2020

Current Trends in the Management of Invasive Cervical Resorption

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A thesis submitted in partial fulfillment of the requirements for the degree of Master of Science in Dentistry at Virginia Commonwealth University.

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May 2020

Acknowledgements

I would like to thank my wife for her tireless support of my pursuit of dentistry and endodontics specialty training. I would also like to thank my three children, Avery, Konner, and Kellan for understanding when I have had to miss school concerts, baseball games, and dance recitals on occasion. In the department of Endodontics at VCU, Dr. Garry Myers, Dr. Clara Spatafore, and Dr. Sameer Jain have been instrumental in advancing my graduate education. A special thanks to Dr. Myers for his assistance in developing and advancing this graduate research project. Additionally, Dr. Caroline Carrico has played an integral part in the compilation and analysis of the study results. This truly was a team effort and I feel fortunate to be surrounded by a competent, dedicated, and highly educated team at VCU.

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Abstract

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Purpose: To determine how endodontic practitioners are currently managing cases of invasive cervical resorption. Also, to analyze how invasive cervical resorption (ICR) has been managed at Virginia Commonwealth University (VCU) over the past ten years.

Methods: Both domestic and international endodontists were invited to participate in a 14-question survey developed and administered via REDCap. Survey invitations were sent via email to currently practicing endodontists. Electronic dental records were queried for patients diagnosed with ICR at VCU in the preceding ten years. Results of both were summarized using descriptive statistics (counts and percentages). Fisher's exact test was used to compare survey responses between domestic and international respondents.

Results: 154 endodontists responded to the survey and 80 cases of ICR were identified in the VCU axiUm chart review. The majority of endodontists reported preferring to treat ICR lesions

immediately upon diagnosis. However, there was a significant amount of responses and cases analyzed where monitoring without intervention was the treatment plan of choice. With increased lesion severity, endodontists were more likely to recommend monitoring lesions with frequent recall.

Conclusion: There appears to be no clear consensus on how ICR cases should be managed. There seems to be precedent for managing cases in several different ways. Each case must be evaluated on an individual basis.

Introduction

From birth to the end of life, the skeletal structure is in a constant state of turn-over. The process of bone breakdown and formation continues throughout life, although at a different pace as time passes and circumstances change. This is commonly referred to as bone remodeling and is a necessary physiologic process whereby the body grows, adapts, and heals. The process is mediated by cells which contribute to formation or breakdown of bone and are tightly regulated to maintain a balance between the two processes. Osteoclast cells are responsible for the breakdown of existing bone, referred to as resorption. This is accomplished by attaching to the bone surface and dissolving both mineral and organic matrix with acids and enzymes, such as collagenase. Osteoblast cells are responsible for formation of new bone and are triggered by the activity of osteoclasts. Early in life, formation of new bone exceeds destruction and the result is steady growth in length, width, and density of bone. This process continues until reaching a peak around the age of 30. For some time thereafter, the two competing processes are balanced to maintain skeletal structure until later in life when resorption begins to exceed formation and bone mass decreases.(1)

The dentition is unique as a mineralized hard-tissue structure in the body. The normal process of bone remodeling takes place in the bony socket surrounding the teeth, but the tissues of the teeth themselves are not continuously replaced. The roots are covered by a hard-tissue substance

called cementum, which has a thin outer layer of unmineralized matrix called pre-cementum. This unmineralized layer is thought to provide a protective barrier against osteoclasts, which can resorb mineralized cementum and dentin underneath. During exfoliation of the primary dentition, clastic cells are recruited to resorb radicular tooth structure in response to eruption of the permanent dentition underneath. In this case there is no replacement with new mineralized tissue and the remaining coronal portion of the tooth is shed. This physiologic mechanism is necessary to create space for the new permanent dentition, which would be unable to take place in the absence of primary tooth root resorption. Once the permanent dentition is in place, further resorption is inhibited, and tooth structure remains intact as surrounding bone is remodeled. However, in some cases clastic cells may attack the roots of permanent teeth causing an unwanted disease process, root resorption, that can result in loss of tooth structure. This can either be mediated by cells of the pulp inside teeth or by cells of the periodontium outside the teeth. The difference in origin leads to a separate classification identified as either internal or external root resorption. The ability to properly diagnose the origin of resorptive lesions is of paramount importance, as treatment and prognosis of the two entities varies.(2)

MECHANISM

External root resorption can be classified according to its mechanism of action and evolution. The main categories are surface, inflammatory, replacement (ankylosing), and cervical root resorption. Surface resorption is a very common, self-limiting, and reversible form of resorption involving only cementum. It is a result of acute injury and healing takes place with new cementum and periodontal ligament if the injury isn’t repeated.

