Received: 31 January 2022 | Accepted: 29 July 2022

DOI: 10.1111/iej.13808

INTERNATIONAL ENDODONTIC JOURNAL | WILEY

REVIEW ARTICLE

Effectiveness of root resection techniques compared with root canal retreatment or apical surgery for the treatment of apical periodontitis and tooth survival: A systematic review

Stefano Corbella[1,2] | **Clemens Walter**[3] | **Igor Tsesis**[4]

[1]Department of Biomedical, Surgical and Dental Sciences, Università degli Studi di Milano, Milan, Italy

[2]IRCCS Istituto Ortopedico Galeazzi, Milan, Italy

[3]Department of Restorative Dentistry, Periodontology, Endodontology, Preventive and Pediatric Dentistry, Dental School, University Medicine Greifswald, Greifswald, Germany

[4]Department of Endodontics, Maurice and Gabriela Goldschleger School of Dental Medicine, Tel Aviv University, Tel Aviv, Israel

Correspondence
Stefano Corbella, IRCCS Istituto Ortopedico Galeazzi, Via R. Galeazzi, 4, 20161, Milan, Italy.
Email: stefano.corbella@unimi.it

Abstract

Background: To manage apical periodontitis in root filled maxillary and mandibular molars, root resection techniques may be employed to avoid the loss of the tooth.

Objectives: The objectives of the study were to systematically analyse the effectiveness of root resection techniques (root resection/crown resection/root amputation) for the management of apical periodontitis with non-surgical root canal retreatment or apical surgery by the evaluation of clinical and patient-related outcomes (PROMS), in human experimental studies and longitudinal studies.

Methods: An electronic literature search in PubMed, MEDLINE via OVID interface, EMBASE and Cochrane Central, supplemented by a manual hand search of the grey literature, was performed up to 25th September 2021. Randomized controlled trials, comparative clinical trials and observational studies reporting on the outcome (tooth survival and patient-reported outcome measures with a minimum follow-up of 1 year) of root resection techniques for treating apical periodontitis were identified. The risk of bias was evaluated using the Newcastle–Ottawa scale.

Results: From a total of 2098 reports, 36 were considered for further screening. Three retrospective studies, published between 2018 and 2020, were included in this systematic review. A high heterogeneity in terms of protocols, study design and the reported outcomes were observed. The risk of bias was scored as low to moderate. These three studies consisted of data from 305 resected teeth, from 254 patients, with a follow-up period of 1–16.8 years. Overall, 151 teeth were extracted during the follow-up period. In these studies, root resection treatment was carried out on 42 teeth exclusively for endodontic reasons. One of these studies reported 12 out of 23 teeth lost at follow-up. None of the studies reported on PROMS.

Discussion: Although root resection techniques may be used for treating teeth with apical periodontitis, the data are limited. Furthermore, the studies are very heterogeneous and associated with high risk of bias.

Clemens Walter and Igor Tsesis both authors contributed equally.

Conclusions: Given the current level of available evidence, it is not possible to recommend, or dismiss, root resection techniques for managing apical periodontitis.
Registration: PROSPERO database (CRD42021260306).

KEYWORDS
apical periodontitis, root resection, surgical endodontics, systematic review, tooth resection

INTRODUCTION

Root resection techniques are mainly employed for teeth with advanced endodontic-periodontal problems. However, these techniques have also been considered for surgical endodontic management (AAE, 2016). Root resection or root amputation may be defined as surgical removal of an entire root and the adherent soft tissues leaving the crown of the tooth intact and supported by the remaining roots (AAE, 2020). In some cases, the resection may include part of the crown of the tooth, such as in mandibular molars and is defined as a hemisection (AAE, 2020). The first detailed case report of an amputation of a root was published in 1884 by Farrar who described the procedure as a 'radical and heroic treatment' (Farrar, 1884).

In multi-rooted teeth, the resection of an entire root may be indicated if affected by persistent apical periodontitis and when non-surgical or surgical endodontic treatment are impractical, that is when the reduced root length is insufficient for root-end resection and retrograde root filling (Alassadi et al., 2020; Derks et al., 2018; El Sayed et al., 2020; European Society of Endodontology, 2006). It may also be indicated when a horizontal or vertical root fracture is present, in cases of periodontal-endodontic lesions or severe periodontal disease (Dommisch et al., 2020; European Society of Endodontology, 2006; Floratos & Kratchman, 2012; Schmidt et al., 2014; Walter et al., 2011).

Treatment concepts are subject to constant changes and innovative approaches for surgical endodontic management (including intentional tooth replantation) and root resection treatment, in particular, have been published in recent years (Kim & Kratchman, 2006). These newer strategies include, for example root resection of vital teeth without prior non-surgical root canal treatment (Jepsen et al., 2020), the use of magnification devices such as dental operating microscopes or endoscopes (Pecora & Andreana, 1993; Setzer et al., 2012), the application of microsurgical endodontic techniques (Kim & Kratchman, 2006) and the use of bioceramic endodontic cements such as mineral trioxide aggregate (Parirokh et al., 2018; Torabinejad et al., 2018).

