SYSTEMATIC REVIEW

The treatment options for the management of internal root resorption

ABSTRACT

Aim: *This systematic review aimed to analyze and compare the outcomes of reported treatment options for managing IRR in mature teeth.*
Methodology: *Literature search was conducted using the PubMed, Wiley Online Library and EBSCOhost databases. Clinical trials, case reports/series, which were conducted over a nine-year period describing methodology of IRR treatment were included.*
Results: *From 38 cases of twenty included manuscripts, 19 – described REP, 19 – entire root canal treatment for the management of IRR. The eligible studies showed low risk of bias. The clinical symptoms of causative tooth such as pain or sinus tract, if was related, disappeared during follow up period. Bone destruction healing process was assessed during radiological evaluation despite the applied IRR management method. The resorption area reduced in size or was repaired by mineralized tissue formation in all cases treated by REP.*
Conclusion: *Despite the differences in treatment protocols analyzed for managing of IRR, the outcomes of root canal treatment and REP were comparable and favorable. Based on the limitations of this review, both methods are applicable for treating IRR after evaluating the specific clinical situation in practice.*

Rüta Prialgauskė[1]
Greta Lodienė[1]
Ana Kostenkova[2]*
Neringa Skučaitė[1]

[1]*Lithuanian University of Health Sciences, Faculty of Odontology, Department of Dental and Oral Pathology, Kaunas, Lithuania.*

[2]*Lithuanian University of Health Sciences, Faculty of Odontology, Kaunas, Lithuania.2*

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Corresponding Author
Ana Kostenkova | Lithuanian University of Health Sciences, Faculty of Odontology, Kaunas | Lithuania.
Telephone: +37037326474 Email: ana.kostenkova@lsmu.lt

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Introduction

Internal root resorption (IRR) is a process that occurs in the dental pulp in response to a stimulus, usually an infection. This leads to the destruction of dentine within the root canal space (1). The pathogenesis of IRR is primarily characterized by the activity of odontoclasts (2, 3). The formation of inflammatory IRR starts when the pulp tissue cells and layer of predentin are damaged with a presence of a continuous bacterial stimulation (4). Possible causes of IRR include traumatic injury, caries, endodontic infection, orthodontic treatment, and teeth whitening (2, 3). Scientific literature also describes other potential causes of IRR such as Herpes zoster virus, dens invaginatus, or idiopathic factors (2, 5). Regardless of the origin, IRR can be asymptomatic and may only be discovered through radiographic imaging. It can also present with symptoms of pulpitis or apical periodontitis if the root canal wall is perforated (3, 6, 7). Diagnosing IRR usually requires thorough radiological examination, including the assessment of cone beam computed tomography (CBCT) (8).

Various types of root resorptions potentially affect all anatomical groups of mature permanent teeth. These resorptions usually require different treatment planning strategies in contemporary endodontic practice (1, 6, 9). The progressive loss of dentin within the root canal space as along with possible bone destruction in the resorption site and/or periapically, presents a clinical challenge to select the appropriate treatment method for managing this process in a particular clinical situation. According to the published guidelines of European Society of Endodontology (ESE), the treatment options for managing IRR include root canal treatment with or without internal or surgical repair in case of perforation as well as tooth extraction (10).

Regenerative endodontic procedures (REP) have been identified as a potential option for managing IRR. However, there is currently a lack of strong evidence supporting this treatment method (10). The limited number of published results and heterogeneity of the methodologies pertaining to treatment of IRR highlight the need to analyze published clinical studies or case/case series reports concerning the outcomes of IRR treatment. By reviewing the different clinically recognized methods used to treat this condition, their effectiveness can be compared and the valuable information for clinicians and researchers be provided. Therefore, the objective of this systematic review was to analyze and compare the outcomes of reported treatment options for the managing IRR.

Materials and methods

Protocol and registration

The reporting of this systematic review was in relevance to the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines (11). The review was registered in an international prospective register of systematic reviews (PROSPERO) under the number CRD42024499151.

Focus question

The systematic review was conducted following the population, intervention, comparison, outcomes and study design (PICOS) question: Is the entire root canal treatment with(out) internal or surgical repair of any perforation (I) as effective as REP (C) evaluating clinical and radiological symptoms after the treatment of IRR with at least 12 months follow up period (O) in patients with diagnosed IRR in mature permanent teeth (P)? Study design (S) – case reports, case series reports.

Eligibility criteria and search strategy

The search of the articles was conducted throughout the databases of PubMed, Wiley Online Library, EBSCOhost and limited to English language. The selection of publications was carried out by electronic databases from the 1st of May 2023 until the 1st of February 2024. A detailed search of scientific electronic data was conducted independently by two investigators (RP, NS). The full keywords and

their combinations used for the search on each of the selected databases are presented in Table 1. The first (#1) search with keywords was based on the terms associated with internal root resorption. Subsequent searches (#2, #3, #4) were conducted using keywords related to potential internal root resorption treatment methods using various combinations of the Boolean operators "AND" and "OR". The final search (#5) integrated a combination of previous four searches results. Two investigators (RP, AK) independently analyzed the titles and abstracts of the studies that met eligibility criteria. Duplicate records were eliminated, and the remaining articles were screened according to the inclusion and exclusion criteria.

Inclusion criteria included: 1) case reports or case series with the pathology of IRR in human permanent mature teeth and the treatment of IRR described; 2) postoperative clinical and radiological evaluation of the treatment of IRR after at least 12 months presented; 3) studies published as a full article in English.