Inflammatory root resorption typically involves the presence of necrotic pulp tissue which is susceptible to bacterial infection via migration through dentinal tubules. Infection eventually leads to release of inflammatory factors which stimulate hard tissue resorption. Inflammation in the periodontal ligament with subsequent osteoclast activity leads to resorption of exposed dentin, lamina dura, and adjacent bone. This inflammatory resorption can progress until a communication into the root canal space develops.

The process of a tooth becoming replaced by bone with loss of the periodontal ligament is called ankylosis or replacement resorption. This condition is marked by complete loss of physiologic mobility and the appearance of fusion between tooth and bone radiographically. Damage to the periodontal ligament caused by trauma to the tooth can lead to competitive healing between the bony socket and the periodontal ligament. As clastic cells resorb hard tissue, new bone is formed by osteoblasts while cementum and Sharpey's fibers are formed by cells of the periodontal ligament. The tooth becomes a part of the bone remodeling process where osteooclasts resorb tooth structure, which is then replaced with bone by osteoblasts. This eventually progresses until the tooth root is completely replaced by bone and the crown is lost.

Cervical resorption is a more obscure entity whose mechanism is still somewhat unclear at this point. It is believed to be related to discontinuity or damage of the protective layer of cementum at the level of the cemento-enamel junction. This can be due to developmental defects or physical/chemical trauma. The exposed dentin is then subject to the effects of osteoclasts.(3) This can be a particularly aggressive and insidious form of resorption that can quickly lead to irreversible damage to tooth structure.

NOMENCLATURE

Root resorption has been studied and documented in dental literature for over 100 years. Over the last century, invasive cervical resorption (ICR) has been described with a litany of terms such as internal replacement, asymmetric internal, peripheral cervical, external cervical, extracanal invasive, and invasive cervical resorption.(3,4) Much of the disagreement in regard to nomenclature is a result of a historical lack of understanding in etiology and pathogenesis. Early articles reporting on ICR were largely case-reports or case-studies describing clinical presentation and different methods for treating the lesions. Even with increased research in the last two decades, there remains a dearth of high-level clinical evidence.

PATHOGENESIS

Early research on cervical resorption led clinicians to believe ICR to be a benign neoplasm, fibrous dysplasia, or an ingrowth of periodontal ligament.(5) Technological advancements in imaging and electron microscopy have led to a better understanding of how these lesions develop. ICR usually occurs just below the epithelial attachment at the cervical region of the tooth. (6) The pathogenesis consists of three main stages and is a dynamic process of destruction and repair. These three stages are resorption initiation, resorption progression, and repair. The beginning stage is marked by the disruption of the normal structure of periodontal ligament and cementum. Granulation tissue quickly forms, which is in contact with exposed dentin. Activation of clastic cells secondary to localized tissue damage or bacteria leads to initial breakdown of dentin.(7) Once the process has begun, there are several factors that are postulated to propagate hard tissue breakdown. Some of these include presence of bacteria, continuous mechanical force on the periodontal ligament, and parafunction. These factors are all thought to

contribute in some way to the formation of a hypoxic environment. In response to tissue hypoxia, more highly vascular fibrous tissue is formed. The resorption continues vertically and horizontally until reaching the thin layer of pre-dentin surrounding the pulp. A common feature of ICR lesions is a thin shell of circumpulpal unmineralized dentin averaging 112 microns in thickness. Once the resorptive front reaches this zone, it then spreads vertically and circumferentially without perforating the pulp chamber in most cases.(8) As the lesion progresses, a bone-like material forms in fine trabeculations throughout the fibrovascular tissue.(3) This is regarded as a form of healing and this reparative tissue will eventually become part of the normal alveolar bone structure. Repair and remodeling can evolve simultaneously in different parts of the tooth and this can lead to changes over time in how the lesion presents radiographically.(9)