A systematic review on the benefit of resective surgery for periodontal treatment of furcation-involved molars was conducted by Dommisch et al. Using contemporary criteria, seven studies out of 683 articles identified, published between 1998 and 2020, were included in their systematic review. Given the literature search was restricted to recent studies, they observed a lack of randomized controlled trials and significant heterogeneity of the studies included (Dommisch et al., 2020). It was concluded that there is an absence of high-level published evidence on the merits of root resective surgery when compared to scaling and root planning, or open flap debridement in class II or III furcation involvement. However, in terms of elimination of periodontal inflammation, adjunctive surgical measures, including root resection may be justified, when provided in a specialist care setting with careful case selection (Dommisch et al., 2020). It should be stated that, although the study by Dommisch and coworkers represents the best available evidence on the topic, it does not provide evidence on the indications for resective treatment for multi-rooted teeth with apical periodontitis and purely relates to teeth with advanced periodontal lesions.

Root resection treatment can be challenging and therefore accurate diagnosis and considered case assessment of the restorative, periodontal and endodontic prognoses must be carried out (Alassadi et al., 2020; Derks et al., 2018; El Sayed et al., 2020; Patel et al., 2019; Walter et al., 2010, 2011, 2012). Whilst root amputation may be a valuable treatment modality for the preservation of teeth with high strategic value, or when anatomical factors preclude implant placement (Setzer et al., 2019), it has been questioned as to whether root resective treatment is truly cost-effective due to the possible failures and endodontic complications, such as root fractures and the additional cost of subsequent root canal treatment (Jepsen et al., 2020; Schwendicke et al., 2014).

Therefore, the aim of this systematic review was to investigate the effectiveness of root resection techniques (root resection/crown resection or root amputation) with non-surgical root canal retreatment or apical surgery, in terms of clinical- and patient-related outcomes with a minimum follow-up of 1 year, for managing apical periodontitis in permanent teeth.

MATERIALS AND METHODS

A systematic review of the literature was conducted using the methods as described in the Cochrane Handbook for Systematic Review of Interventions (Higgins et al., 2021). The results are reported in accordance with the Preferred Reporting Items for Systematic Reviews and Meta-Analysis guidelines (Page et al., 2021). The protocol for this systematic review was registered in the PROSPERO database (Registration number: CRD42021260306).

Eligibility criteria

The inclusion criteria were based on the following PICOS:

Population (P): General population with evidence of apical periodontitis (AP), code DA09.6 and DA09.7 according to the International Classification of Diseases (ICD 11) of the World Health Organization (2022).

Intervention (I): Root resection techniques (root resection in general, crown resection with complete separation of root and crown, root amputation namely the surgical removal of the root leaving the crown).

Comparator/Control (C): Non-surgical root canal retreatment or apical surgery (including root-end preparation and filling).

Outcome(s) (O): The main outcome was a combination of clinician- and patient-reported outcomes measures:

- The primary outcome is 'tooth survival'.
- Other critical outcomes are 'pain, tenderness, swelling, need for medication (analgesics, antibiotics)', 'presence of sinus tract, satisfactory soft tissue healing', 'radiographic evidence of reduction of apical lesion size (loose criteria)' and 'radiographic evidence of normal periodontal ligament space (strict criteria)'.
- Important outcomes are 'tooth function (fracture, restoration longevity), 'need for further intervention', 'adverse effects (including exacerbation, restoration integrity, allergy)', 'oral health-related quality of life (OHRQoL)' and 'mobility'.

Studies (S): Human experimental studies (randomized control trials, comparative clinical trials—non-randomized). The search was supplemented by longitudinal observational studies (retrospective and prospective comparative cohort and case–control studies) to ensure that all relevant clinical information, which is often not tested in experimental studies, is captured. Studies published in the English language.

Search strategy and selection process

The electronic search was performed using PubMed, MEDLINE via OVID interface, EMBASE and Cochrane Central using the search strategy shown in Appendix A. In addition, a grey literature search was carried out using Networked Digital Library of Theses and Dissertations, Open Access Theses and Dissertations, DART-Europe E-theses Portal, British Library E-Theses Online Service. Then, a hand search of the reference lists of the included papers, previously published reviews on the topic, and all the issues of the *International Endodontic Journal*, *Journal of Endodontics*, *Journal of Clinical Periodontology*, *Journal of Dental Research*, *Journal of Dentistry* and *Clinical Oral Investigation* of the last 20 years was performed.

The search by the two independent reviewers (SC and IT) was concluded on 25th September 2021; any disagreements or doubts were resolved by discussion to achieve consensus. Duplicates identified in the searches of the various databases were removed. Relevant and appropriate studies selected in this systematic review were based on a three-step process: (1) identification, (2) screening, (3) eligibility. Before the results were analysed, the search was repeated to ensure that any newly found and eligible studies were not excluded.

Data extraction and data items

From the included studies, the following data were extracted by two reviewers (SC and IT): authors' name, year of publication, type of study, characteristics of the sample (age distribution, sex distribution, ethnicity, smoking status, systemic conditions, educational status), number of subjects/teeth treated, diagnosis and details of endodontic status, details about treatment performed, outcomes and the follow-up period. For those studies that were excluded, the reasons were recorded.