Exclusion criteria were: 1) case reports where the strategy of the treatment was tooth extraction; 2) review articles or Meta-analyses, animal, *in vitro* studies; 3) articles regarding diagnostics methods in cases of IRR.

The full texts were then evaluated according to the eligibility criteria by the same group of authors. Cohen's Kappa index (κ) was used to assess inter-rater reliability between the reviewers (RP, NS) during the study selection process. This value was computed based on the contingency table of the reviewers' decisions, with interpretations following standard guidelines to ensure reliability of the review process (12). Cohen's Kappa value of this review complied with substantial agreement ($\kappa = 0.76$, $\kappa > 0.61$). Any disagreements were resolved by discussion with the second and fourth authors, a senior researcher (GL, NS). The selection process of the articles, the excluded studies and the reasons for exclusion are presented in PRISMA flowchart (Fig.1). The relevant articles published from 1st of January, 2015 up to 1st February, 2024 in accordance with keywords were selected.

Data extraction process

The extracted study characteristics included: the patient's and tooth number; the location of the resorption; presence of root perforation; clinical symptoms and radiological findings; treatment steps and materials used; the time of follow-up; the treatment outcomes. The success of managing IRR was assessed based on clinical symptoms and radiological changes during the follow-up period (13). A case was considered favorable when the patient's condition was asymptomatic after treatment, the radiographs revealed absent or decreased in size periapical lesion, no deterioration or appearance of a new defect were detected, and possible mineralized tissue formation was observed in the resorption area. Conversely, a case was considered as unfavorable if one of the following criteria was present during follow up: the patient experienced clinical symptoms (e.g. sinus tract); the radiologically visible lesion of periapical tissues has appeared or remained/increased in size; the increased resorption area was evident in radiogram.

Risk of bias assessment

The risk of bias within the case reports and case series was assessed by a tool based on established criteria, including modifications from the Pierson criteria, Bradford Hill's criteria, and the Newcastle-Ottawa Scale (14). This tool evaluated methodological quality across eight items grouped into four key domains (Table 2): selection, ascertainment, causality, and reporting. Each domain addressed specific aspects of study design and reporting that may influence the reliability and applicability of the findings and was presented as questions with binary responses to indicate whether each item suggests bias. The quality of the report was classified as low risk of bias if all five criteria were met, moderate if four criteria were met, and high risk of bias if three or fewer criteria were met (15). All incorporated articles were subjected to an extensive evaluation by critical appraisers.

Table 1

Strategies for database search

Database	Search Strategy
PubMed	#1 (root resorption) OR (internal root resorption)) OR (internal root destruction)
Wiley Online Library	#2 (internal root resorption treatment) OR (internal root resorption management) AND (root canal treatment)) OR (pulp extirpation) OR (endodontic treatment)) OR (revascularization) OR (regenerative endodontic procedures)) OR (revascularization)
EBSCOhost	#3 (internal root resorption treatment) OR (internal root resorption management) AND (root canal treatment) OR (pulp extirpation) OR (endodontic treatment) OR (revascularization)) OR (regenerative endodontic procedures) OR (revascularization)
	#4 (internal root resorption treatment) OR (internal root resorption management) AND (root canal treatment) OR (pulp extirpation) OR (endodontic treatment) OR (revascularization) OR (regenerative endodontic procedures) OR (revascularization)
	#5 #1 OR #2 OR #3 AND #4

Results

Quality assessment

Twenty studies (16-35) were included and evaluated according to the checklist for case reports and case series as seen in Table 2. The overall risk of bias among the incorporated manuscripts was assessed. One case report was rated as moderate quality, while the remaining 17 articles were considered high-quality reports. As all articles met most of the criteria of the checklist questions it was concluded that the selected articles for this review are of good quality and the risk of bias is low.

Question n 1. Does the patient(s) represent(s) the whole experience of the investigator (center) or is the selection method unclear to the extent that other patients with similar presentation may not have been reported?

Question n 2. Was the exposure adequately ascertained?

Question n 3. Was the outcome adequately ascertained?

Question n 4. Were other alternative causes that may explain the observation ruled out?

Question n 5. Was there a challenge/rechallenge phenomenon?

Question n 6. Was there a dose–response effect?

Question n 7. Was follow-up long enough for outcomes to occur?

*Question n 8. Is the case(s) described with sufficient details to allow other investigators to replicate the research or to allow practitioners make infer*ences related to their own practice?

