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Understanding and addressing invasive cervical resorption: a systematic review on diagnostic and treatment challenges in permanent dentition

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THESIS

UNDERSTANDING AND ADDRESSING INVASIVE CERVICAL RESORPTION: A SYSTEMATIC REVIEW ON DIAGNOSTIC AND TREATMENT CHALLENGES IN PERMANENT DENTITION

by

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ABSTRACT

Invasive cervical resorption (ICR) is a complex and multifaceted dental condition characterized by the progressive loss of hard tooth tissue in the cervical region of permanent teeth. This literature review aims to critically examine the current knowledge on ICR, focusing on its etiology, diagnosis, and treatment approaches, as well as identifying potential variables that could impact treatment outcomes and rehabilitation. Due to the limited availability of randomized clinical trials and the reliance on case reports and case series, drawing definitive conclusions about the predisposing factors and their association with ICR remains challenging.

This review found that maxillary central incisors are the most frequently affected teeth in the dentition. Cone-beam computed tomography (CBCT) has been identified as an invaluable tool for the accurate diagnosis of ICR lesions, with its three-dimensional imaging capabilities providing critical information for the classification and treatment planning of ICR cases. In contrast, two-dimensional radiographs may not always lead clinicians to the correct diagnosis.

The use of trichloroacetic acid (TCA) as a diagnostic material for ICR lesions is not well-supported in the existing literature. In terms of restorative materials, glass ionomer (GI) and resin-modified glass ionomer (RMGI) demonstrated the highest success rates in the treatment of ICR lesions.

This review highlights the need for further research to establish standardized diagnostic processes and treatment planning for ICR in permanent dentition. Future research should focus on identifying

the factors contributing to treatment failure and determining the most effective methods to reduce tooth loss. The development of randomized clinical trials and longitudinal studies would significantly enhance our understanding of ICR, its etiology, and the most effective strategies for diagnosis and treatment. Overall, this literature review provides a comprehensive and critical analysis of the existing knowledge on ICR and suggests directions for future research to improve treatment outcomes and reduce tooth loss in patients affected by this rare but challenging dental condition.

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LIST OF ABBREVIATIONS

Abbreviation	Full Form
AAE	American Association of Endodontists
CBCT	Cone-Beam Computed Tomography
ECR	External cervical resorption
FeHV-1	Feline Herpesvirus 1
GI	Glass Ionomer
ICR	Invasive Cervical Resorption
IRR	Internal root resorption
JBI	Joanna Briggs Institute
MTA	Mineral Trioxide Aggregate
RMGI	Resin-Modified Glass Ionomer
TCA	Trichloroacetic Acid

INTRODUCTION

Invasive Cervical Resorption: An Overview

Resorption refers to the physiologic or pathologic loss of dentin, cementum, and/or bone, which is not directly caused by caries or trauma. It is a dental complication that may result in tooth extraction. Root resorption was first described by Bates in 1856, followed by Chase in 1875 and Harding in 1878. Bates initially called it absorption. Ketcham was the first author to explain root resorption using radiology[1–3].

Root resorption can be categorized into physiological resorption (associated with the shedding of primary teeth) and pathological resorption. Both resorptive dental diseases and physiological resorption share a common pathogenesis. Resorption occurs when developmental precementum or predentin is lost or damaged, and inflammation in the adjacent soft tissues permits clastic cell invasion. The resorption process involves intricate interactions among inflammatory cells, resorbing cells, and hard tissue structures, with osteoblasts and odontoclasts being the key cells involved. The location of the damage and the associated tissues determine the type of resorption that occurs.

Internal root resorption (IRR) is a distinct entity, while external resorption can take various forms. Internal resorption can be divided into two distinct forms: internal replacement resorption and internal inflammatory resorption. On the other hand, external resorption is classified into three groups according to their clinical and histological features: resorption on the external surface, external inflammatory root resorption, and ankylosis, also known as replacement resorption. External inflammatory root resorption can be further divided into cervical resorption with or without a vital pulp (invasive cervical root resorption (ICR)/External cervical resorption (ECR)) and external apical root resorption. Other variations include combined internal and external resorption. ECR is the most common form of resorption encountered in clinical dental practice. ECR occurs at the cementoenamel junction due to developmentally missing, lost, or damaged precementum, combined with inflammatory tissues in the junctional epithelium of the periodontal attachment apparatus at the base of the gingival sulcus.

Different terms for invasive cervical resorption include root resorption, external cervical resorption, invasive cervical resorption, extracanal invasive resorption, peripheral cervical resorption, and idiopathic external resorption [4,5].

Characteristics of ICR

The cells responsible for ICR originate from the attached or junctional epithelium at the base of the gingival sulcus. Given its sulcular source, these lesions are typically observed in the cervical area of teeth. Exceptions can occur in areas of attachment loss or in newly erupting teeth where the periodontal attachment is apically located [6]. The cells attach to tooth structure in areas of precementum loss, allowing the invasion of fibrovascular tissue, followed by degradation of the mineralized root structures [7]. In later stages, unless epithelial downgrowth into or bacterial contamination of the defect is prevented, some degree of osseous ingrowth from neighboring bone may occur [8].

Although histologically similar to replacement resorption, where osseous ingrowth occurs following loss or damage to the periodontal ligament, osseous repair of ICR is localized to the portal of entry of the resorptive lesion [7]. The predentin surrounding the pulp, like intact precementum, serves a protective role in preventing the extension of the resorbing tissues directly into the pulp space until cavitation or breakdown of the predentin allows pulpal involvement . As a result, ICR lesions often encircle the pulp without direct contact and spread apically or coronally throughout the dentin [9].

Etiology of ICR

Several etiological factors have been associated with the development of ICR, but direct causation has not yet been proven. Common predisposing factors include a history of orthodontic treatment, traumatic dental injuries, orthognathic surgery, periodontal treatment, intracoronal restorations, and nonvital bleaching [6]. Most of these factors are believed to damage the cementum in the cervical region of the tooth by causing direct physical or chemical trauma.

Oral habits that exert force on the teeth, such as a history of woodwind instrument practice, may predispose a patient to ICR in a similar manner as orthodontics because the anterior maxillary teeth can be subject to potentially damaging, excessive force [10]. The use of systemic bisphosphonate medications has also been linked to ICR development, with a proposed mechanism of action on clastic cells and altered bone turnover [11]. Furthermore, a potential viral etiology for ICR has been suggested. Feline odontoclastic resorption, common in cats due to Feline Herpesvirus 1 (FeHV-1) infection, shows a marked clinical resemblance to ICR found in human dentition. A small-scale study on patients with multiple ICRR lesions discovered that 100% of subjects tested positive for FeHV-1, implying a potential viral etiology of ICR in humans [12].

In addition, a familial relationship has been reported among patients diagnosed with ICR, suggesting a genetic component. Like many other conditions, however, ICR may also have some idiopathic origin. There is evidence pointing to a possible sex-linked recessive inheritance related to ICR. Trio-based whole-exome sequencing revealed a missense mutation c.5630 C > T in the filamin A (FLNA) gene at chromosome X of the subject, indicating a potential genetic link to the condition [13].

Diagnosis of ICR

Most cases of ICR are asymptomatic and clinically undetectable. Lesions are often discovered incidentally during routine radiographic exams, when investigating pathology on neighboring teeth, or even when retracting the gingiva for restorative work. When lesions are detected with an explorer, subtle cavitation or a chalky surface is typically noted just beneath the gingival margin. More progressive lesions may present with noticeable, often subgingival, cavitation with solid margins. These defects are often filled with soft tissue that bleeds readily upon probing. Since the predentin layer surrounding the dental pulp prevents invasion of ICR until the lesions have reached a very late stage, pulp sensitivity testing usually remains normal, and pulpitis or necrosis is infrequently observed, even among very progressive lesions. Symptoms of periodontal ligament inflammation, such as percussion or palpation sensitivity, and periodontal pocketing are generally absent [14].

Historically, pink teeth have been considered an indicator of internal resorption, but the majority of teeth with visible pink discoloration of the coronal tooth structure are now correctly diagnosed

with ICR. Periapical radiographs are essential for diagnosing ICR. However, these radiographs reveal limited information about the dentoalveolar anatomy due to their two-dimensional nature, geometric distortion, and anatomic noise [15,16]. As a result, conventional radiographs can contribute to misdiagnosis, inadequate assessment, and improper management of ICR [17–19].

Cone beam computed tomography (CBCT) has emerged as a crucial imaging tool for diagnosing and devising treatment strategies for intricate endodontic issues [20–22]. The significance of CBCT is emphasized in the position statement released by the European Society of Endodontology in 2019, as well as the collaborative statement by the American Association of Endodontists and the American Academy of Oral & Maxillofacial Radiology in 2015. With CBCT, ICR can be examined in multiple planes without the interference of surrounding structures or geometric distortion. Users can easily navigate through multiple images, generating a real-time dynamic view. This feature enables a comprehensive understanding of ICR and its geometric associations [23]. CBCT enables the detailed observation of complex resorptive pathways originating from the main lesion, as well as the detection of abnormal calcified deposits. It is essential to locate and eliminate these conduits, given that they may establish a connection with the periodontal ligament at the apical end and house resorptive tissues and blood vessels that contribute to the progression of internal replacement resorption. Failing to address ectopic calcified tissue can lead to ongoing resorption beneath the fibro-osseous base, negatively affecting treatment outcomes [23]. CBCT provides essential information on the actual size, location, circumferential extent, proximity to the root canal, and accessibility of ICR. This data is vital in determining if ICR can be treated and in developing an appropriate treatment plan [23].

Numerous case studies have shown that periapical radiographs frequently fail to accurately represent the true characteristics of ICR when compared to CBCT. Additional research has verified that CBCT is superior to periapical radiographs in evaluating external resorption. A group of scientists investigated the capacity of evaluators to differentiate between artificial internal and ICR defects in an ex vivo model. Their findings revealed that CBCT imagery considerably surpassed the effectiveness of three parallax periapical radiographs in making such distinctions. This conclusion was supported by a clinical study, which demonstrated that employing CBCT resulted in a better-suited treatment plan for managing these lesions [19,23,24].

Heithersay developed a system to classify ICR based on the size and proximity of the lesion to the root canal. This classification, derived from conventional radiographs, divides ICR into four categories according to the extent of the lesion's penetration into coronal and root dentin (**Figure 1**): Class I consists of small cervical lesions with minimal dentin penetration; Class II is characterized by clearly outlined lesions close to the coronal pulp, with minimal or no penetration into the radicular dentin. Class III involves lesions that reach further into the coronal third of the root. In Class IV, the lesions extend past the coronal third of the root.

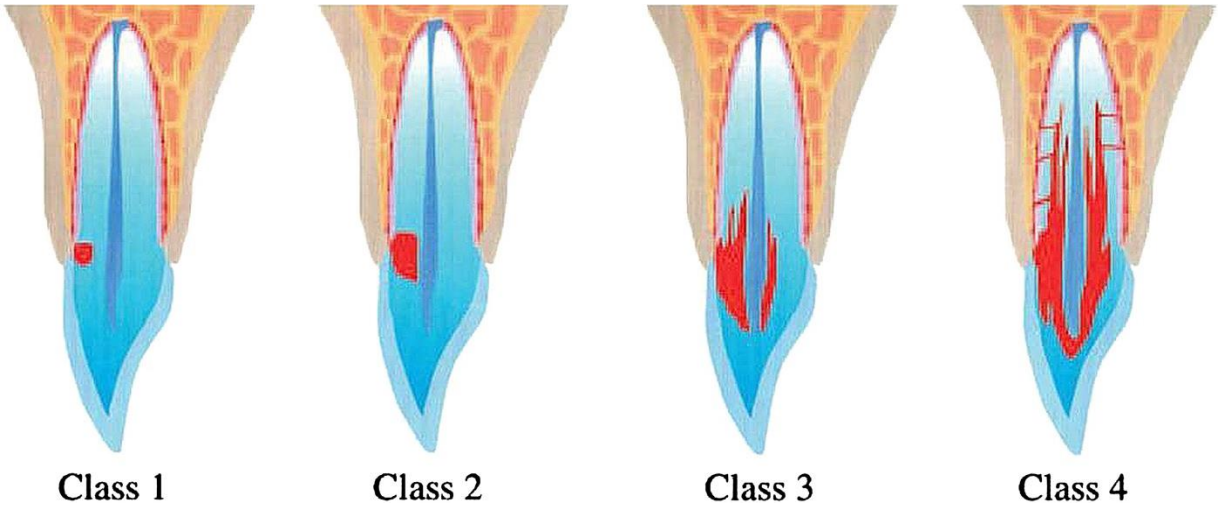


Figure 1: The Heithersay classification system for ICR, is used with permission.

Advancements in ICR Diagnosis

Nonetheless, this classification scheme is only suitable for cases where ICR is confined to the tooth's proximal region and can be fully examined in two dimensions. Utilizing this system becomes difficult when the lesion is situated on the buccal or lingual side of the root. Additionally, it does not account for the lesion's circumferential or pulpal involvement. As a result, accurately describing most ICR lesions in three dimensions using the existing classification is often unattainable. Given the growing importance and widespread use of CBCT in diagnosing and planning ICR treatment, a three-dimensional classification system has become increasingly essential.

Vaz de Souza et al. conducted a study comparing the diagnostic effectiveness of periapical radiographs and CBCT in detecting and categorizing simulated ICR lesions using an ex vivo model. The researchers developed simulated lesions of varying dimensions to represent the Heithersay categories. Their study determined that CBCT demonstrated substantially improved sensitivity, specificity, and overall precision compared to periapical radiographs when assessing ICR size and location. In 48.5% of cases using periapical radiographs and 70% with CBCT, evaluators had difficulty accurately identifying the Heithersay classification. Moreover, periapical radiographs showed significantly reduced intra- and inter-examiner agreement compared to CBCT. These results call into question the validity and dependability of the Heithersay classification, which could be due to the constraints of employing two-dimensional periapical radiographs for categorizing intricate three-dimensional ICR lesions [19,25].

In a recent clinical study, 115 ICR lesions were evaluated using both periapical radiographs and CBCT. Receiver operating curve (ROC) analysis revealed significant shortcomings of periapical radiographs in detecting ICR and determining lesion size (0.75), extent of the circumferential spread (0.60), and position in comparison to CBCT (1.0). This discrepancy directly led to considerable differences in the treatment plans devised by the six evaluators. Parallax radiographs offered no extra advantages over a single radiograph. The study's conclusion was that a CBCT scan should be contemplated prior to managing a potentially restorable ICR lesion. While the Heithersay classification was employed to define lesion size, supplementary categories like lesion circumference and location were needed for a comprehensive description of the lesion, thereby underlining the constraints of the Heithersay classification in describing ICR lesions. Furthermore, an inaccurate classification of the ICR lesion could adversely affect the assessment of treatment outcomes. [19].

