Concise Review

Occurrence and Risk Factors of Dental Root Perforations: A Systematic Review

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ABSTRACT

Background: Iatrogenic root perforations are an unfortunate accident that can occur during dental treatment and can lead to peri-radicular damage, poor treatment outcome and extraction of the tooth. The aim of this review was to analyse the occurrence and risk factors for root perforation.

Methods: A systematic search of the literature was conducted in CINAHL, Cochrane, EMBASE, Medline and SCOPUS in May 2019. Additional literature was identified through a hand search. Clinical studies enrolling adults with permanent dentition were included. Single case studies and case reports were excluded. Duplicate articles were removed, titles and abstracts were screened and studies were selected according to the inclusion criteria. Data were collected and reported in accordance with PRISMA guidelines. Risk of bias was assessed using the Joanna Briggs Institute Critical Appraisal Tools.

Results: A total of 916 articles were screened, from which 47 full-text articles were analysed and 22 articles were finally included in the study. The data were analysed qualitatively because meta-analysis could not be conducted owing to lack of heterogeneity among the studies. Most of the articles were retrospective cross-sectional studies on root canal treatments performed by undergraduate students. The occurrence of perforation ranged from 0.6% to 17.6%. Risk factors for perforation included experience of the practitioner, tooth type, and tooth morphology. The risk of bias in most of the studies included was assessed as low.

Conclusions: This systematic review suggests a need for additional studies on the risk factors associated with iatrogenic root perforation as the current literature is insufficient. Educational efforts in dental schools should address the issue of perforations and provide more clinical experience prior to graduation in order to improve the clinical skills of graduates.

Introduction

A root perforation is any pathological communication between the root canal system and the surrounding periodontium.[1] Perforations can be a result of internal or external root resorption, invasive dental caries or an iatrogenic accident occurring during a root canal treatment or post space preparation.[2]

Perforations negatively affect the prognosis of root canal-treated teeth.[3] It is estimated that up to 10% of root canal treatment failures are caused by perforations, which are the second most common cause of failure associated with endodontic treatment.[4,5] When bacterial infection and/or irritative restorative material are compounded on top of a traumatic perforation, healing does not occur.[6] Once an infectious process has begun at a perforation site that may have gone undetected, the prognosis for treatment is precarious and complications may be severe enough to result in an extraction.[7]

Strip and apical perforations can be especially difficult to manage as gaining access to the perforation site could pose a significant risk of collateral damage or treatment failure, and retreatment may not be an option.[8] According to Farzaneh et al.,[9] there was a significantly increased risk of disease in patients requiring retreatment, who also presented with preoperative perforation. Preoperative perforations were also found to be significant predictors of 4- to 6-year retreatment outcomes ($P < 0.05$).[10] Additionally, the observed healing rate

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in teeth with a perforation was significantly lower (by 31%) than in teeth without a perforation, emphasising that perforations should be avoided in the first place.[10]

Cases referred to endodontic specialists have become more challenging as a result of the increased numbers of dentists with varying skill sets and levels of training who are providing endodontic treatment.[6] In contrast to other causes of perforations, such as resorption or caries, which are pathological in nature, iatrogenic perforations are mostly avoidable. As such, prevention remains the most effective clinical approach to perforations.[11]

Classic literature often cited in reference to the frequency of perforations spans a time period ranging from 1961 to 1979.[4,12–14] As a result of the advancements in technology now employed during endodontic treatment, such as the use of microscopes, nickel titanium (NiTi) rotary files, limited field-of-view cone beam computed tomography (CBCT) and new-generation electronic apex locators, these estimates might have become outdated. To the best of our knowledge, no cohesive, evidence-based literature review has been published that evaluates the occurrence of root perforations and possible risk factors to date.

The aim of this systematic review was to analyse the occurrence and risk factors associated with root perforation in adult patients who underwent root canal treatment or post space preparation.