Risk of bias evaluation

The Newcastle–Ottawa scale was used for the assessment of risk of bias for observational studies (Wells et al., 2011). The risk of bias evaluation was performed by two authors independently (SC and CW) and, in case of disagreement, the third author (IT) was involved to resolve the matter. When five or less points were scored, the study was considered as low quality; any studies with scores between five and eight were considered as medium quality; when eight points were scored the study was considered as high quality.

Summary measures and synthesis of the results

Due to the heterogeneity of the included studies, it was not possible to perform a quantitative synthesis of the results. Hence, the results of these studies are presented in a narrative manner.

RESULTS

Study selection

The study selection process is shown in Figure 1. Briefly, from a total of 2098 records initially identified, 36 papers were evaluated for inclusion after screening. Three studies presented data focused on the review PICOS question. The remaining 33 papers were excluded, and the reasons are presented in Appendix B; in particular, relevant information about the initial endodontic status of the teeth was not provided. A narrative account of the results is presented in Tables 1 and 2.

Assessment of risk of bias

The assessment of the risk of bias of the studies found that two papers were classified as low quality (Alassadi et al., 2020; Derks et al., 2018), and one study was classified as moderate quality (El Sayed et al., 2020; Appendix C). No funding bias was found in relation to these three studies.

Population

Two studies (Derks et al., 2018; El Sayed et al., 2020) were of German populations whilst one study was of an American population (Alassadi et al., 2020). Taken together, the three studies summarized data from 305 teeth, with 196 maxillary and 109 mandibular teeth from a total of 254 patients (Alassadi et al., 2020; Derks et al., 2018; El Sayed et al., 2020). The follow-up period ranged from 1 to 16.8 years (Alassadi et al., 2020; Derks et al., 2018; El Sayed et al., 2020). The mean age and the female/male ratio were reported in all three studies (Alassadi et al., 2020; Derks et al., 2018; El Sayed et al., 2020). Additional information, such as prevalence of systemic diseases and smoking status were reported by two of the studies (Alassadi et al., 2020; El Sayed et al., 2020).

Intervention

Root resection treatment was performed after comprehensive non-surgical periodontal treatment in an academic setting (Alassadi et al., 2020; El Sayed et al., 2020) or