The position statement from the European Society of Endodontology endorses the use of CBCT for assessing and managing root resorption. In light of the aforementioned studies that corroborate the superior accuracy of CBCT compared to periapical radiographs in identifying ICR characteristics and location, a practical three-dimensional classification system for ICR is much sought after. This novel classification takes into consideration lesion height, the extent of circumferential spread, and the closeness to the root canal, effectively categorizing ICR in a three-

dimensional manner. Consequently, this innovative clinical classification incorporates lesion height, circumferential spread, and root canal proximity to classify ICR in three dimensions:

Height Assessment

The height, or the coronal-apical scope, of a lesion is ascertained by its highest vertical point on the root surface and the location of the bone crest. The relationship between the bone crest and the lesion is taken into account when planning treatment. By segmenting the root into coronal, middle, and apical thirds using the cemento-enamel junction and apex as fixed reference points, the height of the lesion can be optimally assessed using periapical radiographs and both coronal and sagittal CBCT views:

1: Level with the cemento-enamel junction or above the bone crest (supracrestal);
2: Extending into the coronal third of the root and beneath the bone crest (subcrestal);
3: Reaching the middle third of the root; and
4: Progressing into the apical third of the root.

Circumferential Extension

A lesion's circumferential spread is graded based on its widest expansion within the root. Axial CBCT views (below **Table 1**) provide the best assessment:

A: ≤90°
B: >90° to ≤180°
C: >180° to ≤270°
D: >270°

Height	Circumferential spread	Proximity to the root canal
1: At cemento-enamel junction level or coronal to the bone crest (supracrestal)	**A:** ≤90°	**d:** Lesion confined to dentine
2: Extends into coronal third of the root and apical to the bone crest (subcrestal)	**B:** >90° to ≤180°	**p:** Probable pulpal involvement
3: Extends into mid-third of the root	**C:** >180° to ≤270°	
4: Extends into apical third of the root	**D:** >270°	

Table 1

Proximity to the Root Canal

Axial CBCT views offer the best evaluation of the lesion's proximity to the root canal:

d: Lesion limited to dentine

p: Likely pulpal involvement

By examining the periapical radiograph and CBCT scan, the maximum height, circumferential spread, and depth of the lesion can be recorded, resulting in a three-dimensional grading of the lesion.

Treatment

Research on ICR suggests that early lesions can be treated with a high degree of predictability, but more extensive lesions might not be suitable for intervention. Addressing these defects necessitates surgical exposure, debridement, trichloroacetic acid (TCA) application, and restorative measures. Accessibility to the defect is a crucial factor in surgical care. For instance, lesions on buccal roots are more easily accessible surgically, while interproximal, palatal, or lingual lesions are relatively inaccessible and may not be readily treated. Applying TCA for 1 to 4 minutes eliminates residual clastic cells, averting resorption recurrence and treatment failure. TCA is highly caustic and reactive when in contact with orofacial soft tissues, so extreme caution is necessary to prevent spills, and a glycerol backdrop is recommended to safeguard the surrounding periodontium. After TCA application, the area should be rinsed with sterile water or saline, dried, and then repaired with an appropriate restorative material, such as a resin-modified glass ionomer cement.

Depending on the defect's location, suitable soft tissue surgical procedures, including flap design and suturing, should be employed28. Class 1 lesions can be managed without endodontic treatment, while Class 2 and Class 3 lesions often necessitate root canal treatment alongside the repair process [26].

Although the aforementioned techniques may effectively address Class 1 through Class 3 lesions, they are not suitable for managing Class 4 lesions [4,27]. Class 4 lesions generally have a poor prognosis, as the required removal extent would make a tooth non-restorable, so neither endodontic nor surgical treatment is recommended. These lesions can remain asymptomatic without causing pathological effects on adjacent bone for an extended period and might even experience some osseous repair [28]. As a result, opting for follow-up instead of extraction is often the most prudent course of action [5,28].

Potential complications of untreated tooth resorption

Without appropriate intervention, resorption can result in various complications, which may have a significant impact on oral health. Some of these complications include:

- Infection: Untreated resorption can lead to the spread of bacteria, resulting in infections that can affect the surrounding soft tissues, bone, and even systemic health [29].
- Discoloration and weakening of teeth: Resorption can cause the tooth structure to weaken, making it susceptible to discoloration, fractures, or breakage [30].
- Malocclusion: As teeth are progressively resorbed, they may become misaligned, causing issues with biting, chewing, and overall dental occlusion [31].
- Tooth chipping: Weakened teeth due to resorption are more prone to chipping or breaking under pressure or impact.
- Cavity-like holes: Resorption can create cavity-like holes in the tooth structure, making them susceptible to further decay and bacterial invasion.
- Gum recession: In some cases, resorption can lead to gum recession, exposing the root surface and increasing the risk of periodontal disease and tooth sensitivity.

- Complete loss of teeth: In severe cases of resorption, the tooth structure may be so compromised that complete tooth loss is inevitable, necessitating extraction and possible replacement with dental prosthetics.
- Toothache: Resorption can cause toothache, sensitivity, and discomfort, affecting the patient's quality of life and ability to perform daily activities [27].

Early diagnosis and appropriate treatment are crucial to prevent these complications and preserve the patient's oral health. Treatment strategies may vary depending on the type and severity of resorption, and may include preventive measures, restorative procedures, endodontic treatment, or even extraction and tooth replacement in severe cases.

THESIS OBJECTIVES

An initial review of the literature revealed that there is currently no universally accepted treatment approach for ICR in permanent dentition. The etiology of ICR remains poorly understood, which could result in misdiagnosis, improper management, and ultimately tooth loss. Various factors, such as the number and location of ICR lesions, pathogenesis, appropriate diagnostic tools, and different restorative materials, have been widely discussed in treatment planning. However, there is a scarcity of studies that comprehensively assess and report all these potential variables, which could directly impact the treatment outcome and rehabilitation of ICR patients.

Treatment failure of ICR often leads to tooth loss. Therefore, it is crucial to identify factors that may contribute to treatment failure and ultimately reduce the failure rate. By gaining a better understanding of these variables, we can work towards establishing standardized treatment protocols for this relatively rare condition.

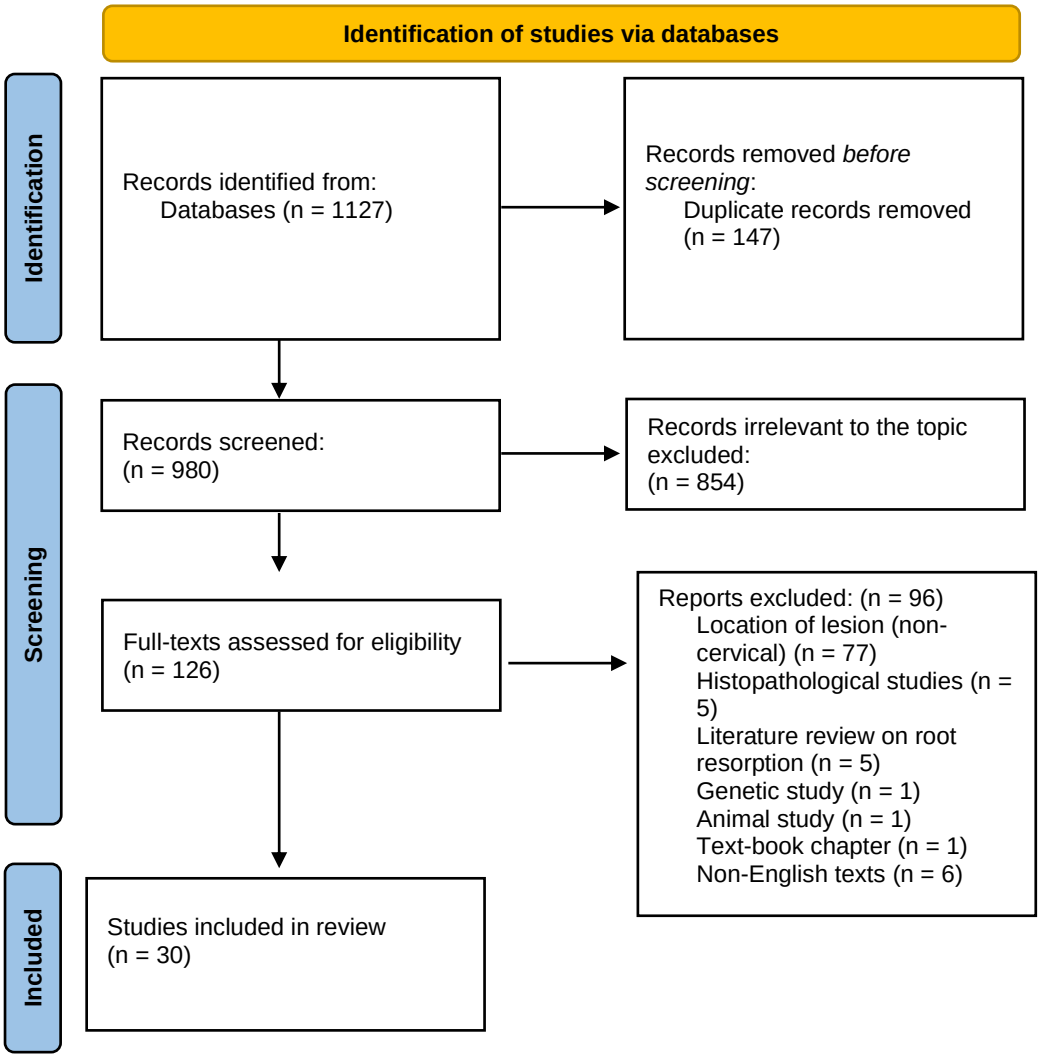
The objectives of this thesis are:

1. To critically review the existing literature on ICR, focusing on its etiology, diagnosis, and treatment approaches.
2. To identify and assess potential variables that could impact the prognosis and outcome of ICR patients.
3. To analyze treatment failures for factors that may contribute to unsuccessful outcomes.
4. To propose standardizing recommendations for diagnostic, treatment planning and treatment techniques for ICR in permanent dentition.
5. To suggest future research directions to further enhance the understanding of ICR and treatment approaches.

MATERIALS AND METHODS

This review adheres to the PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) guidelines, a rigorous research protocol that establishes the rationale for the review and outlines a pre-planned methodological and analytical approach for systematic reviews. **Figure 2** depicts the flowchart of the search results obtained through this PRISMA-based strategy.

Figure 2: The flowchart of the entire search results with this search strategy.



Search strategy (Inclusion and exclusion criteria)

A literature search was conducted in November 2020 using PubMed, Google Scholar, and Cochrane Library databases. The search terms included 'root resorption,' 'external cervical resorption,' 'invasive cervical resorption,' 'extra-canal invasive resorption,' 'peripheral cervical resorption,' and 'idiopathic external resorption.' Duplicate articles were removed using a reference management system, and the titles and abstracts of the remaining articles were screened for relevance. If the title and abstract did not provide enough information to determine eligibility, the full text was reviewed. Full texts from this initial screening were then assessed using predetermined inclusion and exclusion criteria.

No date restrictions were applied during the search, but only studies published in English were ultimately included in this review. The inclusion criteria were as follows: 1) involve non-syndromic patients as participants; 2) report on a clinical case of external root resorption in the cervical area; 3) describe the type of intervention, if any. Exclusion criteria comprised studies that were not specific to the cervical area, focused on the histopathological analysis of invasive cervical resorption, or involved animal participants. Review articles and authors' replies were also excluded.

A total of 1127 articles were identified through the search of the databases. Following the removal of 147 duplicate articles, 854 studies irrelevant to the topic were excluded. Few studies were published in a language other than English and were excluded as well. The remaining 126 papers were considered for full-text assessment. After analyzing the articles using the inclusion and exclusion criteria, 96 studies were further excluded. In total, 30 studies were included in this review.

JBI Critical assessment

Each article was evaluated and scored using the Joanna Briggs Institute (JBI) Critical Appraisal Tools scaling system. The JBI is an international, membership-based research and development organization within the Faculty of Health Sciences at the University of Adelaide. The Institute

specializes in promoting and supporting evidence-based healthcare by providing resources for professionals in nursing, midwifery, medicine, and allied health.

Systematic reviews form the core of evidence synthesis, as they involve a comprehensive analysis of the available literature on a particular intervention, condition, or issue. These reviews assess the effectiveness of a practice through a series of complex steps. JBI adopts a particular perspective on what constitutes evidence and the methods employed to synthesize various types of evidence. In line with this broader view, the Institute has developed theories, methodologies, and rigorous processes for the critical appraisal and synthesis of diverse forms of evidence to support clinical decision-making in healthcare. Consequently, JBI has established guidance for conducting reviews on effectiveness research, qualitative research, prevalence/incidence, etiology/risk, economic evaluations, text/opinion, diagnostic test accuracy, mixed-methods, umbrella reviews, and scoping reviews.

JBI Critical Appraisal Tools play a crucial role in all systematic reviews, as they incorporate a process of critique or appraisal of the research evidence. The purpose of this appraisal is to assess a study's methodological quality and determine the extent to which it has addressed the possibility of bias in its design, conduct, and analysis.

The articles were independently evaluated and graded by three dental examiner. In cases of discrepancies in the scores, the examiner engaged in discussions to reach a consensus on the final grading. **Table 2** presents the checklist used by each examiner for evaluation. The results for the quality assessment is presented in **Table 3**.