Methods

Eligibility criteria

The Population, Intervention, Comparison, Outcome, Study designs (PICOS) guidelines were used to develop the question for this systematic review[15-17]:

- Population: adult dental patients with permanent dentition; no restrictions on sex.
- Intervention: root canal treatment or post space preparation.
- Comparison: no root perforation.
- Outcome: iatrogenic root perforation.
- Study designs: clinical trials, or prospective or retrospective observational studies performed in a clinical setting and not on extracted teeth. No restriction on sample size was placed.

The PICOS question used was 'What is the occurrence and the risk factors of root perforation in adult patients with root canal treatments or post space preparation?'

Articles were excluded if they were in any of the following categories: case report; no perforations reported; study only on deciduous teeth; not in English; non-clinical study on extracted teeth; opinion article; or article on treatment or complications of root perforations.

Information sources and search strategy

An electronic search was conducted in CINAHL, Cochrane (all databases), EMBASE, Medline and SCOPUS databases in May 2019. The search was conducted according to the PRISMA guidelines[16] with the help of an experienced reference librarian.

Search strategy

Medical Subject Headings (MeSH) were used as in the example presented below:

Database: EBSCO Medline.

1. (MH "Endondontics") OR (MH "Root Canal Therapy+") OR (MH "Root Canal Preparation")
2. (MH "Tooth Preparation, Prosthodontic") OR (MH "Dental Pins")
3. (MH "Post and Core Technique")
4. (("root canal*" or endodontic) W3 (treatment* or therap*)) OR (("post space" or "root canal*" or tooth) W3 preparation*) OR "post placement*" OR retreatment* OR ("post and core")
5. 1 OR 2 OR 3 OR 4
6. ((Root or strip or furcal or foramen or apex or apical or lateral) W3 perforat*) OR furcat* OR complication*
7. 5 AND 6
8. (MH "Animals+") NOT (MH "Animals+" AND MH "Humans +")
9. 7 NOT 8

Additional literature was identified through hand search by reviewing the references of articles selected through the electronic search process. Duplicates were removed using the RefWorks reference manager (Pro-Quest, RefWorks, LLC) software.

The authors screened all titles and abstracts for studies that met the eligibility criteria. Questionable titles were discussed until consensus was reached. Upon completion of screening, the full texts were retrieved.

Data collection process

Data extraction and methodological quality assessment were performed independently by the authors. Data extraction was carried out using a data extraction form. The form included the following information: study design; sample size; sample type; type and experience of dental provider; foramen locator or microscope use; number and location of root perforations; tooth type and morphology; and procedure during which the perforation occurred.

Risk of bias

As non-randomised controlled studies were included, the Joanna Briggs Institute Critical Appraisal Tools were used to assess the risk of bias in the articles.[18] This tool was modified to suit the types of studies evaluated in this review.

Results

Study selection

A total of 916 articles were screened from all the databases. From those, 47 full-text articles were retrieved and 22 articles were finally included in the study (Figure 1). The studies included in this review are summarised and presented in