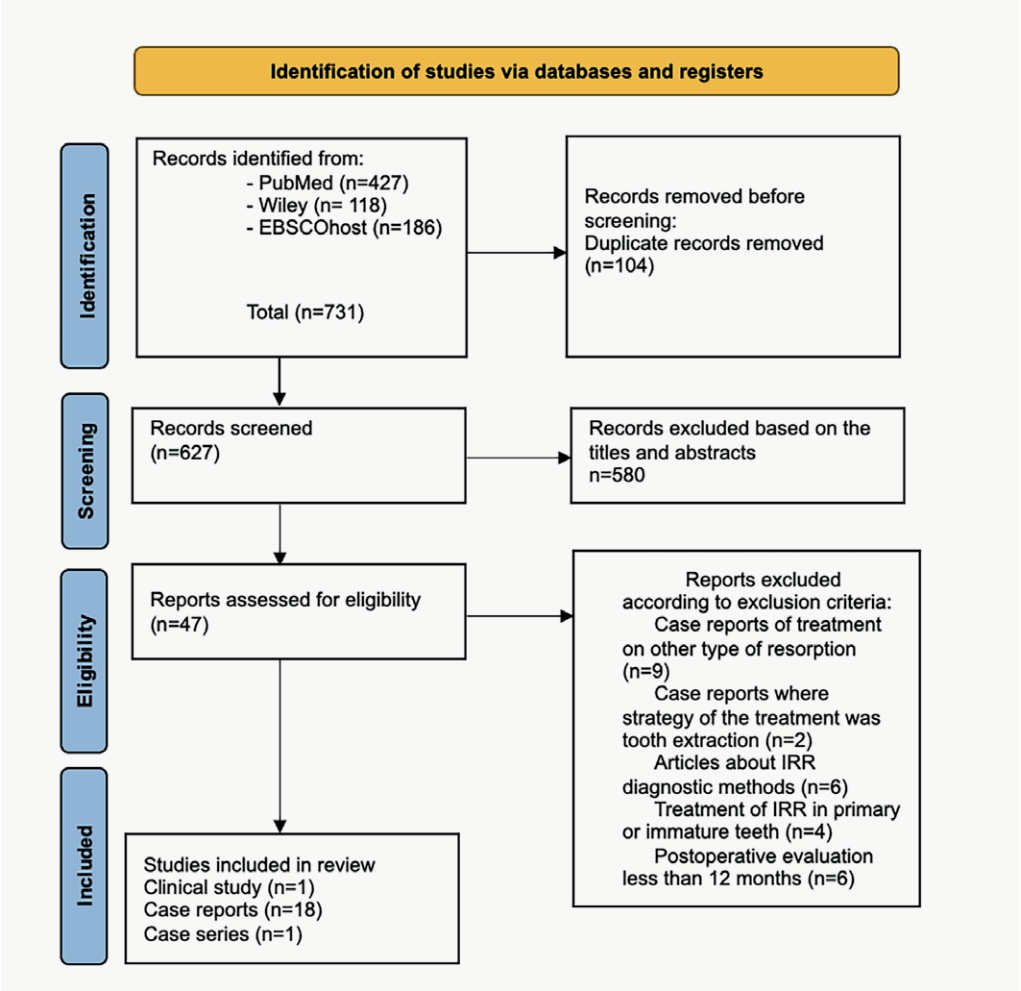
Literature search process

The initial identification resulted in 731 articles from the PubMed, Wiley Online Library and EBSCOhost databases. After the screening and evaluation of inclusion/exclusion criteria 20 studies were included into review: 18 case reports (22 cases), and 2 case series studies (16 cases). Complete selection process of the scientific literature for this review is illustrated in PRISMA flowchart (Fig. 1).

Characteristics of the included studies

All the selected articles were divided according to the treatment method for managing IRR: root canal treatment or REP. In this systematic review, 38 teeth (35 patients) diagnosed with IRR were analyzed. Three patients had 2 teeth with this pathology (21). The diagnoses were confirmed on the basis of radiological data, for 29 teeth, diagnosis was confirmed by CBCT (18-23, 26-30, 32, 33, 35) and for the remaining 9 teeth, diagnosis was

Figure 1
PRISMA flowchart outlining the search strategy



confirmed on the basis of periapical radiographs (16, 17, 24, 25, 31, 34). The characteristics of the all included cases (16-35) are presented in Table 3. Symptoms, treatment procedures provided for the management of IRR and the outcomes of the REP or root canal treatment are presented in Table 4 and Table 5, respectively.

Regenerative endodontic procedures for the management of internal root resorption

The treatment protocols for IRR varied among authors (Table 4) when treated with REP. The sodium hypochlorite (NaOCl) was used in all cases for irrigation of root canals with IRR, but the concentration of it ranged from 1% to 5.25% in different cases. Some authors used saline (16, 17, 21), distilled water (18) or 0,1% chlorhexidine (16) in addition to NaOCl. Ethylenediaminetetraacetic acid (EDTA) was used for additional irrigation before obturation in 17 teeth out of 19 teeth treated by REP (17-21). The instrumentation of the root canals also varied. In 4 treated teeth, the coronal part of the root canal was instrumented until/with resorption (16, 19, 20), while three authors (15 treated teeth) reported instrumentation of the entire length of the root canal (17, 18, 21).

More than one visit treatment was applied in almost all (18 teeth) of the analyzed cases (16-18, 20-23, 25-28, 30-35). Calcium hydroxide ($Ca(OH)_2$) was used as intracanal medication between visits in most of the treatment protocols (16-18, 20, 21). The triple antibiotic paste for dressing the root canal was used only in one of all analyzed cases (17). The duration of intracanal medication with $Ca(OH)_2$ ranged from 2 weeks to 4 years. The root canal was temporarily sealed with $Ca(OH)_2$ for 2 to 4