Table 2: JBI Critical appraisal checklist

	Yes	No	Unclear	Not applicable
1. Were there clear criteria for inclusion in the case series?	☐	☐	☐	☐
2. Was the condition measured in a standard, reliable way for all participants included in the case series?	☐	☐	☐	☐
3. Were valid methods used for identification of the condition for all participants included in the case series?	☐	☐	☐	☐
4. Did the case series have consecutive inclusion of participants?	☐	☐	☐	☐
5. Did the case series have complete inclusion of participants?	☐	☐	☐	☐
6. Was there clear reporting of the demographics of the participants in the study?	☐	☐	☐	☐
7. Was there clear reporting of clinical information of the participants?	☐	☐	☐	☐
8. Were the outcomes or follow up results of cases clearly reported?	☐	☐	☐	☐
9. Was there clear reporting of the presenting site(s)/clinic(s) demographic information?	☐	☐	☐	☐
10. Was statistical analysis appropriate?	☐	☐	☐	☐

Table 3: The JBI critical assessment checklist was utilized for the studies incorporated in the systematic review

Author Year	Q1	Q2	Q3	Q4	Q5	Q6	Q7	Q8	Q9	Q10
Nikolidakis D. et al. [32]	Y	Y	Y	Y	Y	N	Y	Y	N	AN
Gonzales et al. [33]	Y	Y	Y	Y	Y	N	Y	Y	Y	NA
Krug R. et al. [34]	Y	Y	Y	Y	Y	N	Y	Y	Y	NA
Avi Shemesh et al. [35]	Y	Y	Y	Y	Y	N	Y	Y	N	NA
Vinothkumar et al. [36]	Y	Y	Y	Y	Y	N	Y	Y	Y	NA
Barrato-Filho et al. [37]	Y	Y	Y	Y	Y	N	Y	Y	Y	NA
Mavridou et al. [38]	Y	Y	Y	Y	Y	N	Y	Y	Y	NA
Discacciati et al. [39]	Y	Y	Y	Y	Y	N	Y	Y	N	NA
Fernandez et al. [40]	Y	Y	Y	Y	Y	N	Y	Y	N	NA
Patel et al. [11]	Y	Y	Y	Y	Y	N	Y	Y	N	NA
Gunst et al. [41]	Y	Y	Y	Y	Y	N	Y	Y	N	NA
Patel et al. [42]	Y	Y	Y	Y	Y	N	Y	Y	N	NA
Nedir et al. [43]	Y	Y	Y	Y	Y	N	Y	Y	Y	NA
Kqiku et al. [44]	Y	Y	Y	Y	Y	N	Y	Y	Y	NA
Dias et al. [45]	Y	Y	Y	Y	Y	N	Y	Y	N	NA
Bal et al. [46]	Y	Y	Y	Y	Y	N	Y	Y	Y	NA
Gulsani et al. [47]	Y	Y	Y	Y	Y	N	Y	Y	N	NA
Bharti et al. [48]	Y	Y	Y	Y	Y	N	Y	Y	Y	NA
Ali et al. [49]	Y	Y	Y	Y	Y	N	Y	Y	N	NA
Smidt et al. [50]	Y	Y	Y	Y	Y	N	Y	Y	N	NA
Iwamatsue et al. [51]	Y	Y	Y	Y	Y	N	Y	Y	N	NA
Llavayol et al. [52]	Y	Y	Y	Y	Y	N	Y	Y	Y	NA
Shemesh et al. [53]	Y	Y	Y	Y	Y	N	Y	Y	Y	NA
Matarazzo et al. [54]	Y	Y	Y	Y	Y	N	Y	Y	Y	NA
Tavares et al. [55]	Y	Y	Y	Y	Y	N	Y	Y	N	NA
Karypidou et al. [56]	Y	Y	Y	Y	Y	N	Y	Y	N	NA
Asgary et al. [57]	Y	Y	Y	Y	Y	N	Y	Y	N	NA
Yoshpe et al. [58]	Y	Y	Y	Y	Y	N	Y	Y	N	NA
Perlea et al. [59]	Y	Y	Y	Y	Y	N	Y	Y	N	NA
Ehlinger et al. [60]	Y	Y	Y	Y	Y	N	Y	Y	N	NA

All data that gathered from the 30-researches cover following topics:

1- Type of the study

2- Years of publications that help us to monitor evolution of material in use

3- Gender distribution to find out if there is any sex predisposing factor related to ICR

4- Diagnostic tools that help dentist to identify ICR in various stage

5- Type of the resorption and the stage that dentist noticed ICR

6- Possible etiologies and associated factors that can be related to ICR. The patient medical history, systemic disease, any kind of dental treatment, and history of trauma were gathered for further evaluation.

7- Teeth numbers that are involved with ICR

8- Treatment methods internal approach/ surgery

9- Material in use that evolved through the time and showed different success rate.

10- Out come of the treatment and follow up time that is the most important factor to evaluate the success of treatment.

RESULTS

The following data was gathered from each of the 30 studies: author's name, publication year, study type, sample size, participants' age, gender distribution, etiology (related factors), resorption type and class, number of teeth affected, tooth number, type of x-ray utilized for diagnosis, treatment method, diagnostic and repair materials used, duration of follow-up, and the outcome (**Table 4**).

Table 4: Detailed information about each specific case from each study is summarized:

Author (s)	Year	Type	Sam-ple size	Age of partici-pants	Type of resorption	Diagno-sis tools	Etiology	Method of treatment RCT/Surgery	Material of Use	Outcome	Length of Follow up
Nikolidakis D. et al.	2008	Case report	1	46-year old male	External cervical resorption: teeth #13 (UL canine, facial surface) & # 23 (LL canine, facial & lingual surfaces) (FDI)	PA 1x-rays	Generalized gingivitis, para-functional habits (clenching and grinding) Good health, no systematic disease	Removal of the granulation tissue by opening a flap, surgery (Ostectomy), and RCT	Glass ionomer cement (FUJI II), composite	6 months: stable perio status, shallow probing pocket depth, reduced bleeding, stable radiolucent spot in cervical region of # 13; 3 years: Stable and uneventful clinical recovery	6 months and 3 years follow-ups
Gonzales J. et al.	2007	Case report	1	27-year old male	External cervical resorption: tooth #7, labial surface (Universal)	PA x-rays	Possibly history of orthodontics No mention of health status	RCT and periodontal microsurgery ,granulation tissue was removed using an excavator, full-thickness flap was raised from buccal	NaCl (0.9%), Glass ionomer cement, Ionoseal, H202 (3%), NaOCl (5%), Calcium hydroxide, Cavit, AH Plus sealer, composite resin	Stable and asymptomatic at re-evaluation	2 years
Krug R. et al.	2019	Case report	1	37-year old male	External cervical resorption: Tooth # 11, palatal surface (FDI)	PA x-rays; CBCT	Possibly history of orthodontics Unremarkable medical history	Intentional replantation with an atraumatic extraction system	High-translucency composite	2 weeks: no symptoms, class II mobility of replanted tooth; 2.5 years: Asymptomatic; no	2 weeks; 2.5 years

										signs of resorption or ankylosis	
Avi Shemesh et al.	2017	Case series	4	22 (M), 44 (M), 37 (M), and 41 (F) years old	Invasive cervical resorption: Case 1: tooth #9, palatal surface; Case 2: tooth #9, palatal surface; Case 3: tooth #11, distal surface; Case 4: tooth #9, buccal surface All cases were Class IV (Universal)	PA x-rays; CBCT	Dental trauma (case 1), no history of trauma or orthodontic treatment (other cases) General good health (all cases)	RCT	Sodium hypochlorite; calcium hydroxide; Cavit; no mention of final restoration material	Clinically asymptomatic; no new resorptive areas	5 years (case 1), 3 years (all others)
Vinothkumar et al.	2011	Case report	1	15-year old male	Invasive cervical resorption (Class 2), tooth #9, M & D surfaces involved (Universal)	PA x-rays	Dental trauma 2 years prior No relevant medical history	RCT & periodontal surgery (full-thickness mucoperiosteal flap), granulomatous tissue was removed	Sodium hypochlorite, chlorhexidine, sterile saline, 17% EDTA, AH plus sealer, microfilled composite & RMGIC , 90% TCA for coagulation necrosis	Asympotmatic, no further resorption, no gingival recession at 1 year follow-up	1 year
Baratto-Filho et al.	2005	Case report	1	23- year old male	Invasive cervical resorption: tooth #10, buccal, palatal, and mesial surfaces involved (Universal)	PA x-rays	No predisposing factors No medical problems	RCT, resorptive tissue removed with a curette	MTA, Composite, GIC	No periodontal problems, no color change 2 years after treatment	1 year & 2 years after treatment
Mashyakhy et al.	2018	Case report	1	18-year old female	Invasive cervical resorption Class III (mesiocervical surface); tooth #19	Pa x-rays; CBCT	No history of trauma, referred by an orthodontist	Non-surgical RCT; lesion removed from coronal access	Sodium hypochlorite, calcium hydroxide,	Asymptomatic at 6 months, slight mesial bone loss and probing depth	6 mo, 1 year, 2 years

					(Universal)		Non-contributory medical history		Cavit, RMGIC, AH plus sealer, glass ionomer, final restoration with composite	of 3 mm at 1 year, no further bone destruction at 2 years	
Discacciati et al.	2012	Case report	1	40-year old male	Invasive cervical resorption: upper right canine (tooth #6), lingual surface involved, Class IV (Universal)	PA x-rays; CT scan	No history of trauma, tooth was treated endodontically 2 years prior No medical history	Extraction was done due to too much mobility, an implant was finally installed after bone healing	N/A	Osseointegration at 6 months	3 times (7 days, 30 days, and 6 months after treatment)
Fernandez et al.	2017	Case report	1	67-year old male	Invasive cervical resorption : tooth #25 (Mandi CI), lingual surface involved, class IV (Universal)	Pa x-rays; CBCT	No history of trauma, tooth was treated periodontally (non-surgical scaling and root planning) 9 years prior; 6 months later a GTR procedure was performed Non-contributory medical history	Surgical endodontic treatment (full-thickneflap), devitalized tissue was curetted from the resorptive cavity	90% TCA, glycerol, chlorhexidine gluconate gel, sterile saline solution, ProRoot WMTA, flowable compomer	Healthy perio tissues, no bleeding, and normal probing depths 6 years after treatment	Evaluated periodically (clinically every 3 months, and radiographically every 6 months). Final evaluation 6 years post-treatment.
Patel et al.	2015	Case series	3	82-year old male, 66 and 62 year old females	External cervical resorption: Case 1: teeth #27 (cervico-palatal, Class IV), #28 (mesial, Class II), & # 16, 26 & 48 (DB, Class III);	PA x-rays; CBCT	No predisposing factors for any of the cases; Case 3 had tooth # 16 restored with GI previously	Case 1: RCT of #28, others left untreated due to patient's request; Case 2: #24's coronal portion was	Not mentioned	All the treated cases remained asymptomatic	Patients were periodically evaluated: Case 1: every 6

					Case 2: Teeth # 24 (middle 1/3 of the root, Class IV), #26 (DB, Class IV); Case 3: Tooth #16 (Mesiopalatal, Class IV) (FDI)		Case 1: took oral BSP alendronate sodium for 5 years for osteoporosis, was advised to stop Fosamax 3 years ago Case 2: had mild high BP, had been on Fosamax for the last 6 years for osteoporosis Case 3: had been on Fosamax for 7 years for osteoporosis	removed, apical portion kept intact, gap restored with resin-retained bridge, #26 left untreated due to ECR being inaccessible. Case 3: Palatal portion of tooth removed, RCT of buccal canals, indirect cuspal coverage restoration			months for the first year and annually thereafter; still asymptom atic after 4 years. Case 2: Evaluated annually. Case 3: evaluated 2 years post-treatment
Gunst et al.	2013	Case report	1	41-year old female	External cervical resorption: Tooth #47 (mesio-buccal involved, Class IV) (FDI)	PA x-rays; CBCT	No predisposing factors; #47 tilted due to prior exo of #46 (mechanical trauma of exo could have contributed to ECR) Non-contributory medical history	Extraction	N/A	Electron microscopy, and computed tomography analysis of ECR	N/A
Patel S. et al	2007	Case series	2	Case 1: 32-year old M; Case 2: 37-year old F	External cervical resorption Case 1: tooth #45 (cervico-buccal); Case 2: tooth # 11 (cervico-mesial)	PA x-rays; CBCT	No history of trauma; both cases had undergone orthodontic treatment before;	Case 1: triangular full-thickness mucoperiosteal flap, cortical plate overlying the lesion removed, granulomatous tissue removed,	Case 1: GI cement; Case 2: N/A	Case 1: Asymptomatic. Clinical and radiographic findings unremarkable; Case 2: N/A	Case 1: 1 year post-treatment; Case 2: N/A

					(FDI)		Case #2 was about to start another ortho treatment Both cases had unremarkable medical history	defect repatied with GI cement; Case 2: not amenable to surgical repair, finish ortho treatment first, monitor for progress of resorption and replace with implant if required			
Nedir et al.	1997	Case report	1	38-year old male	Cervical resorption (DB of tooth #35) (FDI)	PA x-rays	Associated with recurrent peripheral giant cell granuloma; no other pre-disposing factors Patient in good general health; unremarkable medical history	Surgical excision of the granuloma followed by scaling of the affected tooth	N/A	No further recurrence or resosption	14 months post-treatment
Kqiku et al.	2012	Case series	2	31-year old female,; 16-year old male	Invasive cervical resorption Case 1: tooth # 9 (labial surface), class II ; Case 2: tooth # 8 (palatal), class III (Universal)	PA x-rays; CBCT	Case 1: no predisposing factors; Case 2: history of dental trauma, orthodontic treatment No relevant medical history for both cases	Case 1: surgical treatment with mucoperiosteal flap, granulomatous tissue removed, restore d with a 3 layer sandwich technique; Case 2: same as case 1	White MTA, 0.1% chlorhexidin e, GIC, and composite as 3 layers for both cases	Both cases healed and asymptomatic at different evaluations	Case 1: 1 week, 6 months, and 1 ½ year follow-up; Case 2: 1 week and 6 months follow-up
Dias et al.	2015	Case report	1	11-year old male	External cervical resorption, tooth #7 (distal) (Universal)	PA x-rays	History of dental trauma, crown fracture, pulpotomy was done initially with formocresol;	RCT and surgical access to seal the cervical defect	GIC, composite	Normal clinical and radiographic findings, no root fracture	6 years post-treatment

							authors believe the etiology of ECR was ectopic eruption of canine No mention of medical history				
Bal et al.	2015	Case report	1	50-year old female	Invasive cervical resorption, tooth #25 (mandi CI), facial surface (Universal)	PA x-rays	Gingival enlargement of ant. Mandible, thyroid disorder, and controlled hypertension	Surgical removal of lesion (flap), RCT followed	GIC, composite, AH 26 sealer	Asymptomatic at each re-evaluation	6 months, 1 year, 2 years and 3 years follow-ups
Gulsahi et al.	2007	Case series	3	48-year old male, 66-year old male, and 35-year old female	Invasive cervical resorption: Case 1: tooth #20 (mesial surface), Class II; Case 2: tooth #27 (lingual surface, Class II; Case 3: tooth #18 (distal), Class III (Universal)	PA x-rays; CBCT; Axial CT; Panoramic	Case 1: no predisposing factors; Case 2: unremarkable medical history, history of bruxism; Case 3: no predisposing factors Unremarkable medical history	RCT	Glycerol, 90% TCA, Sodium hypochlorite, AH Plus sealer, GIC cement, Cavit G (cases 2&3), composite, amalgam (case 3)	All cases were asymptomatic following treatment	6 months follow-up for all cases; Case 2 had a 3-months follow up as well
Bharti et al.	2014	Case report	1	18-year old female	External cervical resorption: Tooth #8 (facial surface), Class II (Universal)	PA x-rays; panoramic	Undergoing orthodontic treatment No mention of medical history	RCT, lateral pedicle graft (full-thickness mucoperiosteal flap)	Cavit, white MTA, GIC, composite	Asymptomatic, intact restoration, no color change	6 months and 1 year follow-ups