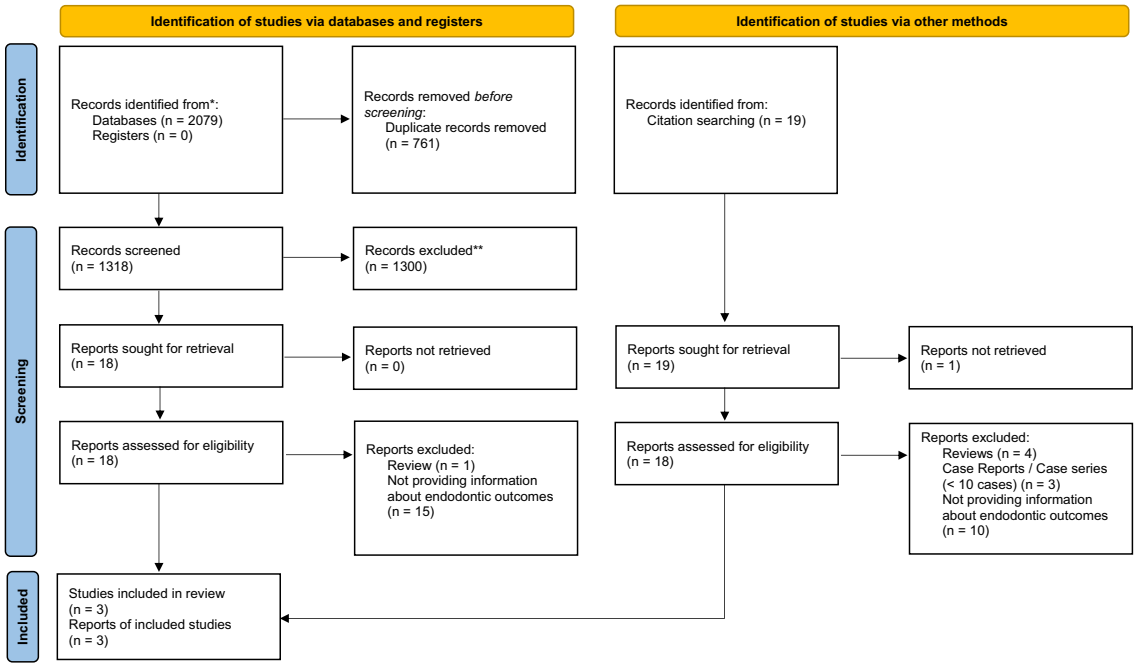

FIGURE 1 PRISMA diagram of article selection process

TABLE 1 Characteristics of the included studies

Study	Year	Study type	Country	Population (y—years)	No subjects/no teeth	Assessment of endodontic status/ diagnosis	Treatment	Treatment setting	Outcomes	Follow-up (y—years)
Alassadi et al. (2020)	2020	Retrospective case series	United States	57.6% male; mean age 62.5 ± 10.8 y; 38.8% smokers; 9.4% diabetes	85/85 69 (81.2%) maxillary, 16 (18.8%) mandibular; 64 (73.3%) crowns, 9 (10.6%) with fillings, 12 (14.1%) fixed partial dentures	Not reported	Non-surgical periodontal treatment followed by root resection	Academic institution	Tooth survival (any tooth remained in functional loading)	Mean follow-up 5 ± 4.3 y; (range 1–16.8 y)
Derks et al. (2018)	2018	Retrospective case series	Germany	56.5% male; median age 54 y (range 23–89 y)	69/90 29 (32.2%) maxillary, 61 (67.8%) mandibular; 33 crowns, 51 fixed partial dentures, six double-crown	Periapical Index (PAI), quality of root canal fillings	Root separation and resection; osteotomy/ osteoplasty as needed	Private dental office	Tooth survival; periodontal situation (PPD)	Mean follow-up 14.7 ± 6.8 y (range 4.2–30 y)
El Sayed et al. (2020)	2020	Retrospective case series	Germany	35% male; mean age 51.3 ± 10.8 y; 21% smokers; 39% with systemic disease; 37.5% high education level, 47.9% moderate education level	100/130 98 (75.4%) maxillary, 32 (24.6%) mandibular; 74 (56.9%) with fillings; 53 (40.8%) with crown; 3 (2.3%) fixed partial dentures	Not reported	Professional teeth cleaning and oral hygiene training and motivation; non-surgical periodontal treatment followed by root resection	Academic institution	Tooth survival; periodontal situation (PPD, GBI, BOP; furcation involvement	Mean follow-up 9.6 ± 3.08 y (range 5–16 y)

TABLE 2 Outcomes

Study	No of teeth treated by resective therapy	Survival of teeth treated by resective therapy	No of teeth treated by resective therapy for endodontic reasons	Survival of teeth treated by resective therapy for endodontic reasons	Additional analysis
Alassadi et al. (2020)	85	47	23	11	12 teeth treated, due to the presence of periapical lesion on the resected root, failed (31.6% of the total failures); as compared to teeth treated for periodontal reasons, teeth treated for endodontic reasons has a HR = 3.1 for failure over time
Derks et al. (2018)	90	30	11 (13.6% out of 81 teeth with documented reason for resection)	n.r.	The incidence of endodontic complications leading to overall tooth extraction was 26.7%.
El Sayed et al. (2020)	130	74	8 (6.2%)	n.r.	Of the teeth extracted, 9 (16.1%) were extracted due to endodontic complications. The endodontic indications for treatment were not correlated to a higher risk of failure as compared with periodontal indications (HR = 0.902 [0.224; 3.639])

after clinical assessment in a private dental clinic (Derks et al., 2018). The treatment was most frequently performed for periodontal and/or endodontic reasons, due to the presence of a root fracture or unrestorable caries.

The reason for root resection in one study was endodontic in 27.1% ($n = 23$) of the teeth (Alassadi et al., 2020) whilst it was 13.6% ($n = 11$) in another study (Derks et al., 2018) and 6.2% ($n = 8$) in the third study (El Sayed et al., 2020).

Comparison

None of the studies included a control group. Comparative data with respect to non-surgical retreatment and/or apical surgery were not available in the included studies.

Outcome and synthesis of data with respect to the primary outcomes tooth survival and patient-reported outcome measures (PROMs)

In the three included studies (Alassadi et al., 2020; Derks et al., 2018; El Sayed et al., 2020), of the 305 resected teeth, 151 teeth were extracted during the follow-up period, for various reasons. The studies provided limited data on the reason/s for tooth extraction. Therefore, calculation of the failure rate for teeth treated exclusively for endodontic reasons was difficult. In addition, the low number of included studies and the high level of heterogeneity, in terms of study design and outcome reporting, prevented a meta-analysis of the data; therefore, the outcome of the three included studies (Alassadi et al., 2020; Derks et al., 2018; El Sayed et al., 2020) had to be described in a qualitative manner.

In one of the included studies, of the 23 teeth treated with root resection for endodontic reasons, 12 (52.2%) failed (31.6% of all the failures [$n = 38$]; Alassadi et al., 2020). Derks et al. reported that 30 teeth were extracted after a mean follow-up period of 14.7 years; of these, only eight teeth were extracted due to endodontic reasons and all of the teeth had a periapical index (PAI; Orstavik et al., 1986) score of 3, 4, or 5.

El Sayed & coworkers reported that of all the teeth extracted, nine teeth were removed for endodontic reasons (El Sayed et al., 2020). In addition, in this study, there was no statistically significant difference ($p = .885$) in tooth survival regardless of whether root resection was carried out for periodontal or endodontic reasons (El Sayed et al., 2020).

None of the included studies reported on PROMs.

DISCUSSION

A systematic review enables the integration of the results of several independent studies to be combined (Higgins et al., 2021). Systematic reviews use an organized approach and explicit methodology to review and synthesize research evidence; the aims are to minimize bias, clearly address the issues of the completeness of the identified evidence and assess the quality and combinability of the included studies (Egger et al., 1997; Greenhalgh & Peacock, 2005; Sutherland & Matthews, 2004; Tsesis et al., 2010).