Table 2

Risk of bias assessment of included studies

First author/Year	Question 1		Question 2		Question 3		Question 4		Question 5		Question 6		Question 7		Question 8		Risk of bias
	Y	N	Y	N	Y	N	Y	N	Y	N	Y	N	Y	N	Y	N	
Ebeleseder&Kqiku (2015) (16)	+		+		+		+		+			+	+		+		low
Saoud et al (2016) (17)	+		+		+		+		+			+	+		+		low
Kaval et al. (2018) (18)	+		+		+		+		+			+	+		+		low
R. Pereira da Costa et al. (2020) (19)	+		+		+		+		+			+	+		+		low
Arnold M. (2021) (20)	+		+		+		+		+			+	+		+		low
Nageh et al. (2022) (21)		+	+		+		+		+			+	+		+		moderate
Bendyk-Szeffer et al. (2015) (22)	+		+		+		+		+			+	+		+		low
Ramazani M et al. (2016) (23)	+		+		+		+		+			+	+		+		low
de Souza SN et al. (2017) (24)	+		+		+		+		+			+	+		+		low
Subay et al. (2018) (25)	+		+		+		+		+			+	+		+		low
Mehra N. et al (2018) (26)	+		+		+		+		+			+	+		+		low
Patni PM. et al. (2018) (27)	+		+		+		+		+			+	+		+		low
Yildirim S. et al. (2019) (28)	+		+		+		+		+			+	+		+		low
Fráter M et al. (2020) (29)	+		+		+		+		+			+	+		+		low
Tavsan O. et al. (2020) (30)	+		+		+		+		+			+	+		+		low
Pérez-Alfayate R. et al. (2020) (31)	+		+		+		+		+			+	+		+		low
Mandviwala DK. et al. (2022) (32)	+		+		+		+		+			+	+		+		low
Pawar S. et al. (2022) (33)	+		+		+		+		+			+	+		+		low
Riyahi AM. (2022) (34)	+		+		+		+		+			+	+		+		low
Gupta G. et al. (2022) (35)	+		+		+		+		+			+	+		+		low

Table 3

Characteristics of the studies

Characteristics	Number
Patients	35
Teeth	38
Age of the patient	
<18 years	10
19-30 years	18
31-50 years	4
51<years	2
No mention	1
Tooth type	
maxillary incisors	31
maxillary molars	1
mandibular incisors	2
mandibular molar	2
mandibular premolar	1
maxillary canine	1
Location of resorption (parts of the root)	
coronal	10
middle	12
apical	8
coronal and middle	4
middle and apical	4
Clinical/radiological symptoms	
root perforation (bone destruction in resorption area)	11(10)
pain and tenderness to percussion	26
sinus tract	>5
Sensitivity test	
negative	15
positive	3
no mention	20
periapical lesion	21
IRR diagnosted by	
periapical radiographs	9
CBCT	29

weeks by two authors (14 teeth) (17, 21), and for more than two year – by one author (2 teeth) (16). However, one author treated IRR in one visit (19) (Table 4).

Mineral trioxide aggregate (MTA) was used as the cement for obturation of the root canals in all of the analyzed cases when IRR was treated applying REP. Five authors (6 teeth) indicated that they used MTA to fill the coronal part of the root up to the resorptive lesion (16-20). In 3 treated teeth a blood clot was created before filling the coronal part of the root (17, 18, 20). The blood clot formed after bleeding, which was induced by the sterile instrument from the periapical tissue (2 teeth) (17, 18) or from tissues in the area of resorption (1 tooth) (20). In the clinical study, the authors used injectable platelet-rich fibrin (i-PRF) for REP and placed MTA underneath the cementoenamel junction (21). IRR with root perforation was present in 5 clinical cases treated by REP (16-20). The REP protocol for IRR treatment was similar in all of the analyzed cases, regardless of the presence of perforation.

Procedures for managing internal root resorption during root canal treatment

Nineteen teeth with IRR included in this review were treated by conventional root canal treatment with or without surgical intervention (Table 5). The sodium hypochlorite (NaOCl) was used almost in all cases for irrigation of root canals with IRR, only one author did not specify the protocol of root canal irrigation (32). The concentrations of NaOCl used to disinfect the root canals varied from 1% to 5.25%. During five teeth treatment (23, 29, 33-35) only the NaOCl was used for root canal disinfection, whereas in other 13 cases (22, 24-28, 30, 31) other irrigating solutions in addition to NaOCl, such as saline (22, 26), 17% EDTA (22, 24, 27, 28, 30, 31), 10% citric acid (26), 2% chlorhexidine solution (27) were used.

Although four teeth without perforation of IRR were treated in a single visit (24, 29, 31, 34), most of the published treatment protocols included two or more visits root canal treatment (15 cases) (22, 23, 25-28, 30-33, 35). $Ca(OH)_2$ was used as intracanal medicament during these visits. The duration of intracanal medication varied from 7 days to 3 months (22-35).

The obturation protocols for root canals with IRR varied depending on the authors and clinical situation, such as the location of the IRR, or the presence of perforation. In all the cases analyzed, obturation was performed using hydraulic calcium silicate (HCS) based cements (22, 23, 25-32,

Table 4

Regenerative endodontic procedures for the management of internal root resorption and outcomes

	Criteria / Article	Amount of treated teeth	clinical/radiological symptoms				root canal disinfection	intracanal medicament, exposure time	
			root perforation (bone destruction in resorption area)	pain/ percussion/ sinus tract	sensitivity test Pre-op/ post-op	periapical lesion			
1	Ebeleseder &Kqiku (2015) (16)	2	Yes (N)	N/N	N/NM	No	3,5% NaOCl, saline, 0,1%CHX	mixture of CaOH and 0,1% CHX replaced in 3-6 months in period of 4 years	
			No	N/N	N/NM	No		mixture of CaOH and 0,1% CHX replaced every 6 months for 2 years	
2	Saoud et al (2016) (17)	1	Yes (P)	P/P	N/N	Yes	2,5% NaOCl, saline, 17%EDTA	CaOH for 2 weeks, triple antibiotic paste for next 2 weeks,	
3	Kaval et al. (2018) (18)	1	Yes (P)	P/P	N/N	No	1% NaOCl, 17% EDTA, distilled water	CaOH for 4 weeks, replaced for next 3 months	
4	R. Pereira da Costa et al. (2020) (19)	1	Yes (P)	N/P	N/NM	No	5.25%NaOCl, 17% EDTA	one visit treatment	
5	Arnold M. (2021) (20)	1	Yes (P)	P/N/sinus tract	N/N	Yes	3% NaOCl, 17% EDTA	CaOH for 2 weeks, replaced for 4 weeks	
6	Nageh et al. (2022) (21)	13	No	P (10)/P (10)/ some cases with sinus tract	NM/N	Yes (10), No (3)	1,5% NaOCl, 17% EDTA, saline	CaOH for 2-4 weeks	

P- positive; N -negative; NM- not mentioned; Pre-op- preoperative; Post-op- postoperative; CaOH- Calcium hydroxide paste; CHX - chlorhexidine solution; PA- periapical radiographs; CBCT- cone beam computed tomography.