Ali et al.	2015	Case report	1	12-year old female	Multiple idiopathic cervical root resorption: Teeth #3, 4, 5, 6, 14, 19, 20, 21 & 22 (exact location and class not mentioned) (Universal)	Panoramic	No predisposing factors; no perio pockets; patient was undergoing ortho treatment Medical history unspecified	RCT, extractions, implant placement Surgical flap (buccal), granulation tissue removed	Calcium hydroxide, GIC, composite, bridges cemented with zinc phosphate	RCTs were futile since resorption recurrence occurred Lesions were progressive and tended to recur	Periodic follow-up over 2 years
Smidt et al.	2007	Case report	1	22-year old female	Invasive cervical resorption: tooth #7 (labial surface), Class III (Universal)	PA x-rays	Adjacent tooth (#8) was intracoronally bleached previously (with sodium perborate and 3% hydrogen peroxide) No mention of medical history	Orthodontic extrusion, fiberotomy, RCT, composite post and core resotration	GIC, 90% TCA, composite	Asymptomatic, properly healed tissues	42 months
Iwamatsu et al.	2005	Case report	1	49-year old female	Multiple idiopathic cervical root resorption (21 of her 25 teeth involved), only proximal surfaces involved	PA x-rays; Panoramic	No history of trauma or orthodontic treatment; diagnosed with osteoporosis and hyper-alkaline phosphatasemia	Extraction, curettage via mucosal flap, fixed and removable partial prosthodontic restorations	GIC	The lesion did not advance; the authors suggest bisphosphonate therapy as the reason for prevention of lesion progression	6 years
Llavayol et al.	2019	Case report	1	26-year old female	Multiple invasive cervical root resorption: teeth # 11, 12, 13, 14, 20, 21, 22, 27, 28, 29, 30 and 31. Buccal and lingual surfaces involved. Two teeth (#21 and 22) were previously extracted due to	PA x-rays; CBCT	History of ovarian cancer and chemotherapy (authors believe this was a predisposing factor)	Implants placement (teeth #21, 22), surgical restoration of tooth #30, monitoring of other teeth.	90% TCA, nano-hybrid composite	Progression and worsening of lesions in most teeth, presence of new lesion on the lingual aspect of tooth #30.	6 months & 18 months follow-ups

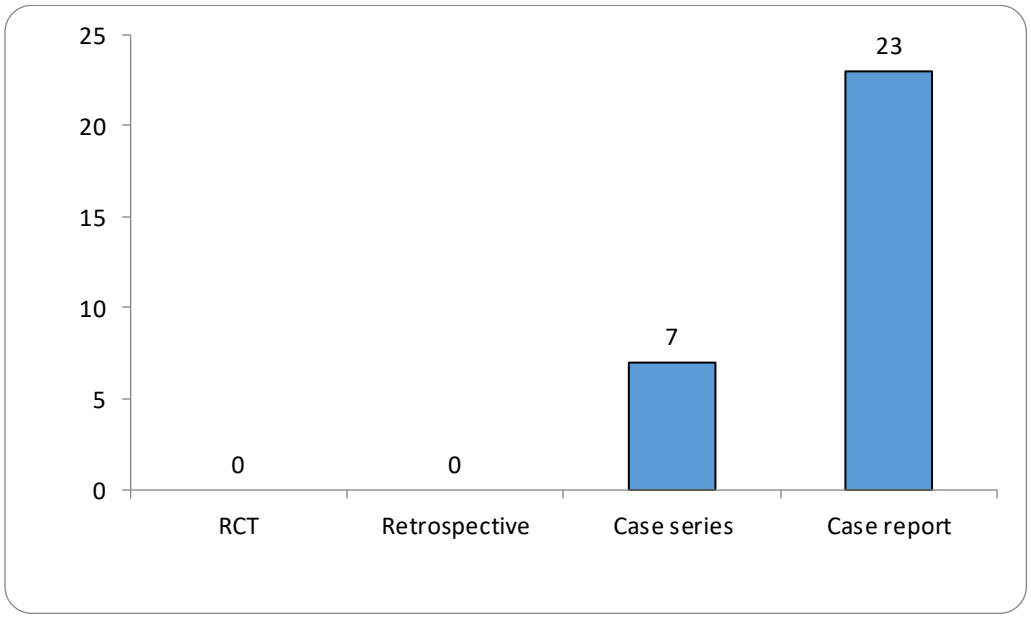
					resorption. All teeth showed either Class III or IV, except tooth #30 (Class I). (Universal)						
Sharma et al.	2019	Case report	1	23-year old female	Multiple idiopathic cervical root resorption: 10 teeth involved: #11, 12, 13, 22, 23, 24,25,26,27, and 28. Buccal/lingual/distal surfaces involved. (Universal)	PA x-rays; CBCT; Panoramic	History of endodontic treatment; no predisposing factors No medical history	Extractions, removal of granulation tissue implant-retained prosthesis	MTA, no other materials mentioned	Progression and worsening of lesions led to extraction of more teeth 2 years later; 7 years later, new lesions developed.	6 months, 2 years, and 7 years
Matarazzo et al.	2020	Case report	1	12-year old female	Invasive cervical root resorption: tooth #6 (class & location not specified) (Universal)	PA x-rays; CBCT; Panoramic	No predisposing factors, large amount of movement due to orthodontic treatment No mention of medical history	Uprighting of #7, axial rotation, distalization of #6 initially. Extraction of #6 in the end.	N/A	N/A	N/A
Tavares et al.	2013	Case report	1	31-year old male	Invasive cervical resorption: Tooth #8 (palatal surface involved), Class III (Universal)	PA x-rays	No history of ortho treatment or bleaching; possible history of trauma No medical problems otherwise	Non-surgical RCT initially, bleeding couldn't be stopped, intrasulcular full-thickness flap, removal of granulation tissue.	Sodium hypochlorite, 17% EDTA, ZoE endodontic cement, 90% TCA, RMGI	Free of pain 1 month post-treatment; no bone loss, asymptomatic, healthy periodontium 1 year after.	1 month & 1 year
Karypidou et al.	2016	Case report	1	20-year old female	Invasive cervical resorption:	PA x-rays	No predisposing factors	RCT, full-thickness flap	Sodium hypochlorite, calcium	Asymptomatic, no recurrence of lesions	3, 6, 12, 24, and 36 months.

					Teeth # 8 (labial), Class II; # 9 (labial and palatal), Class III (Universal)		Unremarkable medical history		hydroxide , 17% EDTA, RMGI, GIC, Cavit, Biodendine (calcium-silicate based cement), composite resin		
Asgary et al.	2015	Case report	1	Male in his early thirties	Invasive cervical resorption: Tooth #27 (buccal surface involved); class not specified (Universal)	PA x-rays	Good oral hygiene, normal dental history No mention of medical history	Instra-sulcular full-thickness flap, granulation tissue removed, restored with CEM cement	CEM (calcium-enriched mixture) cement (BioniqueDent), composite	Completely asymptomatic with normal peri-radicular and periapical tissues 1 year post-treatment	3 months & 1 year
Yoshpe et al.	2016	Case report	1	10-year old male	Invasive cervical resorption: Tooth #27 (palatal surface involved), class not specified; tooth #29 (distal surface involved), class II (Universal)	PA x-rays; CBCT; Cephalo metric	History of orthodontic treatment No mention of medical history	Combined endodontic-periodontal treatment: Full-thickness mucoperiosteal flap, resorptive tissue curetted, granulation tissue removed, RCT	ProRoot MTA placed, sodium hypochlorite, calcium hydroxide, IRM, AH 26 sealer, 17% EDTA (for tooth #29), TCA (for tooth #29)	8 months: distal pocket on tooth #27 measuring 8 mm; 13 months: No distal pocket on tooth #27, new ICR on tooth #29; 4 months: resorption continued on tooth #29	8 months, 13 months (for tooth #27), 4 months (for tooth #29)
Perlea et al.	2017	Case series	3	27, 25 and 39-year old females	Invasive cervical resorption: Case 1: tooth #46 (distal surface involved), Class IV;	PA x-rays; CBCT; Panora mic	All cases had a history of orthodontic treatment	Case 1: tooth replantation due to excessive resorption; Case 2: extraction of canine and	No materials mentioned	Case 2: 6 months: healing of chronic apical periodontitis, stable implant	6 months (case 2)

					Case 2: tooth #23 (multiple surfaces), Class IV; Case 3: tooth #18 (multiple surfaces, broadly affected), Class III (FDI)		Case 1: chronic apical periodontiton tooth #24 All cases had non-contributory medical histories	placement of implant, RCT of tooth #24; Case 3: no treatment		Outcomes of other cases not mentioned	Other cases were not followed post-treatment
Ehlinger et al.	2019	Case series	4	15, 27, 30 and 25-year old females	Invasive cervical resorption: Case 1: tooth #9 (labial surface involved), Class II Case 2: tooth #11 (distal surface involved), Class III Case 3: tooth #3 (palatal surface involved), Class IV Case 4: tooth #7 (palatal surface involved), Class IV (Universal)	PA x-rays; CBCT	Cases 1 and 2: no mention of dental history or predisposing factors Case 3: a provisional crown had been fabricated a few weeks earlier Case 4: pulpal necrosis, secondary periodontal involvement Medical histories of cases were not mentioned	Case 1: sulcular incision, full-thickness flap, RCT Case 2: RCT Case 3: sulcular incision, full-thickness flap, RCT, fiber-reinforced post and core Case 4: RCT	Case 1: composite resin Case 2: Biodentine (Septodont) Case 3: no materials mentioned Case 4: Biodentine, composite	Case 1, 2 & 3: no recurrence of ICR, asymptomatic Case 4: no recurrence of ICR, periapical healing, marginal bone healing on-going	Case 1: 1 week, 3 months, 3 years Case 2: 1 week, 2 months, 6 months, 12 months, and 18 months Case 3: 1 year Case 4: 18 months

Type of Study & Year of Publication: 23 of the studies were case reports with the remaining seven being case series. No randomized controlled trials or retrospective studies about ICR were found in the literature. Most of the studies were published in the 2010s with the publication dates ranging from 1997 to 2020 **(Figure 3).**

Figure 3: Type of Study

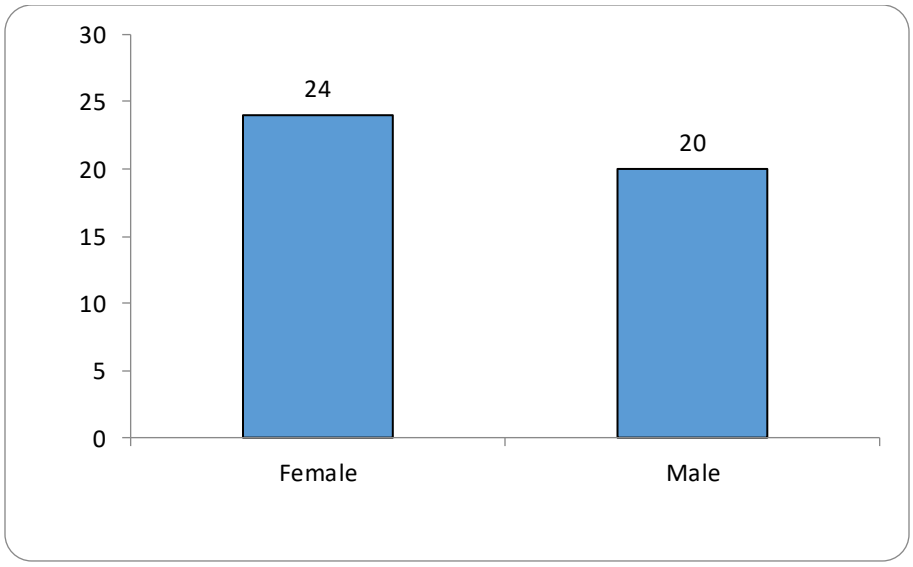


Sample Size: The sample sizes of individual studies were very small given that most were case studies in design. Some of the case series had up to 4 participants and these studies had the largest sample size among the studies included. Cross the 30 studies 69 teeth were reported.

Age of Participants: The age range of participants in the studies was variable, from 10 to 82 years of age, the average age is 32yo with most subjects being adults. Some pediatric and adolescent patients were included as participants as well.

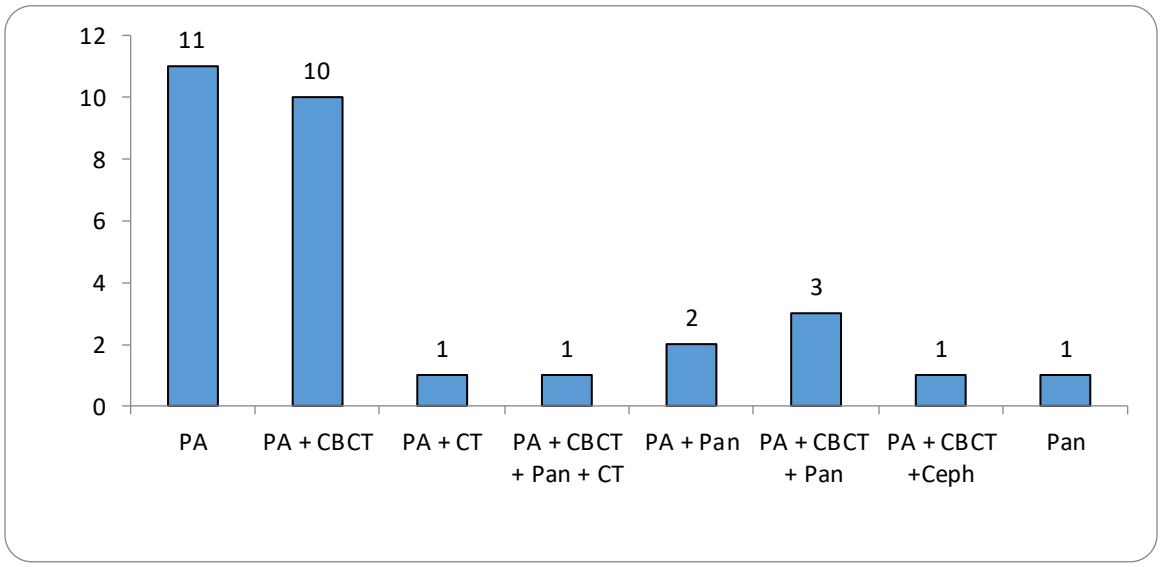
Gender Distribution: The gender distribution among the participants across studies was close to 50% with a total of 24 female subjects and 20 male subjects. Therefore, the gender distribution of participants was quite balanced among the studies **(Figure 4).**