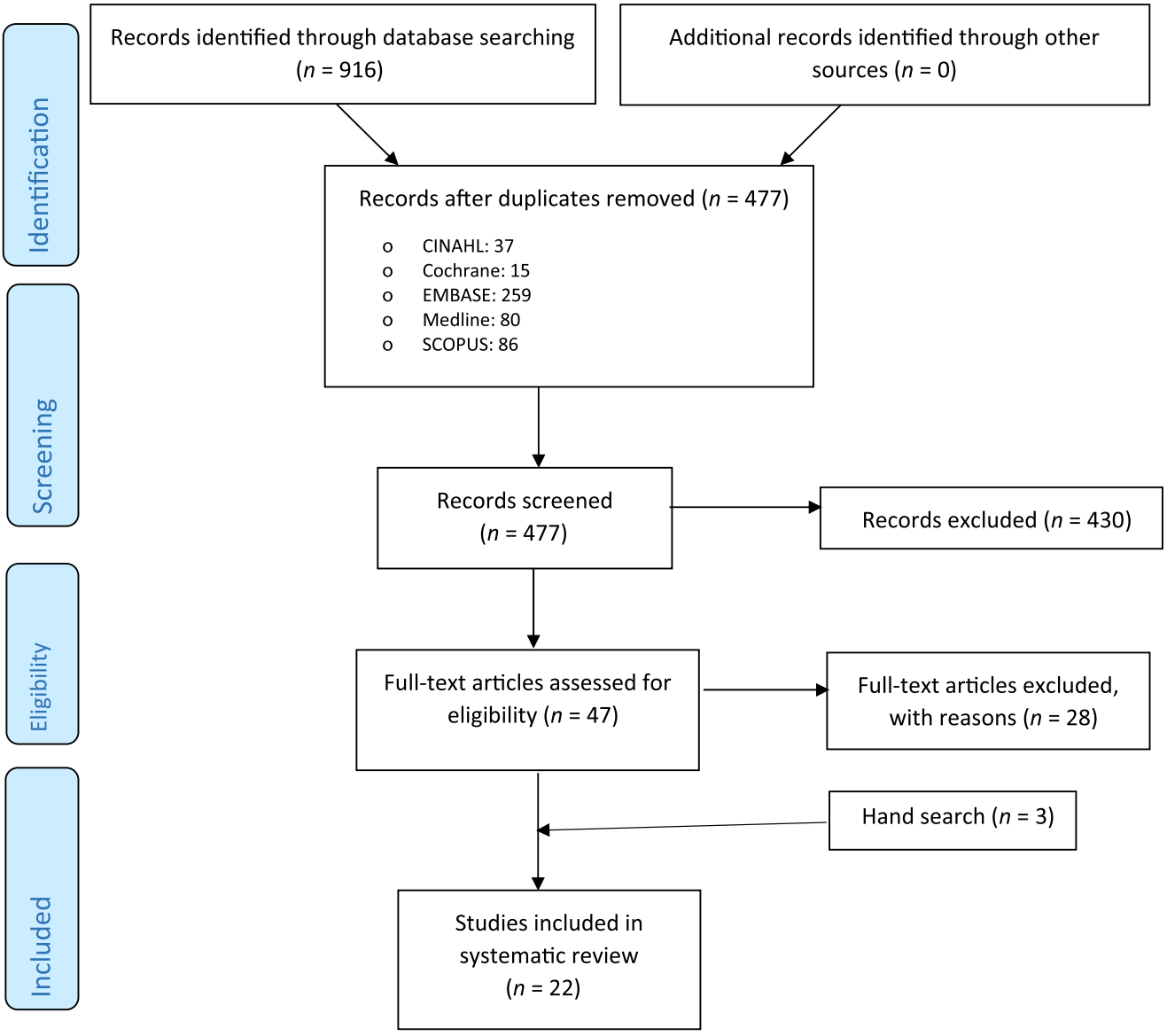

Fig. 1 – PRISMA flow chart.

Table 1. The excluded full-text articles and the reasons for exclusion are presented in the Appendix S1.

Study characteristics

From the 22 included articles (Table 1), 20 were retrospective cross-sectional studies, one was a randomised controlled trial[19] and one was a case–control study.[11] Most of the studies included were retrospective cross-sectional studies on root canal treatments performed by undergraduate students (n = 13).[19–31] In three studies, treatment was performed by general dentists.[32–34] Most of the included studies determined the prevalence of root perforations from the total number of root canal treatments performed or in relation to the total number of canals treated.[11,19,20,22–26,28,30,31] Other studies assessed the prevalence of root perforation in cases of broken instrument removal[33,35] or during post space preparation.[32,36] Types of perforations included strip, furcal, coronal, apical, root, cervical and lateral.

The sample size (i.e. the number of root canal-treated teeth/canals) in the various studies ranged from 60 to 5048. The occurrence of perforations ranged from 0.6% to 17.6%.

Nine studies conducted a statistical analysis on the various factors associated with iatrogenic perforation.[11,21–25,28–30] The most common factors associated with perforation included experience of the practitioner, type of tooth and morphology of the tooth.