34, 35), as well as gutta-percha and sealer (22, 24, 26, 30-34).

These obturation methods were either used in combination (7 teeth) (22, 26, 30-32, 34) or separately with the choice of either HCS (6 teeth) (23, 25, 27-29, 35), or gutta-percha with sealer (6 teeth) (24, 26, 30, 31, 33).

The HCS cements used for obturation of root canals or resorption areas in the analyzed cases included MTA (22, 25, 26, 28-31, 35) followed by Biodentine (27, 32), Calcium enriched mixture (CEM) cement (23), and Endosequence BC RRM Fast set putty (34) (Table 5). Six teeth (22, 23, 25, 26, 28, 33) of IRR treated by conventional root canal treatment presented perforation of the root in resorption area. In four of these treated teeth the MTA was used for root canal obturation (22, 25, 26, 28). This involved using MTA (two teeth) (25, 28) for entire obturation of the root canal, or in combination with gutta-percha, where MTA was used only for obturation of resorption area (two teeth) (22, 26). One study (1 tooth) reported using CEM cement to fill entire root canal space (23). In the remaining one case (33), the canal was sealed with a gutta-percha, and after surgical intervention, the resorption site was filled with Biodentine. Additionally, surgical treatment was

Table 4

Regenerative endodontic procedures for the management of internal root resorption and outcomes

	root canal obturation material	Instrumentation area	follow-up time	Diagnostic assessment		outcomes		
				Pre-op	Post-op follow-up	destruction of periapical tissues	bone destruction in the resorption area	resorption area
	MTA	Coronally to resorption area disinfection only	6 years	PA	PA	absent	absent	calcification
	MTA		4 years	PA	PA	absent	absent	calcification
	MTA	Full WL	19 months	PA	PA	decreased	decreased	reduced in size
	MTA	Full WL	2 years	CBCT, PA	CBCT, PA	absent	decreased	hard tissue formation
	MTA	Coronally to resorption area	5 years and 9 months	CBCT,PA	PA	absent	absent	mineralised tissue formation
	MTA	Coronally to resorption area	3 years	CBCT, PA	CBCT, PA	absent	absent	hard tissue formation
	MTA	Full WL	12 months	CBCT, PA	CBCT	decreased	absent	reduced in size

performed in four teeth, which involved removing the granulation tissue and repairing the perforation defect externally (23, 26, 28, 33). MTA (26, 28) and Biodentine (33) were used to obturate the external surface of resorption defect. In one treated tooth, surgical intervention was performed to remove granulations and excess CEM cement (23).

The perforation of the root was not detected in 13 teeth of IRR when conventional root canal treatment was applied (24, 26, 27, 29-32, 34, 35). The method of obturation for these roots varied among authors. HCS cements (MTA, Biodentin, Endosequendce BC RRM Fast set putty) were used in combination with gutta-percha to fill the root canal (30-32, 34). Some authors filled the entire root canal space using thermoplastic gutta-percha and sealer (24, 26, 30, 31), while others used cement (MTA, Biodentine) (27, 29, 35).

Outcomes of regenerative endodontic procedures in the treatment of internal root resorption

The follow-up period for all cases of IRR treated by REP ranged from 12 months to 6 years as it is shown in Table 4.

Clinical symptoms, changes in resorption

Table 5

Procedures for managing internal root resorption during root canal treatment and outcome

	Criteria / Article	Amount of treated teeth	clinical and radiological symptoms				root canal disinfection	intracanal medicament, exposure time, change frequency	
			root perforation (bone destruction in resorption area)	pain/ percussion/ sinus tract	sensitivity test	periapical lesion			
1	Bendyk-Szeffer et al. (2015) (22)	1	Yes (P)	N/N	N	Yes	2% and 5,25% NaOCl, EDTA, saline	CaOH for 7 days	
2	Ramazani M et al. (2016) (23)	1	Yes (P)	P/P/sinus tract	N	No	1% NaOCl	CaOH for 10 days	
3	de Souza SN et al. (2017) (24)	1	No	P/P	P	No	2,5% NaOCl, 17% EDTA	One visit treatment	
4	Subay et al. (2018) (25)	1	Yes (P)	P/NM/sinus tract	NM	No	saline, 5% NaOCl	3-month treatment with CaOH, it was renewed at various intervals	
5	Mehra N. et al (2018) (26)	2	No	P/P	NM	Yes	2,5% NaOCl, saline, 10% citric acid	CaOH for 2 weeks	
			Yes (P)	P/NM	NM	No	2,5% NaOCl, 10% citric acid	CaOH for 4 weeks	
6	Patni PM. et al. (2018) (27)	1	No	N/NM	N	Yes	2,5% NaOCl, 17% EDTA, 2% CHX	CaOH for 2 weeks	
7	Yildirim S. et al. (2019) (28)	1	Yes (P)	P/P	N	No	1% NaOCl, 17% EDTA	CaOH was changed once a month until the tooth was asymptomatic	
8	Fráter M et al. (2020) (29)	1	No	N/NM	NM	Yes	5% NaOCl	One visit treatment	
9	Tavsan O. et al. (2020) (30)	3	No	N/NM	P	No	2.5-3% NaOCl, 17% EDTA	CaOH for 1 week	
				N/NM	P				
				P/NM	NM				
10	Pérez-Alfayate R. et al. (2020) (31)	3	No	P/P/sinus tract	N	Yes	5,25% NaOCl, 17%EDTA	One visit treatment	
				P/P	N			CaOH for 2 weeks	
				P/P	N			CaOH for 1 week	
11	Mandviwala DK. et al. (2022) (32)	1	No	N/NM	NM	Yes	NM	CaOH for 2 weeks	
12	Pawar S. et al. (2022) (33)	1	Yes (P)	P/P	NM	No	3% NaOCl	CaOH exposure time NM	
13	Riyahi AM. (2022) (34)	1	No	P/P	N	No	5,25% NaOCl	One visit treatment	
14	Gupta G. et al. (2022) (35)	1	No	N/N	N	Yes	2,5% and 5% NaOCl	1) CaOH for 2 weeks, 2) Triple antibiotic paste for next 2 weeks, 3) CaOH for next 2 weeks	