Figure 4: Gender Distribution



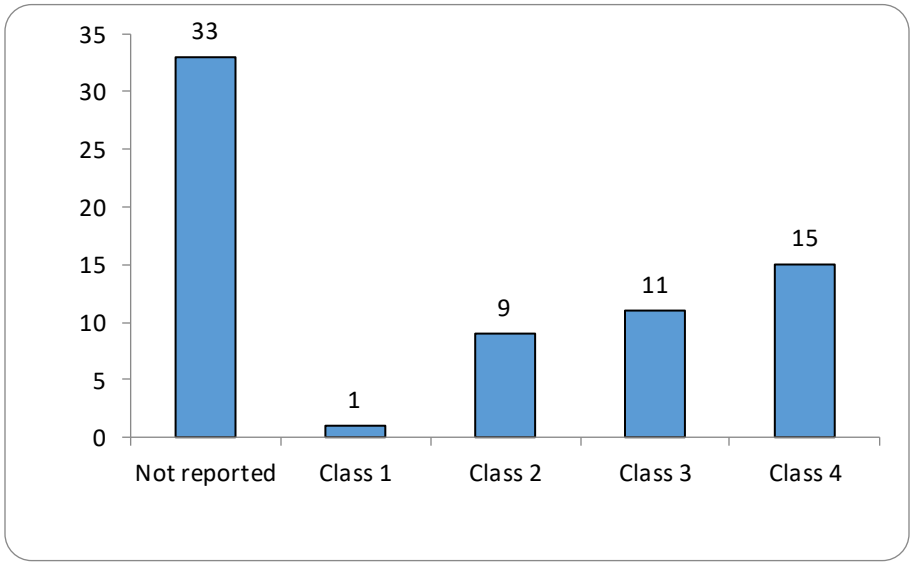
Diagnostic Tools (X-rays/CBCT): In terms of diagnostic measures, 11 studies reported only using periapical x-rays as a diagnostic tool with another 10 using CBCT in addition to the periapical x-rays. 11 studies PA, 2 studies PA + Panoramic and one study used panoramic studies utilized other methods in conjunction to these including panoramic, CT and cephalometric radiographs. **(Figure 5).**

Figure 5: Radiology



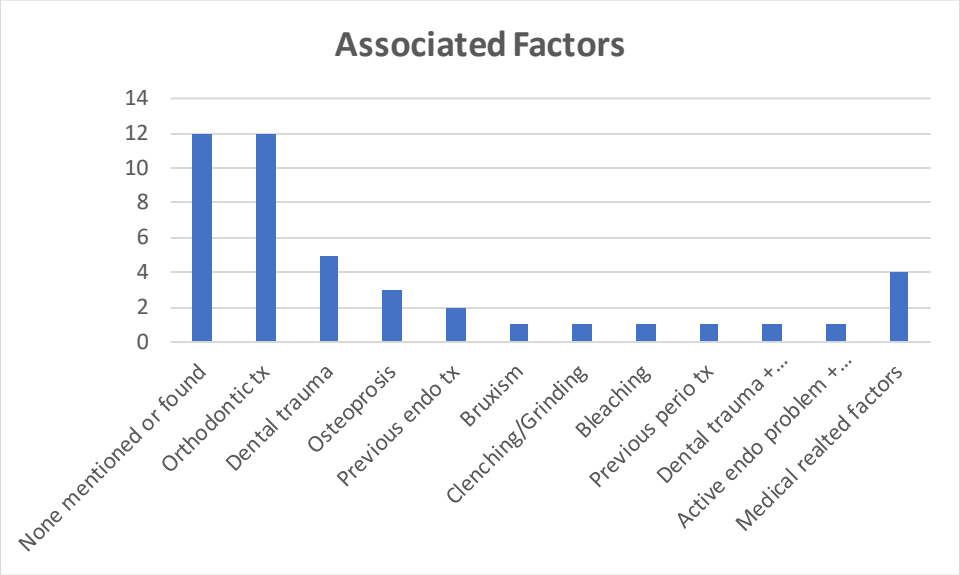
Type & Class of Resorption: Class of the resorption was reported on 36 Of teeth**.** Class 4 resorption was the most frequently reported class (n =15), followed by class 3 (n =11) and class 2 (n =9). Only 1 tooth was reported as having a class 1 invasive cervical resorption. No resorption class was specified for 33 of the teeth examined. Figure 6 demonstrates the distribution of reported class of resorption. **(Figure 6).**

Figure 6: Resorption Class



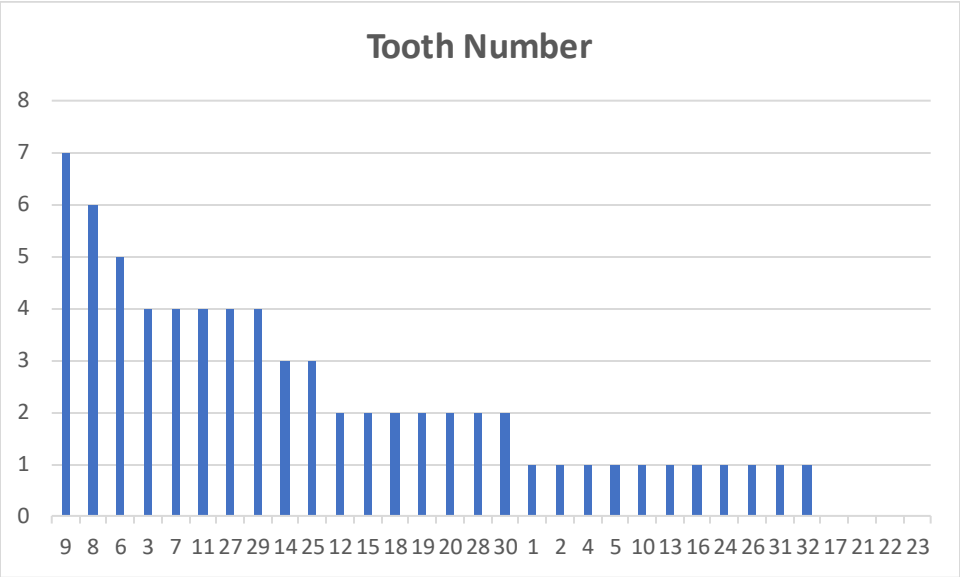
Corelated Factors (Possible Etiology): A wide variety of possible etiologies were reported across studies. Orthodontic treatment was reported as an associated factor in 12 subjects. Dental trauma was the second most reported possible etiology (n =5). Osteoprosis and previous endodontic treatment were reported as potential underlying causes in 3 and 2 subjects respectively. Other associated factors discussed by the rest of the studies in this review included bleaching, previous or active endodontic/periodontic treatment, bruxism, thyroid disorder, cancer, etc. Detailed information regarding these associated factors cited by each study is summarized in **Figure 7**.

Figure 7: Associated (Corelated) Factors



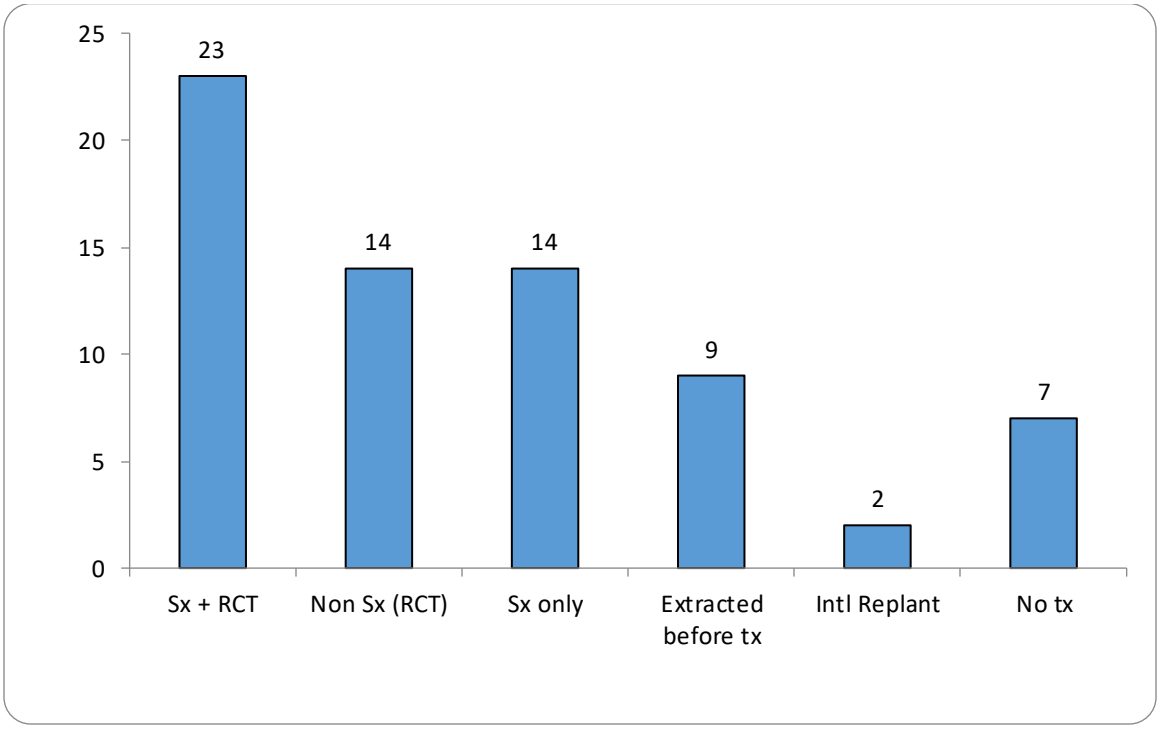
Tooth Number: The most frequently reported tooth affected by invasive cervical resorption was tooth #9 (n=7), followed by tooth #8 (n=6), and #6 (n=5). Except for maxillary central incisors involvement that was reported by many of the studies, the type of tooth involved was quite variable **(Figure 8).**

Figure 8: Tooth Number



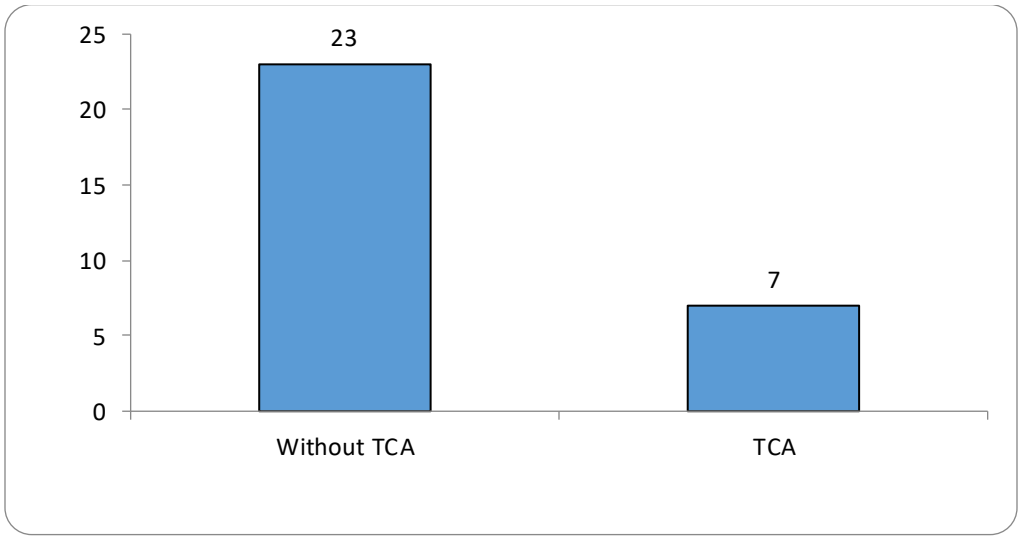
Treatment Methods: Regarding the treatment type, 23 of the studies used surgery along with root canal therapy, 14 studies solely used root canal therapy, and 14 studies treated the condition through surgery only. 9 studies mentioned extracting the teeth involved prior to treatment whereas 2 studies reported intentional replantation as the treatment of choice. Finally, 7 studies did not treat the condition at all **(Figure 8).**

Figure 8: Treatment Type



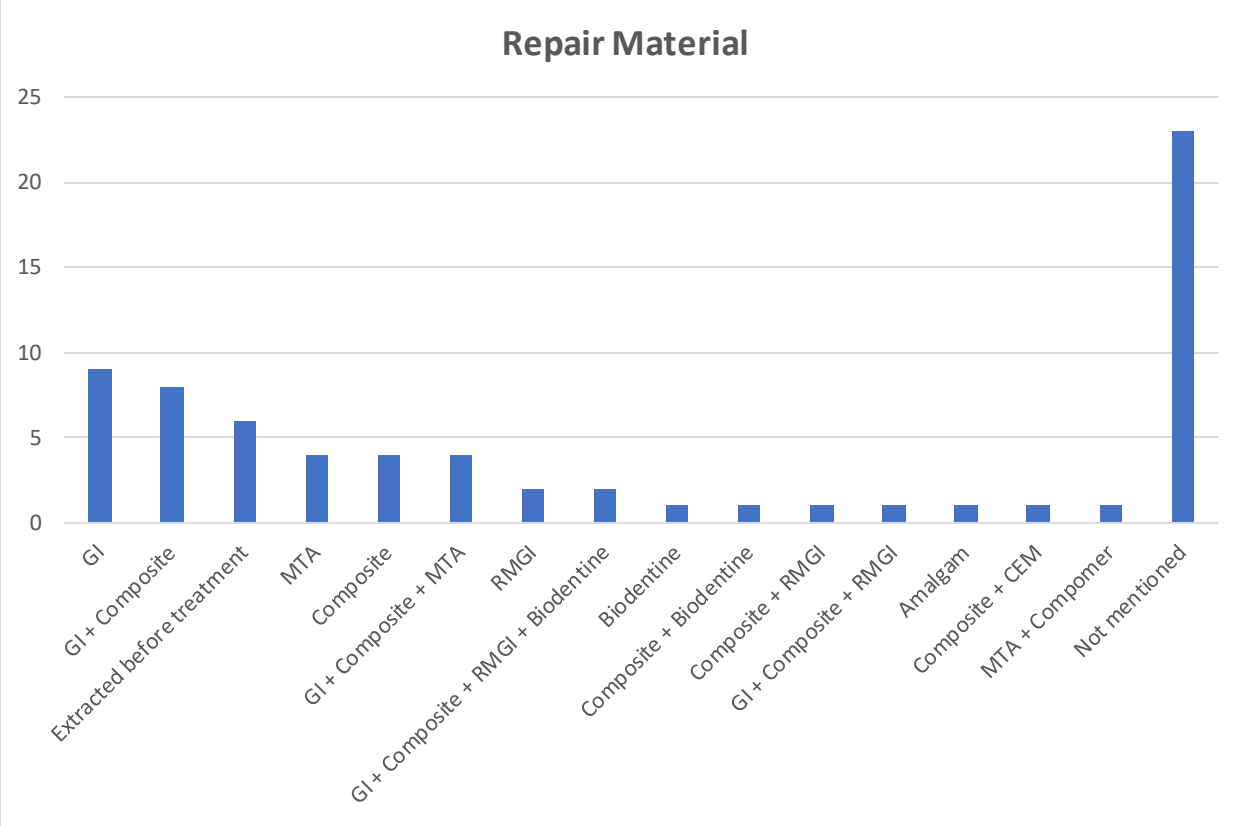
Material to control bleeding and remove resorptive tissue: TCA was the material of choice to control bleeding and dissolve resorptive tissue. Across studies with 7 studies using it during their treatment while the rest did not report such usage **(Figure 9).**

Figure 9: Material to control bleeding and remove resorptive tissue



Repair Materials: Twenty three studies did not mention the repair materials while the most frequently used were the use of GI alone or in combination with composite. The use of RMGI was quite prevalent among the studies. Other repair materials reported were MTA, Biodentine, compomer, and CEM (calcium-enriched mixture). The detailed summary of what repair materials were utilized by each study can be found in **Figure 10**.