In this systematic review, a combined comprehensive literature search of several electronic databases, a grey literature search and a hand search of related articles and literature reviews was conducted. Whilst, numerous investigations have been published on root resection techniques, the studies identified were highly heterogeneous in terms of design, and the methods used were not standardized. In addition, they did not, as questioned by the PICO of this review, present comparative data to non-surgical retreatment and/or apical surgery (Alassadi et al., 2020; Derks et al., 2018; El Sayed et al., 2020). To overcome the heterogeneity of the data, strict inclusion and exclusion criteria were applied. Adhering to the selection criteria, 36 studies were identified; however, only three retrospective studies presented relevant data that had explored treatment outcome. Thus, a meta-analysis was not performed due to the low number of articles and the heterogeneity of these three studies.

Using a systematic approach and stringent inclusion criteria, three studies were identified as suitable for inclusion in this review. Of 305 teeth treated using root resection techniques, only 42 teeth were treated for endodontic reasons exclusively. Whilst the overall failure rate, in terms of tooth loss, accounted for approximately 50%, it was—unfortunately—not possible to calculate the percentage of tooth loss specifically for endodontic reasons. Moreover, the appraisal of endodontic status before treatment was not always reported, so it was impossible to make any consideration about the treatment alternatives in all cases. However, taking the tooth loss rate provided for teeth treated for endodontic reasons in one study (52.2%; Alassadi et al., 2020) and the overall tooth loss rate from the three studies together (Alassadi et al., 2020; Derks et al., 2018; El Sayed et al., 2020), a careful interpretation suggests that the tooth loss rate for teeth treated for endodontic reasons seems to be in the same range as the overall tooth loss rate, independently from the setting and from the sample's demographies.

A recent systematic review and meta-analysis of the literature on crown and root resection, comprised of 19 retrospective studies, accounting for a total of 2679 treated teeth, reported a survival rate of 85.6%, with no difference between maxillary and mandibular teeth, including both periodontally healthy and compromised teeth (Setzer et al., 2019). The authors did not find any comparative research and, as such, the evidence is based solely on observational studies.

Another systematic review on root resection surgery in teeth with furcation involvement (Dommisch et al., 2020) included seven studies and reported that there was significant heterogeneity of the available data. The superiority of root resection techniques, which are mainly indicated in periodontal cases, over root planning and open flap debridement, in terms of tooth survival has not been demonstrated (Dommisch et al., 2020). Comparing the results of this systematic review with that of previous reviews, the main difference observed is that root resection treatment was usually performed for managing teeth with furcation involvement and not specifically for teeth with apical periodontitis. Such differing indications are related to different local anatomical and/or pathological conditions (e.g. tooth anatomy, attachment level, gingival inflammation) that may affect the tooth prognosis. A direct comparison of the results of both reviews is therefore not possible based on the existing literature.

Systematic reviews of interventions require a thorough, objective and reproducible search of a wide range of sources to identify as many relevant studies as possible, to achieve reliable estimates of effectiveness (Higgins et al., 2021). In this systematic review, the methodological quality of the included studies was appraised to evaluate the risk of bias. The risk of bias of the non-randomized studies, including case–control and cohort studies, can be challenging to implement and conduct. The Newcastle–Ottawa scale (NOS) was used for the assessment of risk of the included studies (Wells et al., 2011). The NOS is one of the most well-known scales for assessing quality and risk of bias in observational studies (Stang, 2010). In the review conducted here, the risk of bias of the included research was affected by the lack of information about endodontic diagnosis and by the selection of the cohort.

Based on the results of the current systematic review, the evidence-based data concerning the survival and clinical effectiveness of root resection techniques on teeth with apical periodontitis are limited and insufficient also as compared to other techniques for managing apical periodontitis that demonstrated high success rates. Moreover, such procedures could be indicated in cases with vertical root fracture associated with apical periodontitis and loss of periodontal attachment, whilst the application to roots without any sign of periodontal attachment loss could be considered impractical.

Therefore, there is a need for additional research to assess the actual effectiveness of this treatment modality. Future studies should assess, in a reliable way, the endodontic status of the tooth/root before intervention and results should be reported after an adequate follow-up period. Moreover, to reduce confounding factors, this treatment modality should be performed on teeth/roots with apical periodontitis but without signs of periodontal diseases, although this may only be of limited clinical applicability.

CONCLUSION

On the basis of existing evidence, it is not possible to recommend or dismiss root resection for the treatment of apical periodontitis. The limited studies available, their heterogeneity, and the presence of important confounding factors, for example periodontal furcation involvement meant that there is insufficient, high-quality evidence on the effectiveness of root resection techniques for the management of teeth with apical periodontitis.

AUTHORS CONTRIBUTION

Stefano Corbella, Clemens Walter and Igor Tsesis contributed to conceptualization, data analysis and interpretation and writing and approval of the manuscript; Stefano Corbella contributed to search of the sources; Stefano Corbella and Igor Tsesis contributed to article selection; Stefano Corbella and Clemens Walter contributed to data extraction.