ETIOLOGY

The exact etiology of ICR is still unknown despite an increase in research over the last two decades. Many clinicians have noted associations between certain treatments or conditions and ICR. Heithersay conducted a study to determine those predisposing factors which are most frequently found in association with ICR. As a sole factor, orthodontic treatment was shown to be the single greatest contributor in the affected teeth studied. This was followed closely by history of trauma, restorative treatment, and unknown causes (no associations with factors studied). Other minor associations included surgery, intracoronal bleaching, periodontal treatment, and bruxism.(10) In recent years, there have been other papers reporting on possible etiologic factors that had previously been unnoticed. Many of these are rare and likely represent only a small percentage of total cases. Some of these factors include extraction of a neighboring

tooth, transmission of feline virus to humans, herpes zoster infection, playing a wind instrument, and use of bisphosphonate medications. This list is not exhaustive and any factor causing some form of damage to the cementum resulting in exposed dentin may be considered as contributing in some way to the development of ICR. The majority of cases have been found to be associated with more than one single factor. Very few cases are not associated with any known risk factors.(11) It has been suggested that some of these idiopathic cases may be familial, indicating a possible genetic component in those instances.(12)

DISTRIBUTION

Mavridou et al reported on the distribution of ICR in relation to certain patient demographics. In a study of 284 patients, they found that males were affected slightly more often than females. However, when gender was paired with risk factors, they found that females were more often affected when previous orthodontic treatment was identified as a sole precipitating factor. The age distribution of study participants varied widely and there was no linear relationship between age and incidence. The majority of cases occurred between the ages of 15 to 54 years, with peak incidence found in the 35-39 year age group. When age was paired with risk factors, they found that the 15-19 age group was most often associated with orthodontic treatment. The 20-24 age group was most often associated with history of trauma. The 35-39 age group was most associated with parafunctional habits, such as bruxism. Analysis of tooth type and location showed that 29% were maxillary central incisors, 14% maxillary canines, 14% mandibular molars, and 14% maxillary premolars. The remaining percentage were distributed throughout the dentition. Maxillary teeth represented 72% of total cases. The lowest frequency of appearance was the mandibular anterior teeth.(11)

PRESENTATION AND CLASSIFICATION

Most ICR lesions are asymptomatic and discovered by incidental finding during routine radiographic or clinical examination. Depending on the location and extent of the resorption, there may be some discoloration of tooth structure that is clinically apparent. This is often due to the presence of highly vascularized fibrous tissue in the lesion, creating a pink hue at the cervical region of the crown. There may be an associated periodontal defect that will bleed easily upon probing. In some cases, there may be an irregularity in the contour of the gingival tissues in the corresponding area.(5) Due to the protective effect of the pre-dentin surrounding the chamber and canal, the pulp tissue is often not affected. The teeth will typically respond normally to thermal stimulus, EPT, and percussion. Radiographically, the classic presentation is a radiolucency with moth-eaten borders that appears superimposed over an intact canal. When taking multiple radiographs with different horizontal angulations, the radiolucency will move accordingly. These features are very helpful in distinguishing between lesions of internal or external origins.(4,13) Histologic evaluation reveals variable amounts of fibrovascular tissue with little or no inflammatory cell infiltrates. Bacterial plaques are seldom identified but are considered by some to play a role in lesion progression. Early lesions may show presence of multi-nucleated giant cells, indicating active resorption. More advanced lesions will show mineralized replacement tissue interspersed within the fibrovascular tissue. Even though communications between the pulp and resorptive lesion are uncommon, pulp tissues may exhibit signs of inflammation and tertiary dentin formation.(3)

Heithersay developed a classification system based on the extension of the lesion into mineralized tooth structure. Class 1 lesions are small with shallow penetration into dentin. Class

2 are well-defined lesions that have penetrated close to coronal pulp but have not extended into radicular dentin. Class 3 denotes a lesion with deep penetration into both coronal and radicular dentin. Class 4 lesions are those that have progressed beyond the coronal third of the root.(14) With each level, the extent of damage is increased and the prognosis is decreased.(15) More recently, Patel proposed a novel classification based on 3-dimensional analysis of resorptive defects using cone beam computed tomography (CBCT). This classification accounts for lesion height, circumferential spread, and proximity to the root canal. These systems were developed to both aid in future research and in determination of prognosis and appropriate treatment.(16)