Figure 10: Repair Material

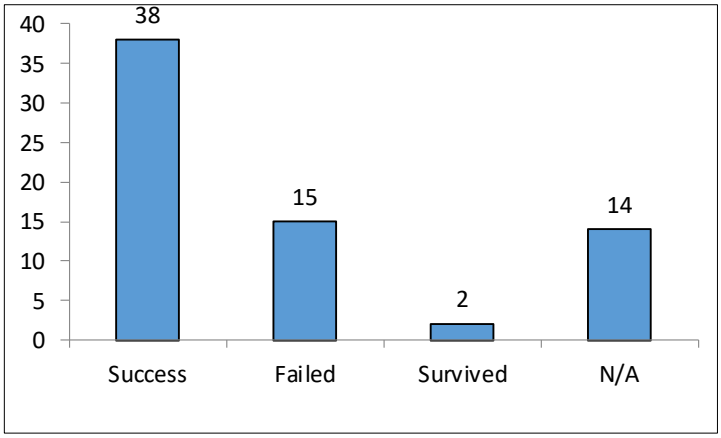


Follow-up Period: The follow-up period was quite variable across studies and ranged from no follow-up to 72 months post-treatment. Thirteen of the selected studies did follow up the subjects between 2 to 3 years following treatment.

Outcome: In terms of the outcome of treatment, 38 of the treated teeth showed no signs of resorption post-treatment and were successfully healed whereas treatment failure was observed in

15 teeth. Treatment outcomes of each individual case is summarized in **Figure 11**.

Figure 11: Treatment Outcome



DISCUSSION

This systematic review aimed to comprehensively analyze the existing literature on invasive cervical resorption (ICR), focusing on its etiology, diagnosis, and treatment approaches. Additionally, the study sought to identify standardization to identify and treatment planning potential variables, impacting treatment outcomes, and suggest future research direction to enhance treatment outcome and reduce tooth lost. To achieve these objectives, a specific search strategy was employed to examine the associated factors in ICR etiology, as well as key considerations for its diagnosis, treatment, and prognosis. However, the literature primarily comprises case reports and case series with low levels of evidence, posing challenges for drawing definitive conclusions or establishing robust associations between predisposing factors and ICR. Despite these limitations, the review offers valuable insights into ICR, including the most frequently affected teeth and the potential benefits of CBCT in accurate diagnosis and classification of ICR lesions, while also addressing the scarcity of evidence supporting the use of TCA as a diagnostic material and the success of glass ionomer (GI) and RMGI as restorative materials in ICR treatment.

Studies on the etiology and pathogenesis of invasive cervical resorption are scarce due to its low prevalence. A multitude of predisposing factors have been associated with invasive cervical resorption. Among various factors, trauma, orthodontic treatment, and periodontal treatment exhibited strong connections with ICR. Heithersay's study also identified internal bleaching as a minor contributing factor. A recent retrospective case-control study, conducted over a 10-year observation period with endodontic patients at a university graduate endodontics clinic, revealed a 2.3% prevalence of ICR this why the most contributed studies are case series and case report in this research. The occurrence of ICR is closely linked to factors that can lead to the loss of protective layers. In this study, around 78% of patients with ICR lesions were found to have such contributing factors [61].

More recent studies incorporate 3D imaging with total of sixteen studies out of thirty were used CT in this study.With advancements in technology and the increasing affordability of CBCT, 3D imaging is becoming a routine diagnostic tool in dentistry, particularly in the field of endodontics [62]. As a result, dentists are now able to diagnose root resorption at earlier stages more frequently [63]. CBCT offers advantages over traditional 2D imaging, such as superior visualization of complex anatomical structures and improved detection of early-stage resorptive lesions. Moreover, CBCT allows for more accurate treatment planning and precise management of resorption cases. The growing use of CBCT in dental practice is expected to lead to better outcomes in the diagnosis and treatment of root resorption, ultimately improving patients' oral health [64,65].

Information regarding the medical and dental histories of subjects in the studies included in this review confirms the association of orthodontic treatment, periodontal therapy, and trauma with ICR. Although a wide variety of other predisposing factors, such as osteoporosis, ovarian cancer, thyroid disorders, hyper-alkaline phosphatasemia, and bruxism, were reported by studies in this review, further research is needed to validate a robust association between these factors and ICR.

Among all tooth types, maxillary anterior teeth were most commonly impacted, indicating that physical and chemical contributing factors, like dental trauma and internal bleaching, might be more frequently linked to these teeth. This is likely because anterior teeth are more prone to trauma and are the main targets for internal bleaching for cosmetic purposes [66–69]. However, based on the

studies included in this review, no predilection for age or gender was found. The gender distribution was fairly even across the reports included in this review, ensuring no skewing of results based on gender.

Accurate diagnosis and evaluation of invasive cervical resorption are essential for effective treatment. Given that ICR lesions are often located subgingivally, radiographic interpretation is crucial for proper identification of the condition. While many studies in this review relied solely on periapical radiographs for ICR diagnosis, the dimensions and positions of the lesions might not be precisely determined using only two-dimensional radiographs. Patel et al. examined the efficacy of periapical radiographs in comparison to CBCT for diagnosing and evaluating ICR. Their clinical research showed that periapical radiographs had restricted effectiveness in appraising the size, extent of the circumferential spread, and locations of the lesions when contrasted with CBCT [70]. Furthermore, periapical radiographs are inferior in terms of sensitivity and specificity than CBCT for detecting ICR lesions. As a result, it is strongly advised to employ CBCT for diagnosing and evaluating resorptive lesions before treatment, in accordance with the joint position statement from the American Association of Endodontists and the American Association of Oral and Maxillofacial Radiology, as well as the European Society of Endodontology position statement regarding the use of CBCT in endodontics [23,71].

Heithersay originally devised the ICR lesion classification system for the purpose of clinical evaluation and research applications [61,72]. ICR lesions are categorized into four groups according to the dimensions and progression of resorptive defects within the dentin: Class 1 consists of a minor resorptive lesion in the cervical region with minimal penetration into dentin; Class 2 involves a more invasive resorptive lesion directed towards the coronal pulp with limited or no engagement of radicular dentin; Class 3 encompasses a profound cervical resorptive lesion extending into the coronal third of radicular dentin; and Class 4 covers an extensive resorptive lesion surpassing the coronal third of radicular dentin. Although Heithersay's classification is quite useful, ICR lesions may not be correctly categorized if two-dimensional radiographs are used.

Patel and colleagues recently developed a three-dimensional classification approach utilizing CBCT [5]. This classification seems to offer a more accurate evaluation of ICR's preoperative status compared to Heithersay's classification, potentially aiding clinicians in improved treatment planning and lesion management. The three factors considered in this new classification encompass the height of ICR lesions, the circumference of the lesions, and the closeness of lesions to root canals. The scoring is as follows: The height of the lesions is scored as supracrestal (1), subcrestal extending into the coronal third of radicular dentin (2), reaching the middle third of radicular dentin (3), and progressing into the apical third of radicular dentin (4). The circumference of the lesions is rated as smaller than 90◦ (A), between 90◦ and 180◦ (B), between 180◦ and 270◦ (C), and larger than 270◦ (D). The proximity of the lesions to the root canal is graded as within dentin (d) and involving pulp (p). The grading value from each parameter is combined to describe the size and extension of an ICR lesion in three dimensions.

All the studies included in this review followed Heithersay's classification, and none discussed the three-dimensional classification. Categorizing ICR lesions more precisely using CBCT can help with a more accurate diagnosis of this rare condition and assist clinicians in their treatment planning to provide the best possible care for patients.

Based on the information found in research literature, there are two primary methods for managing ICR: an external approach and an internal approach [73,74]. Both techniques focus on the removal of clastic cells to arrest the resorptive process, as well as proper restoration to maintain the tooth's structural integrity. The external approach encompasses both surgical and non-surgical treatments. In cases where the lesion is situated and extends significantly below the gingival margin, surgical treatment, such as flap surgery, might be required when accessed externally. Conversely, external non-surgical treatment can be carried out if the lesion is positioned at the gingival margin or does not extend beneath the alveolar bone crest.

The majority of selected case studies and series treated the ICR lesions through both the surgical approach and root canal therapy. The internal approach involves non-surgical access to the lesions via the endodontic access cavity, irrespective of the lesion locations [74]. This was the second most used treatment option across the studies. Orthodontic extrusion serves as an alternative for

accessing lesions without resorting to surgical interventions. Additionally, intentional replantation has been recently suggested for managing lesions that are challenging to access [75].

TCA is recognized for causing coagulation necrosis in the lesions, which aids in the elimination of resorptive tissue, and has been utilized in the treatment of ICR [26]. Nonetheless, it is highly caustic and triggers inflammation in the adjacent periodontal tissue. By the way, there are some studies that contradict the effect of TCA on removal of the resorptive tissue. Moreover, it can significantly strip hydroxyapatites from the dentin surface, which can adversely affect the bonding strength of glass ionomer (GI) [76,77]. Only 7 of the selected studies reported using TCA whereas 24 did not include TCA as a part of their ICR management. In the future, designing clinical randomized trials would be helpful in determining whether the usage of TCA could facilitate the management of ICR.

The most common restorative materials used in the studies included glass ionomer (GI), composite, mineral trioxide aggregate (MTA), or a combination of two or all three of these materials. Many studies did not specify the final restorative material utilized. Due to its beneficial properties such as biocompatibility, hydrophilicity, fluoride release, and chemical adhesion to dentin, GI or resin-modified glass ionomer (RMGI) has been the preferred material for restoring ICR lesions. However, while subgingival placement of GI or RMGI allows for gingival attachment, it does not promote the regeneration of cementum or bone around the materials [78].

Although hydraulic calcium silicate-based materials like Biodentine have been recently adopted to restore resorptive cavities, only two studies reported using it [79]. The main advantage of these materials over GI or RMGI is their ability to regenerate cementum, periodontal ligament, and bone. Biodentine may be a preferred choice for future treatments due to its better results; however, further research is needed to evaluate the superiority of this material. It should be noted that Biodentine may not be a suitable choice in esthetic zones.

The success rate of treated teeth in the selected studies of this review was relatively high, yet the failure rate was not insignificant, highlighting the complex challenges associated with treating ICR. The limited availability of clinical outcome studies has resulted in a dearth of prognostic

information for ICR. Most of the existing research comprises case reports or case series, which may not accurately predict the prognosis of treated teeth due to the reporting bias towards successful cases. Moreover, the rarity of the disease poses a challenge to conducting clinical studies.

Patient and resorption characteristics

The incidence of resorption reported in the included studies was a somewhat higher in females than males (24:20). Interestingly all the failed cases in the included studies were female patients. The average age at success was 38 years old. Average age at failure case was 21 years old. Due the nature of case-study based data in this review, further research would be needed to explore possible gender and age correlation. Orthodontic treatment with or without history of trauma were reported as most common correlated factors. This finding is in agreement with the Heithersay study [74]. The current study reports included demonstrated a success rate, in cases with history of orthodontic treatment of 50% and associated trauma of 60%. This rate was much lower than in cases without the above-mentioned correlations of orthodontics treatment and/or trauma at about 81%. The included studies collectively reported one class I, nine class II, eleven class III and fifteen Class IV resorptions cases. Success rate of resorption reported based on resorption classification was Class I 100%(1/1), Class II 66.67% (6/9), Class III 66.66 (6/11), Class IV 66.6% (10/15). Although dissimilar than the reported success rates from the Heithersay (61) study, the difference in cumulative rates in the current review may be related to selection, follow up length and sample size bias.

CBCT

Cumulatively from the included studies, 33 cases used CBCT as the diagnostic tool of which 28 were successful yielding an 85% success rate. In the rest of the 36 cases CBCT was not used preoperatively. Sixteen cases had no follow up data, 2 were reported as survived and 8 were unsuccessful. The remaining ten cases were reported as successful which concludes a 27% success rate. The higher success rate with the use of CBCT may be attributed to enhanced diagnostic and treatment planning ability of the clinician.

Method of treatment

The included studies reported the most common treatment options as Non-surgical treatment, surgical treatment and a combination of the two. The cumulative case outcomes seem to be highest for the combination approach with reported 18 successful cases indicating a 69% success rate. The

cumulative cases from the reports with surgical approach as well as the non-surgical repair seem to indicate somewhat lower success (67% and 62% respectively). Although treatment planning may dictate the approach for a resorption case, the combination of surgical and non-surgical repair would certainly constitute a comprehensive treatment of resorptive lesion via internal and external approach.

Bleeding Control TCA

TCA was used in 8 cases to control bleeding and remove tissue tags in resorptive areas on the tooth. Its use is reported to reduce the chance of recurrence and/or continued resorptive process. Three of the reported cases were successful indicating a 37.5% success rate. Majority of the reports did not use TCA totaling 61 cases. Although 16 did not report the outcome, of the 45 cases with follow up, 33 reported successful outcome and 12 cases reported failure. Based on these case reports further investigation is warranted for the rationale of TCA use in resorptive lesion repair.

Repair Material:

The included studies reported the most common repair materials as GI, composite and MTA. Composite was used in 19 cases with 6 reported as success (31%). GI was used in 20 cases with 13 reported as success (65%). MTA use seemed to demonstrate the similar success to GI of 55%. A number of studies reported the biocompatibility of these materials which may lend to a higher success rate compared to composite [80–82].

