>
<th>Illustrative comparative risks* (95% CI)</th>
<th>Relative effect (95% CI)</th>
<th>No of Participants (studies)</th>
<th>Quality of the evidence (GRADE)</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>Endodontic success</td>
<td>264 per 1000 (205 to 279)</td>
<td>OR 0.88 (0.72 to 1.08)</td>
<td>3806 (3 studies)</td>
<td>very low1,2</td>
<td>○○○○</td>
</tr>
</tbody>
</table>

*The basis for the assumed risk (eg, the median control group risk across studies) is provided in footnotes. The corresponding risk (and its 95% confidence interval) is based on the assumed risk in the comparison group and the relative effect of the intervention (and its 95% CI).

CI: Confidence interval; OR: Odds ratio.

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</tr>
</tbody>
</table>

1 All studies are observational studies and thus would start with low quality rating.
2 Downgraded 1 level for high RoB in 2/3 studies (failure to adequately control confounding).

Fig 9 GRADE SoF endodontic success rate.
odontic success (rate of apical periodontitis), but we are very uncertain about the estimate as a result of very low quality of evidence. High-quality clinical trials are needed, especially well-designed RCTs. Future studies should better control the confounding factors by restricting the position of teeth, extent of coronal damage, use of post, and quality of endodontic treatment. RCTs are expected to have a larger sample size and longer observation time. Moreover, under the principle of maximum preservation of healthy tooth structure, studies involving restoring endodontically treated teeth with minimal coronal loss, or studies comparing indirect restorations of full or partial coverage, are also of great interest and significance.

ACKNOWLEDGMENTS
The authors would like to thank the Chinese Cochrane Center at the West China School of Medicine, Sichuan University, which provided the theoretical guidance for this systematic review.

REFERENCES
5. Alshiddi IF, Aljinbaz A. Fracture resistance of endodontically treated teeth with minimal coronal loss, or studies comparing indirect restorations of full or partial coverage, are also of great interest and significance.


Clinical relevance: Indirect restorations chiefly using crowns have higher a short-term (5-year) and medium-term (10-year) survival rate than direct restorations using composite or amalgam, but no difference was detected in short-term (≤ 5-year) restorative and endodontic success.
APPENDIX 1  SEARCH STRATEGIES

**A. MEDLINE via Pubmed search strategy (24th Mar, 2017)**

((endodontic*[Title/Abstract]) OR nonvital[Title/Abstract])
OR pulpless[Title/Abstract]
endodontics[MeSH Terms]
((root canal therapy[MeSH Terms]) OR root canal[Title/Abstract]) OR root-filled[Title/Abstract]
((fill*[Title/Abstract]) OR therap*[Title/Abstract]) OR treat*[Title/Abstract]
#4 AND root[Title/Abstract]
#1 OR #2 OR #3 OR #5
direct*[Title/Abstract] OR indirect*[Title/Abstract]
(((dental restorations, permanent[MeSH Terms]) OR dental prosthesis[MeSH Terms]) OR restoration*[Title/Abstract])
OR restored[Title/Abstract] OR restorative[Title/Abstract]
#7 AND #8
((composite[Title/Abstract]) OR resin*[Title/Abstract]) OR composite resins[MeSH Terms] OR amalgam[Title/Abstract]
(((crowsns[MeSH Terms]) OR crown[Title/Abstract]) OR endocrown*[Title/Abstract]) OR partial crown*[Title/Abstract]
OR inlays[MeSH Terms] OR inlay[Title/Abstract]
OR onlay*[Title/Abstract] OR overlay*[Title/Abstract]) OR veneer*[Title/Abstract]
#9 OR #10 OR #11
((randomized[Title/Abstract]) OR randomised[Title/Abstract]) OR randomly[Title/Abstract]
(((controlled[Title/Abstract]) OR clinical trial[Title/Abstract]) OR prospective[Title/Abstract]) OR retrospective[Title/Abstract]
OR pilot[Title/Abstract]) OR longitudinal[Title/Abstract] OR cohort[Title/Abstract] OR case series[Title/Abstract]) OR case-control*[Title/Abstract]
#13 OR #14
#6 AND #12 AND #15
(*in vitro*[Title]) OR *ex vivo*[Title]
#16 NOT #17

Filter: English

**B. EMBASE via OVID search strategy (24th Mar, 2017)**

1 *endodontics/
2 (endodontic* or nonvital or pulpless).ab.
3 exp “root canal therapy”/
4 (“root canal” or root-filled).ab.
5 (root adj6 (therap$ or fill$ or treat$ or resect$)).ab.
6 (direct* or indirect*).ab.
7 *tooth prosthesis/
8 (restoration* or restored or restorative).ab.
9 7 or 8
10 6 and 9
11 *resin/
12 (“composite resin” or composite or resin or amalgam).ab.
13 (crown* or endocrown* or inlay* or onlay* or overlay* or veneer*).ab.
14 (partial and crown*).ab.
15 10 or 11 or 12 or 13 or 14
16 (randomized or randomised or randomly or controlled).ab.
17 ((clinical and trial) or prospective or retrospective or pilot or longitudinal or cohort or “case series” or case-control*).ab.
18 16 or 17
19 1 or 2 or 3 or 4 or 5
20 15 and 18 and 19

**C. CENTRAL (Cochrane Central Register of Controlled Trials) via OVID (25th Mar, 2017)**

1 exp Endodontics/
2 (endodontic* or nonvital or pulpless).af.
3 (root and canal).af.
4 root-filled.af.
5 (root adj6 (therap$ or fill$ or treat$ or resect$)).af.
6 1 or 2 or 3 or 4 or 5
7 (direct* or indirect*).af.
8 dental prosthesis.mp. or exp Dental Prosthesis/
9 (restoration* or restored or restorative).af.
10 exp Composite Resins/
11 (composite resin or composite or resin or amalgam).af.
12 exp Dental Restoration, Permanent/
13 8 or 9 or 12
14 7 and 13
15 exp Crowns/
16 (crown* or endocrown* or inlay* or onlay* or overlay* or veneer*).af.
17 exp Inlays/
18 (partial and crown*).af.
19 10 or 11 or 14 or 15 or 16 or 17 or 18
20 6 and 19