P- positive; N -negative; NM- not mentioned; Pre-op- preoperative; Post-op- postoperative; CaOH- Calcium hydroxide paste; CHX - chlorhexidine solution; PA- periapical radiographs; CBCT- cone beam computed tomography.

Table 5

Procedures for managing internal root resorption during root canal treatment and outcome

	resorption site sealing material, root canal sealing material	additional surgical treatment (material used)	Follow-up time	Diagnostic assessment		outcomes	
				Pre-op	Post-op follow-up	destruction of periapical tissues	bone destruction in the resorption area
	MTA, warm GP, resin sealer	No	12 months	CBCT, PA	CBCT, PA	absent	absent
	CEM cement	Yes	12 months	CBCT, PA	NM	absent	absent
	thermoplastic GP, zinc oxide–eugenol sealer	No	12 months	PA	PA	absent	absent
	MTA	No	6 years	PA	PA	absent	absent
	thermoplasticized GP, resin sealer	No	18 months	CBCT, PA	PA	decreased	absent
	MTA, thermoplasticized GP	Yes (MTA)		CBCT, PA	PA	absent	decreased
	Biodentine	No	5 years	CBCT, PA	PA	absent	absent
	MTA	yes (MTA)	3 years and 6 months	CBCT, PA	PA	absent	decreased
	MTA	No	12 months	CBCT, PA	CBCT	decreased	absent
	GP, resin sealer	No	1 year	CBCT, PA	PA	absent	absent
	GP, resin sealer, MTA						
	MTA, GP	No	8 years	PA	PA	decreased	absent
			3 years				
	GP		8 years				
	GP, Biodentin	No	12 months	CBCT, PA	PA	decreased	absent
	GP, resin sealer	Yes (Biodentine)	12 months	CBCT, PA	PA	absent	absent
	GP, resin sealer, EndoSequence BC RRM-Fast Set Putty	No	18 months	PA	PA	absent	absent
	MTA	No	24 months	CBCT, PA	PA	absent	absent

defect and periapical tissue, as well as destruction of the bone in the resorption area, were evaluated.
After the follow-up period, all teeth, regardless of their symptoms prior to treatment (pain, tenderness to percussion, sinus tract) were asymptomatic.
According to the data provided by the authors, 5 teeth included (16-20) had perforating IRR, and 4 of 5 were diagnosed bone damage in the resorption area as well (17-20). Furthermore, the periapical lesion was evident in 2 of those cases showing combined pathology of alveolar bone in periapical and resorption areas (17, 20).
After evaluating the outcomes of the treatment, it was observed that the periapical lesions decreased in cases with a follow up period of 12 and 19 months (17, 21). In cases with a longer follow-up period of 3 years, there was no periapical lesion present (20). Similarly, cases that did not show any apparent damage of periapical tissues before the treatment, also had no periapical changes after the follow-up period (16, 18, 19) (Table 4).
Regardless the follow up period, the bone destruction in the resorption area decreased in cases of IRR with perforation (17-20). There were no new bone lesions observed over time in any of the treated teeth.
Changes in the IRR area was noticed after the follow-up period when REP was used for managing IRR. Radiographs showed evidence of calcification, mineralised tissue formation, incomplete hard tissue repair, or arrest of resorptive lesions, as reported in this review.
The treatment results of 4 teeth were evaluated using periapical radiographs (16, 17, 19), while the remaining 15 teeth were evaluated using CBCT (18, 20, 21).

Outcomes of internal root resorption treated by root canal treatment with/without additional surgical treatment
The follow-up period for all the cases of IRR managed by the entire root canal treatment, with or without additional surgical treatment, ranged from 12 months to 8 years (22-35). After the follow-up period, all the treated teeth were asymptomatic. When evaluating the periapical pathology of the teeth, it was found that 9 teeth had periapical lesions before treatment (22, 26, 27, 29, 31, 32, 35). Root perforation and bone destruction in area of IRR were identified in 6 teeth (22, 23, 25, 26, 28, 33). However, only one combined bone pathology was detected in cases treated by conventional root canal treatment, where lesions of the bone were evident in both areas (22). The bone destruction in the resorption and periapical areas was absent or decreased in all these cases, regardless of the follow-up period.
Healing results were evaluated using periapical radiographs (16 teeth) (24-28, 30-35) and CBCT (2 teeth) (22, 29). In one case (1 tooth), this was not mentioned (23).
All the authors reported that the resorption process in the root canal was arrested after root canal treatment regardless of the technique used for root canal obturation and surgical intervention for external repair of resorption defect when root perforation was present (23, 26, 28, 33).