Results of individual studies

Experience of the practitioner

Three studies statistically evaluated the experience of the provider in relation to the occurrence of perforations.[23,24,28] One study concluded that there was no significant difference

Table 1 – Summary of findings from studies

Author (year)	Study type	Provider	Number of patients, teeth and canals; Treatment type	Occurrence (%) and type of perforation	Associated factors related to root perforations	Comments
Akbar (2015)	Retrospective record review	General dentists	100 pts, 100 teeth, 130 canals Root canal treatment	In total, 3.85% of all canals with root canal treatment failure: 0.8% coronal, 0.8% furcal and 2.3% strip perfs	Coronal: 1.8% of mandibular molars with root canal treatment failure had a coronal perf. Furcal: 1.8% of mandibular molars with root canal treatment failure had a furcal perf. Strip: 4.8% of maxillary molars and 1.8% of mandibular molars with root canal treatment failure had a strip perf.	Apex locators not used No stat. analyses
AlRahabi (2017)	Retrospective record review	Undergraduate students	280 pts, 280 teeth Root canal treatment	2.3% apical	6.7% of upper incisors and 7.7% of lower premolars with root canal treatment had a perf. 2.4% of root canal treatments performed by 4th yr students and 2.2% performed by 5th yr students had a perf. (P = NS)	Apex locators not used
Balto et al. (2010)	Retrospective record review	Undergraduate students	459 pts, 550 teeth Root canal treatment	Total 9.6%: 6.7% apical, 1.5% root and 1.5% strip perfs	Apical: 1.8% of incisors, 6.1% of canines, 6.3% of premolars and 10.6% of molars with root canal treatment had an apical perf. (P = 0.033) 8.3% of root canal treatments performed by 4th yr students and 4.8% performed by 5th yr students had an apical perf. (P = NS) Root: 4.5% of canines, 0.5% of premolars and 2.2% of molars with root canal treatment had a root perf. (P = 0.047) 0.3% of root canal treatments performed by 4th yr students and 2.8% by 5th yr students (P = 0.016) Strip: 1.5% of canines and 3.9% of molars with root canal treatment had a strip perf. (P = 0.008) 1% of root canal treatments performed by 4th yr students and 2% performed by 5th yr students had a strip perf. (P = NS)	Apex locators used in some cases
Cronström et al. (1998)	Retrospective record review	General dentists	851 teeth Root canal treatment or post space preparation	29% of all insurance claims submitted for dental injuries	Root canal treatment: 7.5% of all insurance claims submitted for dental injuries were for a perf. as a result of root canal treatment Post space preparation: 21.5% of all insurance claims submitted for dental injuries were for a perf. as a result of post space preparation. Most perfs were in mandibular molars	No stat. analysis
Cujé et al. (2010)	Retrospective record review	Endodontist	145 pts, 147 teeth Broken instrument retrieval	0.7% during broken instrument retrieval	N/A	Microscope and apex locator used No stat. analysis
Dadresanfar et al. (2008)	Retrospective record review	Undergraduate students	400 teeth Root canal treatment	Total 4.5%: 0.25% cervical, 0.25% furcal and 4% strip perfs	Cervical: 1.6% of maxillary incisors with root canal treatment had a cervical perf. Furcal: 0.9% of mandibular molars with root canal treatmenthad a furcal perf. Strip: 11.1% of maxillary molars, 4.5% of mandibular incisors, 1.7% of mandibular premolars and 6% of mandibular molars with root canal treatmenthad a strip perf. No significant relationship between the incidence of strip perfs and canal curvature (P = NS)	Apex locators not used

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Table 1 (*Continued*)