Study limitations and future direction

Several limitations of the systematic review in this thesis can be identified. Firstly, the included studies were mostly case reports and case series, providing a lower level of evidence and making it difficult to draw strong conclusions. Heterogeneity among the methodologies, diagnostic criteria, and treatment approaches of the included studies makes it challenging to compare and synthesize findings. Some reports had no follow up and some had multiple teeth but did not report treating all teeth with resorption.

Additionally, the rarity of the disease results in limited sample sizes, impacting the reliability of the findings. A lack of long-term follow-up data in many studies limits the ability to assess treatment durability and prognosis. Language bias may also exist, as only studies published in English were included, potentially excluding relevant non-English studies. Finally, the search strategy may not have captured all relevant studies, particularly unpublished studies or those indexed in databases not covered by the search.

To gain a better understanding of treatment outcomes and establish effective treatment plans, comprehensive clinical research with long-term follow-ups is necessary. This type of research requires national collaboration among universities and the American Association of Endodontists (AAE) to develop proper criteria for treatment, material selection, and prognosis.

Some case report mentioned use of repair materials but did not report the result of treatment. Some studies mentioned use of repair material but did not specify if it was used in all teeth with resorption.

CONCLUSION

This literature review used a specific search strategy to analyze the associated factors involved in the etiology of ICR as well as the most important considerations regarding its diagnosis, treatment, and prognosis. A JBI appraisal tool was utilized to assess included studies' methodological quality and determine the extent to which it has addressed the possibility of bias in its design, conduct, and analysis was done. It was difficult to report a definite conclusion from the selected articles in the present review because they are all case reports and case series with low level of evidence. No randomized clinical trials are available; therefore, it is challenging to infer a robust association between the pre-disposing factors and ICR. With those limitations, the following findings were observed:

1. It is difficult to report a definite conclusion from the selected articles in the present review because they are all case reports and case series with low level of evidence. No randomized clinical trials are available; therefore, it is challenging to infer a robust association between the pre-disposing factors and ICR.
2. Maxillary central incisors are the most frequently affected teeth in the dentition.
3. The use of CBCT could be of immense help in the accurate diagnosis of ICR lesions. Reliance on 2-D x-rays does not always lead the clinicians toward the right path. In addition, CBCT is also helpful in classifying the ICR lesions to better plan the course of treatment for each case.
4. There is not enough evidence in the literature supporting the usage of TCA as a diagnostic material for ICR lesions.

5. GI and RMGI showed the most success as restorative materials in the treatment of ICR lesions.
6. The studies show the treatment failure rate is higher in young female patients.
7. CBCT shows Higher correlation with success rate.

List of Abbreviated Journal Titles

Abbreviation	Full Form
Acta medica	Acta Medica journal
Am J Orthod Dentofac Orthop	American Journal of Orthodontics and Dentofacial Orthopedics
Aust Endod J	Australian Endodontic Journal
ASDC J Dent Child	ASDC journal of dentistry for children
BMJ Case Rep	BMJ Case Reports
Clin Ter	Clinical Therapeutics
Dent Traumatol	Dental Traumatology
Gen Dent	Journal of General Dentistry
In Dental Materials Dent Mater	International Journal of Dental Materials
Int Endod J	International Endodontic Journal
Int J Dent Oral Sci	International Journal of Oral Science
Int J Orthod Oral Surg Radiogr	The International journal of orthodontia, oral surgery, and Radiology
ISRN Dent	ISRN Dentistry
JBI	Joanna Briggs Institute
J Clin Exp Dent	Journal of Clinical and Experimental Dentistry
J Conserv Dent	Journal of Conservative Dentistry
J Contemp Dent Pract	The Journal of Contemporary Dental Practice
J Dent Res	Journal of Dental Research
JOE	Journal of Endodontics
J Periodontol	Journal of Periodontology
Odontology	The Journal Odontology
Oper Dent	Operative Dentistry
Oral Med Oral Pathol Oral Radiol Endodontology	Oral Surgery, Oral Medicine, Oral Pathology, Oral Radiology, and Endodontology
Oral Med Oral Pathol Oral Radiol Endodontology	Oral Surgery, Oral Medicine, Oral Pathology, Oral Radiology, and Endodontology
Quintessence Int	Quintessence International
Rom J Morphol Embryol	Romanian Journal of Morphology and Embryology

REFERENCES

1. Ramanathan C, Hofman Z. Root resorption in relation to orthodontic tooth movement. Vol. 49, Acta medica (Hradec Králové) / Universitas Carolina, Facultas Medica Hradec Králové. 2006; 91–95.

2. Ketcham AH. A preliminary report of an investigation of apical root resorption of permanent teeth. *Int J Orthod Oral Surg Radiogr*. 1927;13(2):97–127.

3. Ketcham AH. A preliminary report of an investigation of apical root resorption of permanent teeth. *Int J Orthod Oral Surg Radiogr*. February 1927;13(2):97–127.

4. Mittal S, Kumar T, Mittal S, Sharma J. "Internal root resorption: An endodontic challenge": A case series. *J Conserv Dent*. November 2014;17(6):590–593.

5. Patel S, Ricucci D, Durak C, Tay F. Internal root resorption: A review. Vol. 36, Journal of Endodontics. 2010; 1107–1121.

6. Patel S, Kanagasingam S, Pitt Ford T. External Cervical Resorption: A Review. Vol. 35, Journal of Endodontics. J Endod 2009; 616–625.

7. Heithersay GS. Clinical, radiologic, and histopathologic features of invasive cervical resorption. *Quintessence Int*. 1999;30(1):27–37.

8. Andreasen JO, Bakland LK, Andreasen FM. Traumatic intrusion of permanent teeth. Part 2. A clinical study of the effect of preinjury and injury factors, such as sex, age, stage of root development, tooth location, and extent of injury including number of intruded teeth on 140 intruded permanent . *Dent Traumatol*. 2006;22(2):90–98.

9. Krastl G, Weiger R, Filippi A, Van Waes H, Ebeleseder K, Ree M, et al. Endodontic management of traumatized permanent teeth: a comprehensive review. *Int Endod J*. August 1, 2021;54(8):1221–1245.

10. Galler KM, Grätz EM, Widbiller M, Buchalla W, Knüttel H. Pathophysiological mechanisms of root resorption after dental trauma: a systematic scoping review. *BMC Oral Heal 2021 211*. March 26, 2021;21(1):1–14.

11. Patel S, Saberi N. External Cervical Resorption Associated with the Use of Bisphosphonates: A Case Series. *J Endod*. 2015;41(5):742–748.

12. von Arx T, Schawalder P, Ackermann M, Bosshardt DD. Human and Feline Invasive Cervical Resorptions: The Missing Link?-Presentation of Four Cases. *J Endod*. 2009;35(6):904–913.

13. Qin W, Gao J, Ma S, Wang Y, Li D mei, Jiang W kai, et al. Multiple Cervical Root Resorption Involving 22 Teeth: A Case with Potential Genetic Predisposition. *J Endod*. December 2022;48(12):1526–1532.

14. Frank AL, Torabinejad M. Diagnosis and treatment of extracanal invasive resorption. *J Endod*. 1998;24(7):500–504.

15. Patel S, Foschi F, Mannocci F, Patel K. External cervical resorption: a three-dimensional classification. Vol. 51, International Endodontic Journal. John Wiley & Sons, Ltd 2018; 206–214.

16. Kamburoğlu K, Kurşun Ş, Yüksel S, Öztaş B. Observer ability to detect ex vivo simulated internal or external cervical root resorption. *J Endod*. February 2011;37(2):168–175.

17. Gunst V, Mavridou A, Huybrechts B, Van Gorp G, Bergmans L, Lambrechts P. External cervical resorption: An analysis using cone beam and microfocus computed tomography and scanning electron microscopy. *Int Endod J*. September 2013;46(9):877–887.

18. Schwartz RS, Robbins JW, Rindler E. Management of invasive cervical resorption: Observations from three private practices and a report of three cases. *J Endod*. October 2010;36(10):1721–1730.

19. Patel S, Dawood A, Wilson R, Horner K, Mannocci F. The detection and management of root resorption lesions using intraoral radiography and cone beam computed tomography - an in vivo investigation. *Int Endod J*. September 2009;42(9):831–838.

20. Brady E, Mannocci F, Brown J, Wilson R, Patel S. A comparison of cone beam computed tomography and periapical radiography for the detection of vertical root fractures in nonendodontically treated teeth. *Int Endod J*. 2014;47(8):735–746.

21. Hashem D, Mannocci F, Patel S, Manoharan A, Brown JE, Watson TF, et al. Clinical and radiographic assessment of the efficacy of calcium silicate indirect pulp capping: A randomized controlled clinical trial. *J Dent Res*. February 2015;94(4):562–568.

22. Rodríguez G, Abella F, Durán-Sindreu F, Patel S, Roig M. Influence of Cone-beam Computed Tomography in Clinical Decision Making among Specialists. *J Endod*. February 2017;43(2):194–199.

23. Patel S, Durack C, Abella F, Roig M, Shemesh H, Lambrechts P, et al. European Society of Endodontology position statement: The use of CBCT in Endodontics. *Int Endod J*. 2014;47(6):502–504.

24. Vaz de Souza D, Schirru E, Mannocci F, Foschi F, Patel S. External Cervical Resorption: A Comparison of the Diagnostic Efficacy Using 2 Different Cone-beam Computed Tomographic Units and Periapical Radiographs. *J Endod*. January 2017;43(1):121–125.

25. Kamburoğlu K, Kurşun Ş, Yüksel S, Öztaş B. Observer ability to detect ex vivo simulated internal or external cervical root resorption. *J Endod*. February 2011;37(2):168–175.

26. Heithersay GS. Treatment of invasive cervical resorption: an analysis of results using topical application of trichloracetic acid, curettage, and restoration. *Quintessence Int.* 1999;30(2):96–110.

27. Mavridou AM, Hauben E, Wevers M, Schepers E, Bergmans L, Lambrechts P. Understanding External Cervical Resorption in Vital Teeth. *J Endod*. 2016;42(12):1737–1751.

28. Neely AL, Gordon SC. A Familial Pattern of Multiple Idiopathic Cervical Root Resorption in a Father and Son: A 22-Year Follow-Up. *J Periodontol*. February 2007;78(2):367–371.

29. Kim J, Amar S. Periodontal disease and systemic conditions: a bidirectional relationship. *Odontology*. September 2006;94(1):10.

30. Thomas P, Pillai RK, Ramakrishnan BP, Palani J. An Insight into Internal Resorption. *ISRN Dent*. May 12, 2014;2014:1–7.

31. Taylor KR, Kiyak A, Huang GJ, Greenlee GM, Jolley CJ, King GJ. Effects of malocclusion and its treatment on the quality of life of adolescents. *Am J Orthod Dentofac Orthop*. September 1, 2009;136(3):382–392.

32. Christodoulides N, Nikolidakis D, Chondros P, Becker J, Schwarz F, Rössler R, et al. Photodynamic Therapy as an Adjunct to Non-Surgical Periodontal Treatment: A Randomized, Controlled Clinical Trial. *J Periodontol*. September 2008;79(9):1638–1644.

33. Gonzales JR, Rodekirchen H. Endodontic and periodontal treatment of an external cervical resorption. *Oral Surgery, Oral Med Oral Pathol Oral Radiol Endodontology*. July 2007;104(1).

34. Krug R, Soliman S, Krastl G. Intentional Replantation with an Atraumatic Extraction System in Teeth with Extensive Cervical Resorption. *J Endod*. November 1, 2019;45(11):1390–1396.

35. Shemesh A, Ben Itzhak J, Solomonov M. Minimally Invasive Treatment of Class 4 Invasive Cervical Resorption with Internal Approach: A Case Series. *J Endod*. November 1, 2017;43(11):1901–1908.

36. Vinothkumar TS, Tamilselvi R, Kandaswamy D. Reverse sandwich restoration for the management of invasive cervical resorption: A case report. *J Endod*. May 1, 2011;37(5):706–710.

37. Baratto-Filho F, Limongi O, Araújo C de JK, Neto MDS, Maia SMAS, Albuquerque DS. Treatment of invasive cervical resorption with MTA: Case report. *Aust Endod J*. 2005;31(2):76–80.

38. Mashyakhy M, Chourasia HR, Halboub E, Roges RA, Gambarini G. Nonsurgical management and 2-year follow-up by means of cone beam computed tomography of an invasive cervical resorption in a molar. *J Contemp Dent Pract*. September 1, 2018;19(9):1152–1156.

39. Discacciati JAC, de Souza EL, Costa SC, Sander HH, de Magalhães Barros V, Vasconcellos WA. Invasive cervical resorption: Etiology, diagnosis, classification and treatment. *J Contemp Dent Pract.* 2012;13(5):723–728.

40. Fernandes M, Menezes L, De Ataide I. Management of invasive cervical resorption using a surgical approach followed by an internal approach after 2 months due to pulpal involvement. *J Conserv Dent.* May 1, 2017;20(3):214–218.

41. Gunst V, Mavridou A, Huybrechts B, Van Gorp G, Bergmans L, Lambrechts P. External cervical resorption: An analysis using cone beam and microfocus computed tomography and scanning electron microscopy. *Int Endod J*. September 1, 2013;46(9):877–887.

42. Patel S, Dawood A. The use of cone beam computed tomography in the management of external cervical resorption lesions. *Int Endod J*. September 2007;40(9):730–737.

43. Nedir R, Lombardi T, Samson J. Recurrent Peripheral Giant Cell Granuloma Associated With Cervical Resorption. *J Periodontol*. April 1, 1997;68(4):381–384.

44. Kqiku L, Ebeleseder KA, Glockner K. Treatment of invasive cervical resorption with sandwich technique using mineral trioxide aggregate: A case report. *Oper Dent.* January 2012;37(1):98–106.

45. Dias C, Closs L, Barletta F, Reston E, Tovo MF, Lambert P. Root Resorption a 6-Year Follow-up Case Report. *Open Dent J*. April 8, 2015;9(1):103–105.

46. Bal MV, Yildirim S, Saygun I. A Case report of gingival enlargement associated with invasive cervical resorption. *Oper Dent.* 2015;40(2):117–122.

47. Gulsahi A, Gulsahi K, Ungor M. Invasive cervical resorption: clinical and radiological diagnosis and treatment of 3 cases. *Oral Surgery, Oral Med Oral Pathol Oral Radiol Endodontology*. March 2007;103(3).

48. Bharti R, Chandra A, Tikku AP, Prasad V, Shakya VK, Singhal R. Management of mucosal fenestration with external root resorption by multidisciplinary approach. *BMJ Case Rep*. October 9, 2014;2014:bcr2014206259.