Discussion

The management of internal root resorption (IRR) in endodontic practice presents a challenge due its complexity. The analysis of the included cases revealed various treatment options that need to be considered when diagnosing IRR along with other pathologies such as root perforation, periradicular lesions. While conventional root canal treatment remains the most common treatment approach, the regenerative endodontic procedure (REP) was introduced as an alternative aiming to stimulate reparative mechanisms and restore damaged tissue (36).
Symptomatology of IRR may vary depending on the clinical situation including tooth pain, a draining sinus tract, changes in tooth color, or even the absence of symptoms (7, 37). More than half of the analyzed cases reported discomfort associated with causative tooth or varying degrees of pain (17-21, 23-26, 28, 30, 31, 33, 34) although only 8 of them had a root perforation (17, 18, 20, 23, 25, 26, 28, 33). Interestingly, some cases showed no complaints or symptoms despite being diagnosed with root perforation (16, 19, 22). These findings suggest that the onset of

symptoms in case of IRR is not solely determined by root canal perforation.
It is evident that both the dental history and a thorough examination of the tooth are crucial for making an accurate diagnosis. The European Society of Endodontology (ESE) recommends using CBCT to precisely determinate the location and extent of the defect before deciding on a treatment plan (8). More than half of the authors in the studies included in this review used CBCT as diagnostic and treatment planning tool for cases of IRR (18-23, 26-30, 32, 33, 35). However, some authors relied solely on dental radiographs (16, 17, 24, 25, 31, 34), and only Subay *et al.* (24) mentioned that the patient declined to undergo a CBCT examination.
The varied clinical presentations observed in the analyzed cases of IRR, which include root perforation and bone destruction in the resorption site or(and) periapical lesions, create a complex scenario for treatment decision-making in order to achieve a successful outcome. Although root canal treatment has traditionally been the preferred approach for treating internal root resorption (38, 39, 40), the published clinical cases demonstrate that REP is also an option. The purpose of root canal treatment is to remove all pulp tissue, disrupt the activity of the damaging cells, and interrupt their blood supply, which is necessary for their nutrition. In order to achieve this goal, the root canal must be fully instrumented, disinfected, and filled along its entire length, including the area of resorption (41). The approach of REP aims to minimize the number of procedures and preserve as much of the root structure as possible. However, there is no established unique methodology regarding the application of REP for treatment of IRR, which remains a major issue for this treatment approach. Some authors (17,18, 21) who have treated IRR by REP have relied on the REP procedures typically used for cases with necrotic pulp in immature teeth as outlined in the guidelines of the American Association of Endodontists (AAE) or the European Society of Endodontology (ESE) position statement (42, 43). However, other authors (16, 19) have referred to these procedures as a novel treatment approach or MTA barrier placement for the treatment of IRR. Nevertheless, the common characteristic of all methodologies related to REP for the treatment of IRR is a focus on obturating the root coronally to the resorption using HCS, while leaving the apical part of the root and resorption area unfilled to promote hard tissue formation. The procedural differences include the area of the root that is instrumented (only the coronal part until the resorption area or the entire root canal), the type of medication used for disinfection of the root canal/resorption area and the duration of intracanal dressing with temporary disinfection material (Table 4). Some authors have chosen to remove the necrotic pulp tissue from the coronal part of the root, leaving the tissues apically over the resorption area without any mechanical shaping procedures (16, 19, 20), while others have instrumented the root canals through full working length (17, 18, 21). In clinical study (21), where 13 teeth were treated by REP with injectable PRF, according to the author, pulp status was necrotic in 10 teeth and vital in 3 teeth, although there was no mention about performing a sensitivity test before treatment. Later, during and after the treatment, a sensitivity test was performed on all 13 teeth to check sensitivity regain, but it revealed negative throughout the observation period. Despite REP procedure implies the regeneration of the pulp tissues so consequently expects the positive pulp sensitivity tests, it should be noted that negative pulp sensitivity test reaction could not be treated as a procedure failure as well as pulp sensitivity test result is not equivalent to real pulp vitality status (44).
Although the treatment strategies of root canal treatment and REP differ, the use of common medicaments such as NaOCl and $Ca(OH)_2$ in protocols of both methods emphasizes their essential roles in disinfection and tissue repair. In almost all analyzed cases root canals were irrigated with 1-5,25% NaOCl (16-31, 33-35). Additionally, saline or distilled water (16-18, 21, 22, 26), 17% EDTA (17-22, 24, 27, 28, 30, 31),

chlorhexidine solution (16, 27) and 10% citric acid (26) were used in most cases. Only 5 out of 38 analyzed cases underwent one-visit treatment (1 for management of IRR by REP (19), 4 for management of IRR by root canal treatment (24, 29, 31, 34)). In other 33 treated teeth, the authors indicate that $Ca(OH)_2$ was used as an intracanal medicament between visits (16-18, 20-23, 25-28, 30-33, 35). Calcium hydroxide can be used not only because of its antimicrobial and disinfection properties (45), but also it can be used during REP procedures as it is evident, that the hydroxide ions released from $Ca(OH)_2$ cause sterile necrosis in remaining untouched pulp tissues (46). This pulp necrosis promotes healing and repair of the pulp tissue by encouraging irritation. As a result, odontoblasts actively produce collagen, and the presence of calcium ions contributes to its mineralization (47). This process is suggested to cause the recovery of damaged tissue. The period of intracanal dressing with $Ca(OH)_2$ varied between 2 weeks and 4 years in cases treated by REP (16-21) and from 1 week to 3 months in cases treated by root canal treatment (22-35). An exceptionally long-term treatment period (2-4 years) with $Ca(OH)_2$ was carried out by Ebeleseder and Kqiku (16) in cases of management of IRR by REP. Some authors (17, 35) used triple antibiotic paste for two weeks in addition to the initial use of $Ca(OH)_2$ for intracanal dressing.