Author (year)	Study type	Provider	Number of patients, teeth and canals; Treatment type	Occurrence (%) and type of perforation	Associated factors related to root perforations	Comments
Eleftheriadis & Lambrianidis (2005)	Retrospective record review	Undergraduate students	388 teeth, 620 canals Root canal treatment	2.7%	4.9% of canals with moderate canal curvature undergoing root canal treatment had a perf. ($P < 0.001$); 7.8% of canals with severe canal curvature undergoing root canal treatment had a perf. ($P < 0.001$)	Apex locators not used
Haji-Hassani et al. (2015)	Retrospective record review	Undergraduate students	1335 teeth Root canal treatment	Total 13%: 12.4% apical and 0.6% strip perfs	Apical: 7.49% of root canal treatments resulted in an apical perf. in a maxillary tooth; 4.9% of root canal treatments resulted in an apical perf. in a mandibular tooth Strip: 0.37% of root canal treatments resulted in a strip perf. in a maxillary tooth; 0.22% of root canal treatments resulted in an strip perf. in a mandibular tooth Most perfs were in lower molars	No stat. analysis
Haug et al. (2018)	Retrospective record review	Undergraduate students	257 teeth Root canal treatment	1.56% lateral or strip perfs	No significant difference between perfs in using hand versus engine-driven instrumentation (P = NS) File separation was positively correlated with lateral perfs ($r_s = 0.189$, $P < 0.01$);	Apex locators used
Hendi et al. (2018)	Retrospective record review	Undergraduate students	432 teeth Root canal treatment	17.6% apical perfs	11.8% of anterior teeth with root canal treatment had an apical perf. as did 12.4% of premolars and 31.4% of molars ($P < 0.05$) 15.6% of maxillary teeth and 21.5% of mandibular teeth with root canal treatment had an apical perf. (P = NS)	
Hülsmann & Schinkel (1999)	Retrospective record review	General dentists	105 pts, 105 teeth Broken instrument retrieval	10.6% during broken instrument retrieval	58% of all perfs were in mesial canals of mandibular molars	No stat. analysis
Kfir et al. (2003)	Retrospective record review	Undergraduate students	291 canals Root canal treatment	5.15%	2% of root canal treatments performed using the 8-step method resulted in a perf. 7% of root canal treatments performed using the serial-step back technique resulted in a perf.	Apex locators used if needed No stat. analysis
Khabbaz et al. (2010)	Retrospective record review	Undergraduate students	734 teeth, 1109 canals Root canal treatment	Total 13.9%: 10.2% foramen and 3.7% root perfs	Apical: 8.4% of all canals treated by 4th yr students had an apical perf. versus 11.3% of all canals treated by 5th yr students ($P < 0.05$) Root: 6.2% of all canals treated by 4th yr students had a root perf. versus 2.1% of all canals treated by 5th yr students ($P < 0.05$)	
Kvinnsland et al. (1989)	Retrospective record review	N/A	55 teeth with perfs Root canal treatment or post space preparation	N/A	Root canal treatment caused 47% of all perfs: 42% in the apical region; 11.5% in the cervical region; 11.5% in the furcation region; and 35% in the mid-root Post space preparation caused 53% of all perfs: 14% in the apical region; 17% in the cervical region; 14% in the furcation region; and 55% in the mid-root Maxilla: 73% of all perfs Mandible: 27% of all perfs Buccal surface: 35% of all perfs Distal surface: 14.5% of all perfs Furcal surface: 13% of all perfs Lingual surface: 4% of all perfs Mesial surface: 35% of all perfs	No stat. analysis Only included perforated cases

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Table 1 (*Continued*)