49. Ali R, Fayle S, Langley D, Altaie A, Nattress B. Dental management of a patient with multiple idiopathic cervical root resorption. *Dent Update*. July 6, 2015;42(7):667–672.

50. Smidt A, Nuni E, Keinan D. Invasive Cervical Root Resorption: Treatment Rationale with an Interdisciplinary Approach. *J Endod*. November 2007;33(11):1383–1387.

51. Iwamatsu-Kobayashi Y, Satoh-Kuriwada S, Yamamoto T, Hirata M, Toyoda J, Endo H, et al. A case of multiple idiopathic external root resorption: A 6-year follow-up study. *Oral Surgery, Oral Med Oral Pathol Oral Radiol Endodontology*. December 1, 2005;100(6):772–779.

52. Llavayol M, Pons M, Ballester ML, Berástegui E. Multiple Cervical Root Resorption in a Young Adult Female Previously Treated with Chemotherapy: A Case Report. *J Endod*. March 1, 2019;45(3):349–353.

53. Sharma S, Kumar P, Jain V, Logani A. Multiple idiopathic cervical root resorption: Diagnosis, clinical/radiographical/histological presentation, and rehabilitation – A 7-year follow-up case report. *J Conserv Dent.* 2019;22(3):313.

54. Matarazzo G, Annelyse GB, Cassabgi G, Gentile T, Galeotti A. A case of Invasive Cervical Root Resorption in a 12 y.o. female patient. *Clin Ter*. May 10, 2020;171(3):E183–E184.

55. Tavares WLF, Lopes RCP, Oliveira RR, De Souza RG, Henriques LCF, Sobrinho APR. Surgical management of invasive cervical resorption using resin-modified glass ionomer cement. *Gen Dent.* 2013;61(7):e16–e18.

56. Karypidou A, Chatzinikolaou I-D, Kouros P, Koulaouzidou E, Economides N. Management of bilateral invasive cervical resorption lesions in maxillary incisors using a novel calcium silicate-based cement: A case report. *Quintessence Int (Berl).* 2016;47(8).

57. Asgary S, Fazlyab M. Surgical repair of invasive cervical root resorption with calcium-enriched mixture cement: A case report. *Gen Dent.* 2015;63(1):37–40.

58. Yoshpe M, Kaufman AY, Lin S, Gabay E, Einy S. Invasive cervical resorption following orthodontic treatment: Two cases involving the same patient. *Quintessence Int (Berl)*. 2016;47(10).

59. Perlea P, Imre M, Nistor CC, Iliescu MG, Gheorghiu IM, Abramovitz I, et al. Occurrence of invasive cervical resorption after the completion of orthodontic treatment. *Rom J Morphol Embryol*. 2017;58(4):1561–1567.

60. Ehlinger C, Ginies E, Bornert F, Bahi-Gross S, Schmittbuhl M, Minoux M. Decision criteria influencing the therapeutic approach to invasive cervical resorption: a case series. *Quintessence Int.* 2019;50(6):494–502.

61. Heithersay GS. External root resorption. Vol. 12, Annals of the Royal Australasian College of Dental Surgeons. Ann R Australas Coll Dent Surg 1994; 46–59.

62. Patel S, Durack C, Abella F, Shemesh H, Roig M, Lemberg K. Cone beam computed tomography in Endodontics - a review. Vol. 48, International Endodontic Journal. Int

Endod J 2015; 3–15.

63. Bornstein MM, Lauber R, Sendi P, Von Arx T. Comparison of periapical radiography and limited cone-beam computed tomography in mandibular molars for analysis of anatomical landmarks before apical surgery. *J Endod*. February 2011;37(2):151–157.

64. D'Addazio PSS, Campos CN, Özcan M, Teixeira HGC, Passoni RM, Carvalho ACP. A comparative study between cone-beam computed tomography and periapical radiographs in the diagnosis of simulated endodontic complications. *Int Endod J*. March 2011;44(3):218–224.

65. Estrela C, Bueno MR, Leles CR, Azevedo B, Azevedo JR. Accuracy of Cone Beam Computed Tomography and Panoramic and Periapical Radiography for Detection of Apical Periodontitis. *J Endod*. March 2008;34(3):273–279.

66. Lauridsen E, Hermann NV, Gerds TA, Kreiborg S, Andreasen JO. Pattern of traumatic dental injuries in the permanent dentition among children, adolescents, and adults. *Dent Traumatol*. October 2012;28(5):358–363.

67. Bijella MF, Yared FN, Bijella VT, Lopes ES. Occurrence of primary incisor traumatism in Brazilian children: a house-by-house survey. *ASDC J Dent Child*. 1990;57(6):424–427.

68. Abbott P, Heah SYS. Internal bleaching of teeth: An analysis of 255 teeth. *Aust Dent J*. 2009;54(4):326–333.

69. Choudhari S, Sharma S, Ramamurthy J. Association of age and gender in patients undergoing non vital bleaching in endodontically treated teeth. *Int J Dent Oral Sci*. 2020;2(Special Issue 10):120–124.

70. Patel S, Dawood A, Pitt Ford T, Whaites E. The potential applications of cone beam computed tomography in the management of endodontic problems. *Int Endod J*. October 2007;40(10):818–830.

71. Fayad MI, Nair M, Levin MD, Benavides E, Rubinstein RA, Barghan S, et al. AAE and AAOMR Joint Position Statement Use of Cone Beam Computed Tomography in Endodontics 2015 Update. Vol. 120, Oral Surgery, Oral Medicine, Oral Pathology and Oral Radiology. Oral Surg Oral Med Oral Pathol Oral Radiol 2015; 508–512.

72. Heithersay GS. Clinical, radiologic, and histopathologic features of invasive cervical resorption. *Quintessence Int*. January 1999;30(1):27–37.

73. Trope M. Treatment of the Immature Tooth with a Non-Vital Pulp and Apical Periodontitis. Vol. 54, Dental Clinics of North America. Dent Clin North Am 2010; 313–324.

74. Heithersay GS. Management of tooth resorption. *Aust Dent J*. 2007;52(1 SUPPL.).

75. Poi WR, Sonoda CK, Martins CM, Melo ME, Pellizzer EP, de Mendonça MR, et al. Storage media for avulsed teeth: A literature review. Vol. 24, Brazilian Dental Journal. Braz Dent J 2013; 437–445.

76. Kimyai S, Pournaghi-Azar F, Mohammadi N, Babri M. Effect of hemostatic agent on marginal gaps of class V giomer restorations. *J Clin Exp Dent*. 2017;9(5):e672–e676.

77. Fathpour K, Khoroushi M. Effect of trichloroacetic acid hydrogel on self-etch adhesive bond strength to dental tissues. *J Contemp Dent Pract*. 2013;14(3):375–380.

78. Sidhu S, Nicholson J. A Review of Glass-Ionomer Cements for Clinical Dentistry. *J Funct Biomater*. June 28, 2016;7(3):16.

79. Grech L, Mallia B, Camilleri J. Investigation of the physical properties of tricalcium silicate cement-based root-end filling materials. In Dental Materials Dent Mater 2013.

80. Mitchell PJC, Pitt Ford TR, Torabinejad M, McDonald F. Osteoblast biocompatibility of mineral trioxide aggregate. *Biomaterials*. January 1999;20(2):167–173.

81. Salehi I, Mousavi S, Aminozarbian M-G, Barati M. Biocompatibility of mineral trioxide aggregate and three new endodontic cements: An animal study. *Dent Res J (Isfahan)*. 2012;9(1):54.

82. Al-Sabek F, Shostad S, Kirkwood KL. Preferential attachment of human gingival fibroblasts to the resin ionomer geristore. *J Endod*. March 1, 2005;31(3):205–208.

CURRICULUM VITAE

EDUCATION

Boston University Henry M. Goldman School of Dental Medicine (GSDM), Boston, MA
06/2020- 06/2023

- Master of Dental Science in endodontics

Boston University Henry M. Goldman School of Dental Medicine (GSDM), Boston, MA
06/2015- 09/2017

- Doctor of Dental Medicine

Centro Escolar University School of Dental Medicine (CEU), Manilla, Philippines
03/2006 - 03/2011

- Doctor of Dental Medicine

Azad University, School of Engineering Saveh, Markazi, Iran
03/1998 - 06/2002

- Bachelor of Electrical Engineering

PROFESSIONAL EXPERIENCE

Resident: GSDM Endodontic Clinic, Boston, MA

- Serve five days a week as endodontic resident. Performing complicated endodontic retreatment, treatment, vital pulp therapy, pulp regeneration, Apexogenesis, Apexification, trauma cases, handling medically compromised patient and performing microsurgery on anterior/posterior root canal treated teeth on outside and inhouse referral cases

Dental Associate: Carr and Associate Dental Office, Boston, MA
10/15/2017- Current

- Serve four days per week in pedodontics, orthodontics, and general dentistry-focused practice. Performed root canal
  treatment, prosthodontic treatment, implant restoration, conventional and digital crowns and bridges.

Dental Associate: Braces Place Dental Office, Framingham, MA
05/12/2017- current

- Serve two days per week in multi-specialty practice as a general dentist. Perform prosthodontic treatment, restorative treatment and minor surgical treatment for adolescents and young patients.

Dental Observer: **GSDM Clinic, Boston, MA**
05/2014 – 07/2014

- Observed several root canal treatments using microscope and two apicoectomy surgeries in endodontic department; learned about increasing vertical dimension and occlusion design through treatment plan classes; observed implant restoration, full anterior ceramic veneers, and inter-coronal endodontic crown designed and milled in the same day.

Dental Observer: **Endodontics Department, Harvard School of Dental Medicine, Boston, MA** 02/2014

- Attended different lectures at endodontic department and become familiar with ongoing research projects, such as effect of specific brand of antibiotic on anaerobic bacteria.

RESEARCH & TEACHING EXPERIENCE

Student Researcher: Department of General Dentistry; GSDM Boston, MA
05/2015- 07/2018

- Worked with Dr. Judith Jones in periodontal research on "Top eight salivary biomarker of periodontal disease."

Student Researcher: Orthodontics & Dentofacial Orthopedic Department; GSDM Boston, MA 09/2015- 09/2017

- Worked with Dr. Melih Motro in orthodontic research on "Effect of rapid maxillary expansion (RME) on upper airway systematic review and meta-analysis."

Teaching Assistant: Endodontic Department, GSDM Boston, MA
01/2017-06/2017

- Helped faculty to teach students to have better understanding about root canal treatment (canal preparation and procedural steps). Taught students to use hand instruments and rotary instruments; explained rationale of using them and having three dimensional visualization about root canal system of different teeth.

Intensive Research Elective Course (IREC) Participant: GSDM, Boston, MA
06/2015 - 09/2016

- Only advanced standing student in history of GSDM to have successfully completed an elective 100 hours of research work (under supervision of Dr. Judith Jones).

Scholar Researcher: Forsyth Institute, Cambridge, MA
03/2014- 08/2016

- Worked with Dr. Bikul Das at Department of Immunology and Infection Diseases; learned immunohistochemistry, RNA & DNA extraction, cell culture, flow cytometry and Micro CT. Collaborated with endodontic residents of Harvard University through their research projects at animal facility of Forsyth Institute.

PUBLICATIONS

Zinzuvadia, K., **Zohrehei, H**., Dabeshlim, K., Kanasi, E., Grover, S. and Jones, J.A., **2018**. Salivary Biomarkers in Periodontal Diseases-a Systematic Review. *International Journal of Medical Dentistry*, *22*(3).

Gayan, S., Li, H., Bhuyan, R., Sandhya, S., Talukdar, J., Pal, B., Garhyan, J., Tasabehji, W., Alkurdi, M.M., **Zohrehei, H**. and Bhuyan, S., **2016**. The potential role of oral mucosa stem cell altruistic behavior as the initiating event of malignant transformation.

Homayouni, H., Majd, N. M., **Zohrehei, H**., Mosavari, B., Adel, M., Dajmar, R., & Homayouni, A. **(2014)**. The effect of root canal irrigation with combination of sodium hypo-chlorite and chlorhexidine gluconate on the sealing ability of obturation materials. The open dentistry journal, 8(1).

Moradi Majd, N., **Zohrehei, H**., Darvish, A., Homayouni, H., & Adel, M. **(2014)**. Continued root formation after delayed replantation of an avulsed immature permanent tooth. Case reports in dentistry, 2014.

PROFESSIONAL MEETING & PRESENTATION

Poster Presenter: Science Day 2017 GSDM, Boston, MA
02/2017

- Presented on **"**Effect of Rapid Palatal Expansion on upper airway systematic review and meta-analysis."

Poster Presenter: Yankee Dental Congress, Boston, MA
01/2017

- Selected as only GSDM student to present in addition to seven students from other schools. Presented on "Effect of Rapid Maxillary Expansion (RME) on upper airways, systematic review."

Poster Presenter: Norte American Salivary Biomarker Symposium, New York University, NY 12/2016

Poster Presenter: Science Day 2016 GSDM, Boston, MA
03/2016

- Presented on "Top eight salivary biomarker of periodontal disease the systematic review."

Poster Presenter: Head & Neck Cancer Symposium 2015 GSDM, Boston, MA
09/2015

- Presented on "The Oral Cancer Carcinogen 4-Nitroquinoline-1-Oxide Enhances Stemness of Mouse Oral Mucosa Stem Cells by Altering p53 Activity."

HONORS & AWARDS

International Congress of Oral Implantologists (ICOI) Pre-Doctoral Student Achievement Award Recipient 05/2017

GSDM Science Day 2017 Research Award Recipient
04/2017

CONTINUING EDUCATION & CONFERENCES

Management Expert, The Keys to Patient Management & Profitability: Boston, MA
04/2019

- Attended course for patient management and best method to address patients with different background and cultures.

American Association of Dental Sleep Medicine, 26th Annual Meeting: Boston, MA
05/2017

- Learned about the management of obstructive sleep apnea in both adults and children through recent field advances.

Elective Periodontology Session, GSDM, Boston, MA
01/2017-03/2017

- Chosen among thirteen other dental students to attend weekly sessions to discuss most controversial topics in periodontology; reviewed by and collaborated with a panel which consisted of four periodontologists.

PROFESSIONAL MEMBERSHIPS

American Association of Endodontists (AAE)
06/2019- Current
American Dental Association (ADA)
06/2017- Current
American Association for the Advancement of Science (AAAS)
06/2016- Current
American Association for Dental Research (AADR)
06/2016- 06/2018
American Academy of Dental Sleep Medicine (AADSM)
06/2017- 07/2018 International Congress of Oral Implantologist (ICOI)
06/2018- 06/2019

TECHNOLOGY & LANGUAGES

Technology: Salud, Dolphin, CEREC
Languages: Farsi (PROFICIENCY LEVEL), English (PROFICIENCY LEVEL)