Regardless of the duration of intracanal application of $Ca(OH)_2$ the radiographs of all clinical cases treated with REP showed the presence of calcification, mineralised tissue formation, incomplete hard tissue repair, or arrest of resorptive lesion. Some studies have highlighted the negative effect of long-term $Ca(OH)_2$ treatment on dentin microhardness and fracture resistance (48-50). Therefore, the long term use of $Ca(OH)_2$ as an intracanal dressing could be controversial. It could be speculated that radiological outcomes of IRR treatment with REP may depend on the follow-up period, as different outcomes such as reduction in size of the resorption defect or formation of hard tissue in the resorption area have been observed at follow-ups of 12-19 months (17, 21) and 2-6 years (16, 18-20), respectively (Table 4).

The HCS cement was used alone or in combination with gutta-percha and sealer for the obturation of root canals in analyzed cases of IRR that were treated by REP or root canal treatment. MTA was the preferred cement in all cases treated by REP followed by Biodentin, Endosequence BC RRM Fast set putty, CEM which were chosen by some authors to treat IRR by traditional root canal treatment. When REP was applied, the tissues of resorption area, as well as the tissues remaining apically from the resorption, were isolated by obturating the coronal part of the root with MTA in all cases analyzed (16-20). The exception regarding the REP technique, compared with other case reports included in this review, was described by Negeh M. *et al.* (21). After chemo-mechanical preparation of the root canals and intracanal medication with $Ca(OH)_2$ for 2-4 weeks, the authors filled the orifices of the root canals (3mm thick layer) with white MTA directly over the platelet-rich fibrin, regardless of the location of resorption area in the root canal. According to the results of their study, the resorption area reduced in size in all the cases included after a 12 months follow-up.

Although there are no uniform methodologies and protocols for treatment of IRR by REP, the outcomes of published cases are similar. The clinical symptoms, such as pain, discomfort related to the causative tooth or sinus tract, disappeared and did not recur. The resorption area either reduced in size or was repaired by hard (mineralized) tissue formation as mentioned above. Additionally, bone destruction regardless of its location (in periapical or resorption area), either was absent or reduced in size during radiological evaluation of treatment outcomes. Two of the analyzed cases treated by REP (17, 20) and one treated (22) by root canal treatment, presented combined pathology, including perforating IRR and apical periodontitis. The radiological assessment of the pathology and treatment outcomes, conducted by periapical radiographs (17) or CBCT imaging

(20, 22), showed healing of periapical tissues and bone repair in the resorption area in all three cases mentioned above. Managing IRR with root perforation by root canal treatment, additional surgical procedures were applied, including the removal of granulation tissues from the bone in resorption area and obturation of the defect on the external surface of the root using HCS cement (23, 26, 28, 33). Nevertheless, some of the cases with perforating IRR were treated without surgical intervention showing favorable outcomes as well (22, 25). Thus, it could be supposed that the need of additional surgical procedures when treating IRR with perforation by root canal treatment depends on the clinical symptoms and the size of the defect.

According to the analyzed cases, it could be suggested that the main advantage of REP over root canal treatment is the potential for damaged tissues to recover on the resorption site, which allows for tooth strength by preserving more of the root structure for healing. Technically, both procedures can be challenging for clinicians. However, using REP to manage IRR, there is no need to clean the resorption area. Considering that root canal treatment is already difficult procedure to perform, it can be speculated that REP is a less difficult treatment method and a more conservative approach for clinicians compared to root canal treatment.

The findings of this review highlight the importance of individualized treatment strategies that are tailored to the specific clinical presentation of IRR. This emphasizes the need for a holistic approach that takes into account patient's dental history, a thorough clinical examination, and an understanding of the mechanisms behind IRR pathogenesis.

A limited number of reported cases, as well as only one clinical study found in the scientific literature, may be considered as limitation of this review. The certainty of evidence derived from case reports is debated and generally considered low (51). Additionally, the exact prevalence of IRR is poorly documented in the literature (52). Moreover, the pathology of root resorption is rarely encountered in clinical practice, making it difficult to obtain a sufficient sample size for clinical studies and higher levels of evidence.

Therefore, it could be speculated that relying on published clinical cases for decision-making would be reasonable, when other higher levels of evidence are not available. The need for further clinical research to comprehensively evaluate the long-term effects and comparative efficacy of identified treatment options for managing IRR remains evident.

Conclusion

Both root canal treatment and regenerative endodontic procedures (REP) provide comparable and favorable outcomes for managing inflammatory internal root resorption (IRR). REP may offer advantages, such as preserving more root structure and enhancing tooth strength, as it avoids cleaning the resorption area. Ultimately, the choice between these methods should be based on a careful assessment of the clinical situation and the patient's dental history.

Clinical Relevance

The review emphasizes the importance of individualized treatment strategies and highlights the potential of REP to preserve more root structure and enhance tooth strength in the cases of IRR.

Conflict of Interests

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