ACKNOWLEDGEMENT

Open Access Funding provided by Universita degli Studi di Milano within the CRUI-CARE Agreement.

CONFLICT OF INTEREST

The authors are free from any conflict of interest in connection with this article.

DATA AVAILABILITY STATEMENT

The data that support the findings of this study are available from the corresponding author upon reasonable request.

ETHICS STATEMENT

Not applicable.

ORCID

Stefano Corbella https://orcid.org/0000-0001-8428-8811
Clemens Walter https://orcid.org/0000-0002-9967-1570
Igor Tsesis https://orcid.org/0000-0002-5824-0379

REFERENCES

AAE. (2016) *Guide to clinical endodontics*, 6th edition. Chicago: American Association of Endodontists.

AAE. (2020) *Glossary of endodontic terms*, 10th edition. Chicago: American Association of Endodontists.

Alassadi, M., Qazi, M., Ravidà, A., Siqueira, R., Garaicoa-Pazmiño, C. & Wang, H.L. (2020) Outcomes of root resection therapy up to 16.8 years: a retrospective study in an academic setting. *Journal of Periodontology*, 91(4), 493–500.

Derks, H., Westheide, D., Pfefferle, T., Eickholz, P. & Dannewitz, B. (2018) Retention of molars after root-resective therapy: a retrospective evaluation of up to 30 years. *Clinical Oral Investigations*, 22(3), 1327–1335.

Dommisch, H., Walter, C., Dannewitz, B. & Eickholz, P. (2020) Resective surgery for the treatment of furcation involvement: a systematic review. *Journal of Clinical Periodontology*, 47(Suppl 22), 375–391.

Egger, M., Smith, G.D. & Phillips, A.N. (1997) Meta-analysis: principles and procedures. *British Medical Journal*, 315(7121), 1533–1537.

El Sayed, N., Cosgarea, R., Rahim, S., Giess, N., Krisam, J. & Kim, T.S. (2020) Patient-, tooth-, and dentist-related factors influencing long-term tooth retention after resective therapy in an academic setting-a retrospective study. *Clinical Oral Investigations*, 24(7), 2341–2349.

European Society of Endodontology. (2006) Quality guidelines for endodontic treatment: consensus report of the European Society of Endodontology. *International Endodontic Journal*, 12, 921–930.

Farrar, J.N. (1884) Radical and heroic treatment of alveolar abscess by amputation of roots of teeth, with description and application of the cantilever crown. *The Dental Cosmos*, 26, 135–139.

Floratos, S.G. & Kratchman, S.I. (2012) Surgical management of vertical root fractures for posterior teeth: report of four cases. *Journal of Endodontics*, 38(4), 550–555.

Greenhalgh, T. & Peacock, R. (2005) Effectiveness and efficiency of search methods in systematic reviews of complex evidence: audit of primary sources. *British Medical Journal*, 331(7524), 1064–1065.

Higgins, J.P.T., Thomas, J., Chandler, J., Cumpston, M., Li, T., Page, M.J. & Welch, V.A. (2021) *Cochrane handbook for systematic reviews of interventions*. Chichester: Cochrane.

Jepsen, K., Dommisch, E., Jepsen, S. & Dommisch, H. (2020) Vital root resection in severely furcation-involved maxillary molars: outcomes after up to 7 years. *Journal of Clinical Periodontology*, 47(8), 970–979.

Kim, S. & Kratchman, S. (2006) Modern endodontic surgery concepts and practice: a review. *Journal of Endodontics*, 32(7), 601–623.

Orstavik, D., Kerekes, K. & Eriksen, H.M. (1986) The periapical index: a scoring system for radiographic assessment of apical periodontitis. *Endodontics & Dental Traumatology*, 2(1), 20–34.

Page, M.J., McKenzie, J.E., Bossuyt, P.M., Boutron, I., Hoffmann, T.C., Mulrow, C.D. et al. (2021) The PRISMA 2020 statement: an updated guideline for reporting systematic reviews. *PLoS Medicine*, 18(3), e1003583.

Parirokh, M., Torabinejad, M. & Dummer, P.M.H. (2018) Mineral trioxide aggregate and other bioactive endodontic cements: an updated overview - part I: vital pulp therapy. *International Endodontic Journal*, 51(2), 177–205.

Patel, S., Brown, J., Semper, M., Abella, F. & Mannocci, F. (2019) European Society of Endodontology position statement: use of cone beam computed tomography in Endodontics: European Society of Endodontology (ESE) developed by. *International Endodontic Journal*, 52(12), 1675–1678.

Pecora, G. & Andreana, S. (1993) Use of dental operating microscope in endodontic surgery. *Oral Surgery, Oral Medicine, Oral Pathology and Oral Radiology*, 75(6), 751–758.

Schmidt, J.C., Walter, C., Amato, M. & Weiger, R. (2014) Treatment of periodontal-endodontic lesions—a systematic review. *Journal of Clinical Periodontology*, 41(8), 779–790.