Author (year)	Study type	Provider	Number of patients, teeth and canals; Treatment type	Occurrence (%) and type of perforation	Associated factors related to root perforations	Comments
Mozayeni et al. (2006)	Retrospective record review	N/A	150 teeth; root canal treatment	0.7% Strip perfs	N/A	No stat. analysis
Mukhaimer (2013)	Retrospective record review	Undergraduate students	612 teeth, 1013 canals; root canal treatment	4.6%	3.4% of anteriors with root canal treatments had a perf., as did 2.6% of premolars and 6.6% of molars ($P < 0.05$)	
Pettiette et al. (1999)	Prospective randomised control trial	Undergraduate students	60 teeth; root canal treatment	5% Strip perfs	10% of root canal treatments performed using SS K-files had a strip perf.	No stat. analysis
Saatchi et al. (2018)	Retrospective record review	Undergraduate students	784 teeth, 1674 canals; root canal treatment	Total 4.5%: 2% foramen and 2.4% root perfs	Apical: 1.6% of root canal treatments performed by 4th yr students, 2.4% by 5th yr students and 1.9% by 6th yr students had an apical perf. Root: 2.2% of root canal treatments performed by 4th yr students, 2.4% by 5th yr students and 2.5% by 6th yr students had an root perf.	No stat. analysis
Santos et al. (2010)	Retrospective record review	Postgraduate endodontic students	1347 canals; root canal treatment	0.6%	N/A	Apex locator used No stat. analysis
Silva et al. (2012)	Retrospective record review	N/A	200 teeth; root canal treatment	4.5% of CBCT examinations after root canal treatment	Anterior maxilla: 1.5% of CBCT examinations after root canal treatments showed perf. in the anterior maxilla Posterior maxilla: 2.5% of CBCT examinations after root canal treatments showed perf. in the posterior maxilla Posterior mandible: 0.5% of CBCT examinations after root canal treatments showed perf. in the posterior mandible	No stat. analysis
Tsesis et al. (2010)	Retrospective case–control study	N/A	2002 pts, 5048 teeth root canal treatment	2.3%	1.6% of all root canal treatments in upper anteriors were perforated, as were 1.8% in upper premolars, 1.2% in upper molars, 0.6% in lower anteriors, 1% in lower premolars and 5.3% in lower molars ($P < 0.05$)	
Yavari et al. (2015)	Retrospective record review	Undergraduate students	620 pts, 620 teeth, 1183 canals; root canal treatment	1.9%	N/A	No stat. analysis

CBCT, cone beam computed tomography; N/A, not available; Perf(s)., perforation(s); Pts., patients; stat., statistical.

between 4th- and 5th-year students in relation to the type or frequency of procedural errors.[28] A different study concluded that root perforation had a significant association with the stage of education of the student ($P = 0.016$) and that root perforations were more prevalent in procedures carried out by 5th-year students than in those carried out by 4th-year students.[23] The authors suggested that the higher occurrence of perforations in 5th-year students might be because those students were more confident and took fewer radiographs, therefore increasing the risk of procedural errors, or because their clinical supervision ratio was less than that of the 4th-year students.[23] A third study concluded that 5th-year students created significantly more foramen perforations than 4th-year students, but that 4th-year students created significantly more root perforations than 5th-year students.[24] Only one study reported perforations during treatments carried out by postgraduate endodontic students,[37] and no studies evaluated rates of perforation in general dentists or endodontists.

Tooth type

Four studies statistically evaluated the type of tooth in relation to the occurrence of perforations.[11,23,25,30] One study concluded that there was no significant difference in the occurrence of perforation between the jaws but that the prevalence of apical perforation was significantly higher in molar teeth than in other teeth.[30] Another study concluded that there was no statistically significant difference between anterior and premolar teeth or between premolar and molar teeth in the occurrence of a perforation.[25] Balto *et* al. concluded that posterior teeth had significantly more apical ($P = 0.033$), root ($P = 0.047$) and strip ($P = 0.008$) perforations than anterior teeth.[23] Finally, Tsesis et al. found significantly more perforations in mandibular molars than in other teeth.[11]

Tooth morphology

Two studies statistically evaluated the morphology of the tooth in relation to the occurrence of perforations.[21,22] One study did not find any significant relationship between the incidence of strip perforation and canal curvature.[22] However, another study found that canal curvature was the only statistically significant factor related to canal perforations, and that there was a significant difference between straight and moderately curved canals ($P < 0.001$) and between straight and severely curved canals ($P < 0.001$) in the occurrence of perforations.[21] They also concluded that in molars, canal curvature had the strongest correlation with root perforations.[21]

Other variables

Haug et al. concluded that there was no statistically significant difference in the occurrence of perforations between hand-driven and engine-driven instruments.[29] Furthermore, the same study concluded that file separation was positively correlated with lateral perforation ($P < 0.01$) and short obturation ($P < 0.05$).[29]