Schwendicke, F., Graetz, C., Stolpe, M. & Dorfer, C.E. (2014) Retaining or replacing molars with furcation involvement: a cost-effectiveness comparison of different strategies. *Journal of Clinical Periodontology*, 41(11), 1090–1097.

Setzer, F.C., Kohli, M.R., Shah, S.B., Karabucak, B. & Kim, S. (2012) Outcome of endodontic surgery: a meta-analysis of the literature—part 2: comparison of endodontic microsurgical techniques with and without the use of higher magnification. *Journal of Endodontics*, 38(1), 1–10.

Setzer, F.C., Shou, H., Kulwattanaporn, P., Kohli, M.R. & Karabucak, B. (2019) Outcome of crown and root resection: a systematic review and meta-analysis of the literature. *Journal of Endodontics*, 45(1), 6–19.

Stang, A. (2010) Critical evaluation of the Newcastle-Ottawa scale for the assessment of the quality of nonrandomized studies in meta-analyses. *European Journal of Epidemiology*, 25(9), 603–605.

Sutherland, S.E. & Matthews, D.C. (2004) Conducting systematic reviews and creating clinical practice guidelines in dentistry: lessons learned. *Journal of the American Dental Association*, 135(6), 747–753.

Torabinejad, M., Parirokh, M. & Dummer, P.M.H. (2018) Mineral trioxide aggregate and other bioactive endodontic cements: an updated overview—part II: other clinical applications and complications. *International Endodontic Journal*, 51(3), 284–317.

Tsesis, I., Rosen, E., Tamse, A., Taschieri, S. & Kfir, A. (2010) Diagnosis of vertical root fractures in endodontically treated teeth based on clinical and radiographic indices: a systematic review. *Journal of Endodontics*, 36(9), 1455–1458.

Walter, C., Weiger, R., Dietrich, T., Lang, N.P. & Zitzmann, N.U. (2012) Does three-dimensional imaging offer a financial benefit for treating maxillary molars with furcation involvement? A pilot clinical case series. *Clinical Oral Implants Research*, 23(3), 351–358.

Walter, C., Weiger, R. & Zitzmann, N.U. (2010) Accuracy of three-dimensional imaging in assessing maxillary molar furcation involvement. *Journal of Clinical Periodontology*, 37(5), 436–441.

Walter, C., Weiger, R. & Zitzmann, N.U. (2011) Periodontal surgery in furcation-involved maxillary molars revisited--an introduction of guidelines for comprehensive treatment. *Clinical Oral Investigations*, 15(1), 9–20.

Wells, G.A., B Shea, D O'Connell, J Peterson, V Welch, M Losos, P Tugwell (2011). The Newcastle-Ottawa Scale (NOS) for assessing the quality of nonrandomised studies in meta-analyses. Available at: http://www.ohri.ca/programs/clinical_epidemiology/oxford.asp

World Health Organization. (2022). *International classification of diseases*. Available at: https://icd.who.int/en.

How to cite this article: Corbella, S., Walter, C. & Tsesis, I. (2022) Effectiveness of root resection techniques compared with root canal retreatment or apical surgery for the treatment of apical periodontitis and tooth survival: A systematic review. *International Endodontic Journal*, 00, 1–12. Available from: https://doi.org/10.1111/iej.13808

APPENDIX A

A.1 | SEARCH STRATEGY

A.1.1. | MEDLINE via Ovid

1946 to 25/09/2021: 691.

	MeSH terms	Free text
Population	Exp Periapical diseases OR radicular cyst	*apical disease? OR *apical periodont* OR *apical lesion? OR *apical bone resorption OR *apical granuloma$ OR *apical abscess* OR *apical cyst? OR *radicular cyst? (periapical disease?) OR (periapical periodont*) OR (periapical lesion?) OR (periapical bone resorption) OR (periapical granuloma$) OR (periapical abscess*) OR (periapical cyst?) OR (periradicular cyst?) OR (peri-apical disease) OR (peri-apical periodont*) OR (peri-apical lesion?) OR (peri-apical bone resorption) OR (peri-apical granuloma$) OR (peri-apical abscess*) OR (peri-apical cyst?) OR (peri-radicular cyst?) OR root disease? OR root lesion? OR endodontic lesion* OR endodontic pathology* OR endodontic infection OR periodontal disease? OR furcat*
Intervention	Exp Oral Surgical Procedures	(root ADJ1 resect*) OR (root ADJ1 amputation*) OR root separation OR radectomy OR rizectomy OR rhizectomy OR rizotomy OR rhizotomy OR periodontal surgery OR resective surgery OR crown resection

Limitation to human studies.

A.1.2. | Cochrane library via CENTRAL

(25/09/2021): 1227.