Two studies separated the occurrence of perforation during root canal treatment versus post space preparation.[32,36] One study found that of all the dental insurance claims filed about injuries during treatment, 21.5% were for perforations made during post space preparation while 7.5% were for perforations made during root canal treatment.[32] Another study evaluated 55 perforations and found that 53% of the perforations occurred during post space preparation while 47% occurred during root canal treatment.[36] However, neither conducted statistical analyses.[32,36]

Risk of bias within studies

A modified version of the Joanna Briggs Institute Critical Appraisal Tools was used to assess the risk of bias in the articles.[18] The risk of bias in most of the studies included was assessed as low (Table 2). For example, the criteria used to evaluate the risk of bias in cross-sectional studies included: clear definition of inclusion criteria; detailed description of study subjects and setting; valid and reliable measurement of exposure; use of objective and standard criteria for measurement of condition; identification of confounding factors; statement of strategies to deal with confounding factors; and use of appropriate statistical analysis. Studies were evaluated as 'yes', 'no' or 'unclear' in meeting the criteria.

Discussion

In the current review, the occurrence of perforations in the studies analysed ranged from 0.6% to 17.6%. The most common factors associated with perforations included experience of the practitioner, type of tooth and morphology of the tooth. As the experience of the practitioner enhances their ability to avoid perforations, and generally molars and teeth with difficult morphologies have a higher prevalence of perforations, the practitioner might consider referring those cases to an endodontic specialist.

General limitations and comments

Certain factors may have contributed to underestimation of the perforation rate in some articles. In some studies, cases of perforation that were referred to the graduate endodontics programme were not included in the search of treatments performed by undergraduate students.[21,24,27] In another study, teeth with perforations were extracted before the study was conducted and were not included in the calculation of occurrence rate11. Additionally, in some of the studies, perforation rates were determined from dental insurance claims filed about injuries during treatment or from procedures involving retrieval of a broken instrument and were not a direct measurement out of the total number of root canal treatments performed; this may have underestimated the perforation rate.[32,33,35]

Several studies did not outline a definition for the type of perforation or the radiographic evaluation criteria and therefore may not be comparable with studies in which a detailed methodological description of the perforation or radiographic evaluation method was given. In a few studies, the students' experience prior to the study or the quality of the radiographs (which are the basis for perforation diagnosis) are not provided; therefore, it becomes difficult to compare the occurrence rates with those reported in other studies.

Table 2 – Joanna Briggs Institute Critical Appraisal Tools for Cross-Sectional Studies (modified): A: Cross-Sectional Studies, B: Randomised Controlled Trials, C: Case Control Studies

(A) Cross-Sectional Studies

Author (year)	Were the criteria for inclusion in the sample clearly defined?	Were the study subjects and the setting described in detail?	Was the exposure (root canal treatment/post space preparation) measured in a valid and reliable way?	Were objective, standard criteria used for measurement of the condition (perforation)?	Were confounding factors identified?	Were strategies to deal with confounding factors stated?	Was appropriate statistical analysis used?
Akbar (2015)	y	y	y	y	y	y	y
AlRahabi (2017)	y	y	y	y	y	y	y
Balto (2010)	y	y	y	y	y	y	y
Cronström (1998)	y	y	n	Unclear	Unclear	n	n
Cujé (2010)	y	y	y	y	y	y	n
Dadresanfar (2008)	y	y	y	y	y	y	y
Eleftheriadis (2005)	Unclear	y	y	Unclear	y	y	y
Haji-Hassani (2015)	y	y	y	y	y	y	y
Haug (2018)	y	y	y	y	y	y	y
Hendi (2018)	Unclear	y	y	y	y	y	n
Hülsmann (1999)	n	y	y	y	y	y	y
Kfir (2003)	y	y	y	y	y	y	y
Khabbaz (2010)	Unclear	y	y	y	y	y	n
Kvinnsland (1989)	Unclear	Unclear	y	Unclear	Unclear	n	y
Mozayeni (2006)	y	y	y	y	y	y	y
Mukhaimer (2013)	y	y	y	y	y	y	y
Saatchi (2018)	y	y	y	y	y	y	y
Santos (2010)	y	y	y	y	y	y	y
Silva (2012)	y	y	y	y	y	y	y
Yavari (2015)	y	y	y	y	y	y	y

(B) Randomised Controlled Trials

Author (year)	Was true randomisation used for assignment of participants to treatment groups?	Was allocation to treatment groups concealed?	Were treatment groups similar at the baseline?	Were participants blind to treatment assignment?	Were those delivering treatment blind to treatment assignment?	Were outcomes assessors blind to treatment assignment?	Were treatment groups treated identically other than the intervention of interest?	Was follow up complete and if not, were differences between groups in terms of their follow up adequately described and analysed?	Were participants analysed in the groups to which they were randomised?	Were outcomes measured in the same way for treatment groups?	Were outcomes measured in a reliable way?	Was appropriate statistical analysis used?	Was the trial design appropriate, and any deviations from the standard root canal treatment design accounted for in the conduct and analysis of the trial?
Pettiette (1999)	y	y	Unclear	n	n	y	y	y	y	y	y	y	y

(C) Case Control Studies

Author (year)	Were the groups comparable other than the presence of disease in cases or the absence of disease in controls?	Were cases and controls matched appropriately?	Were the same criteria used for identification of cases and controls?	Was exposure measured in a standard, valid and reliable way?	Was exposure measured in the same way for cases and controls?	Were confounding factors identified?	Were strategies to deal with confounding factors stated?	Was the exposure period of interest long enough to be meaningful?	Was appropriate statistical analysis used?
Tsesis (2010)	y	y	y	y	y	Unclear	Unclear	y	y

Only a few studies in the current literature review conducted statistical analyses on the occurrence of perforations and related factors. Additionally, the conclusions reported by many studies after statistical analyses of the same risk factor were conflicting. Therefore, because of the insufficient quantity and variable quality of evidence currently available, a definite conclusion cannot be made regarding the risk factors associated with iatrogenic perforation. Owing to the lack of statistical analyses comparing the rates of perforation during root canal treatment and post space preparation, conclusions cannot be drawn on whether one procedure results in a significantly higher percentage of perforations; moreover, variation in reporting on the location of perforations makes it difficult to conclude whether perforations are significantly more prevalent in one particular location.

This systematic review shows that there is currently a gap of knowledge regarding the causes of root perforation. The data currently available are inconsistent and do not provide a high level of evidence. One limitation of the review is that a meta-analysis could not be conducted because of the lack of sufficient, homogenised studies on this topic. Therefore, more studies with high levels of evidence (such as prospective randomised control trials and case–control studies) that report on rates of perforation among general dentists (with different levels of experience), endodontists and postgraduate endodontic students, are necessary. Another limitation of the current review is that studies not available in English were excluded.

Most of the articles published on this topic have publication dates that range from 1961 to 1979.[4,12–14] Since then, there have been many improvements in the technology used during root canal treatments, such as microscopes, NiTi rotary files, CBCT and foramen locators. No cohesive, evidence-based literature review has been published that evaluates the occurrence of root perforations and possible risk factors to date.

This review should serve as a call for action to begin collecting homogenous, high-quality data on perforations in a standardised manner. Authors conducting studies on perforations should collect data on the total number of root canal-treated teeth and number of perforations and, for each perforation, report the tooth type, perforation location, instrumentation technique employed, stage of treatment during which the perforation occurred (or if it was detected postoperatively), provider experience, microscope or foramen locator use and tooth morphology. The creation of a database that allows general dentists and endodontists to report perforations and associated factors is also recommended as it will allow for a more widespread pool of data collection.

Conclusions

The occurrence of perforation in the studies analysed ranged from 0.6% to 17.6%. The most common factors associated with perforation included experience of the practitioner, type of tooth and morphology of the tooth. Educational efforts in dental schools should address the issue of perforations and provide more clinical experience prior to graduation in order to improve the clinical skills of graduates.

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Supplementary materials

Supplementary material associated with this article can be found, in the online version, at doi:10.1111/idj.12602.

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