	MeSH terms	Free text
Population	Exp Periapical diseases OR radicular cyst	*apical disease? OR *apical periodont* OR *apical lesion? OR *apical bone resorption OR *apical granuloma$ OR *apical abscess* OR *apical cyst? OR *radicular cyst? OR (periapical disease?) OR (periapical periodont*) OR (periapical lesion?) OR (periapical bone resorption) OR (periapical granuloma$) OR (periapical abscess*) OR (periapical cyst?) OR (periradicular cyst?) OR (peri-apical disease) OR (peri-apical periodont*) OR (peri-apical lesion?) OR (peri-apical bone resorption) OR (peri-apical granuloma$) OR (peri-apical abscess*) OR (peri-apical cyst?) OR (peri-radicular cyst?) OR root disease? OR root lesion? OR endodontic lesion* OR endodontic pathology* OR endodontic infection OR periodontal disease? OR furcat*
Intervention	Exp Oral Surgical Procedures	(root NEAR/1 resect*) OR (root NEAR/1 amputation*) OR root separation OR radectomy OR rizectomy OR rhizectomy OR rizotomy OR rhizotomy OR periodontal surgery OR resective surgery OR crown resection

A.1.3. | EMBASE

(25/09/2021): 161.

	MeSH terms	Free text
Population	Exp Periapical diseases OR radicular cyst	(apical disease?) OR (apical periodont*) OR (apical lesion?) OR (apical bone resorption) OR (apical granuloma$) OR (apical abscess*) OR (apical cyst?) OR (radicular cyst?) OR (periapical disease?) OR (periapical periodont*) OR (periapical lesion?) OR (periapical bone resorption) OR (periapical granuloma$) OR (periapical abscess*) OR (periapical cyst?) OR (periradicular cyst?) OR (peri-apical disease) OR (peri-apical periodont*) OR (peri-apical lesion?) OR (peri-apical bone resorption) OR (peri-apical granuloma$) OR (peri-apical abscess*) OR (peri-apical cyst?) OR (peri-radicular cyst?) OR (root disease?) OR (root lesion?) OR (endodontic lesion*) OR (endodontic pathology*) OR (endodontic infection) OR (periodontal disease?) OR furcat*
Intervention	Exp Oral Surgical Procedures	(root NEAR/1 resect*) OR (root NEAR/1 amputation*) OR (root separation) OR radectomy OR rizectomy OR rhizectomy OR rizotomy OR rhizotomy OR periodontal surgery OR resective surgery OR crown resection

Limit to human studies: [humans]/lim.

APPENDIX B

B.1 | LIST OF EXCLUDED PAPERS AND REASONS FOR THEIR EXCLUSION

Authors	Year	Reason for exclusion
Bergenholtz	1972	No information about outcomes in teeth with endodontic lesion
Hamp et al.	1975	No information about outcomes in teeth with endodontic lesion
Highfield	1978	Review of the literature
Langer et al.	1981	No information about outcomes in teeth with endodontic lesion
Erpenstein	1983	No information about outcomes in teeth with endodontic lesion
Buhler	1988	No information about outcomes in teeth with endodontic lesion
Kuhrau et al	1990	No information about outcomes in teeth with endodontic lesion
Carnevale et al.	1991	No information about outcomes in teeth with endodontic lesion
Muller et al.	1995	No information about outcomes in teeth with endodontic lesion
Babay et al.	1996	No information about outcomes in teeth with endodontic lesion
Blomlof et al.	1997	No information about outcomes in teeth with endodontic lesion
Carnevale et al.	1998	No information about outcomes in teeth with endodontic lesion
Basten et al.	1999	No information about outcomes in teeth with endodontic lesion
Hou et al.	1999	No information about outcomes in teeth with endodontic lesion
Svardstrom & Wennstrom	2000	No information about outcomes in teeth with endodontic lesion
Fugazzotto	2001	No information about outcomes in teeth with endodontic lesion
Polson & Blieden	2002	No information about outcomes in teeth with endodontic lesion
Park et al.	2009	No information about outcomes in teeth with endodontic lesion
Zafiropoulos et al.	2009	No information about outcomes in teeth with endodontic lesion
Huynh-Ba et al.	2009	Review of the literature
Lee et al.	2012	No information about outcomes in teeth with endodontic lesion
Oh	2012	Case report/Case series
Yuh et al.	2013	No information about outcomes in teeth with endodontic lesion
Kasaj et al.	2014	Review of the literature
Graetz et al.	2015	No information about outcomes in teeth with endodontic lesion
Tahmooressi et al.	2016	Case report/Case series
Dannewitz et al.	2016	No information about outcomes in teeth with endodontic lesion
Strbac et al.	2017	Case report/Case series
De Beule et al.	2017	No information about outcomes in teeth with endodontic lesion
Megarbane et al.	2018	No information about outcomes in teeth with endodontic lesion
Jepsen et al.	2019	No information about outcomes in teeth with endodontic lesion
Setzer et al.	2019	Review of the literature
Mokbel et al.	2019	Review of the literature

APPENDIX C

C.1 | NEWCASTLE–OTTAWA SCALE

Authors	Year	Representativeness of the exposed cohort	Selection of the non-exposed cohort	Ascertainment of exposure	Demonstration that the outcome of interest was not present at start of study	Comparability of cohorts on the basis of the design or analysis	Assessment of outcome	Was follow-up long enough for outcomes to occur	Adequacy of follow-up of cohorts	
Alassadi et al.	2019	–	X	–	X	–	X	X	X	5X
Derks et al.	2017	–	X	X	X	–	–	X	X	5X
El Sayed et al.	2019	–	X	X	X	–	X	X	X	6X