DIAGNOSIS

Resorption lesions can be difficult to correctly diagnose, which can lead to inappropriate treatment planning. Clinicians must be thorough in their examination, which begins with documentation of the patient's medical and dental history. Subjective information combined with clinical findings provide justification for further evaluation. Radiographic examination should be performed to verify subjective and clinical findings or clarify contradictory information. Historically, clinicians relied mainly upon intraoral radiographs for this purpose. These images, while useful, did not provide a true 3-dimensional representation of the lesion since the 3-dimensional anatomy is compressed into a 2-dimensional image. The extent of the lesion as well as the portals of entry cannot be predictably determined. In addition, intraoral radiographs can lose diagnostic quality when neighboring anatomic structures are superimposed on the area of interest. Because of these issues, treatment of root resorption has been complex, time consuming, unpredictable, and expensive.(17) The use of CBCT in other disciplines of dentistry has led to increased research in the ability of this imaging modality to increase

diagnostic accuracy in resorption cases. Patel et al found that CBCT had higher sensitivity in detecting internal and external root resorption compared to intraoral radiographs. Examiners were able to correctly identify and diagnose 100% of the lesions studied, although this resulted in the correct treatment plan only 80% of the time. Also of note, intra-examiner agreement with CBCT was higher when compared to intraoral radiographs. This study demonstrated the reliability of CBCT imaging in correctly diagnosing root resorption.(18) Evaluation of 3-dimensional images has been shown to lead to frequent alteration in treatment plans by practitioners who had previously referenced only periapical intraoral radiographs.(19) This represents a significant shift in approach with implications on prognosis and outcome.

TREATMENT

Classification systems for ICR have been developed, in part, to assist practitioners in making the decision of when and how to treat these lesions. Once the correct diagnosis and assessment has been established, the decision must be made regarding treatment timing, modality, and materials used. Regardless of approach, the goal of treatment is inactivation of all active resorbing tissue and restoration of the defect with a suitable filling material so that the tooth can be retained.(20) Heithersay class 1 and 2 ICR lesions that have not advanced into the radicular dentin can often be repaired with a high level of success. Treatment of class 3 and 4 lesions is more unpredictable, with decreased success noted as lesions progress apically. In these cases, consideration should be given as to whether intervention would provide a better outcome than leaving the tooth alone until symptoms appear.(21)

Repair is typically achieved either externally after reflection of overlying soft tissues, or internally after extirpation of pulp tissue. In cases where surgical repair is not advisable,

orthodontic extrusion can be employed in order to gain greater access to the resorption site. During external repair, the affected root surface is exposed and the fibrovascular tissue is removed from the bone and root defects. This can be accomplished by application of a chemical escharotic agent, trichloroacetic acid (TCA), followed by mechanical debridement with a bur or curette. The risk of pulp exposure during external repair may be an indication for elective root canal therapy. Accessing the pulp chamber can provide improved visualization and access to resorptive tissues.(22)

Once the defect has been adequately debrided, replacement of lost tissue with a restorative material is required. A restorative material with superior sealing capability should be chosen to provide the highest chance for long-term survival. Unlike underlying dentin, the restorative material is not susceptible to the resorptive action of osteoclasts. Unfortunately, these materials are also not amenable to the attachment apparatus of the periodontal ligament. Use of various restorative materials has been described in the body of literature relating to ICR. In the past, many clinicians have opted to restore with amalgam due to the lack of superior alternatives. This can result in staining of adjacent tooth structure and soft tissue, creating an esthetic problem in some cases. Resin-modified glass ionomers (RMGI), such as Geristore, have been recommended due to their biocompatibility, adhesion, color, and beneficial physical properties.(23) Bioactive cements, such as mineral trioxide aggregate (MTA), provide adequate seal, high biocompatibility, hard tissue stimulation, and bacteriostatic effect. Direct contact with the periodontal tissues and esthetics both present a concern in some cases where bioactive cements are used. None of these have been shown to meet all the ideal requirements for an ICR repair. However, using a combination of these materials to take advantage of the beneficial properties of each has been successfully implemented. Kqiku et al described a sandwich technique using

MTA as a base with a protective layer of glass ionomer cement and a bonded veneer of composite resin to improve esthetics.(24)

Despite the recent increase in research, the endodontic community has yet to come to a definitive conclusion as to the appropriate management of ICR lesions. Differences in training and experience, an inadequate body of clinical research regarding outcomes, and recent advances in technology and materials have led to development of varying treatment philosophies. Ideally, endodontic specialists would reference the current evidence base to guide treatment decisions regarding these challenging cases. Due to the lack of high-level evidence available, many endodontists are looking to their peers through various physical or virtual groups for confirmation of their treatment plans. This inevitably leads to debate among practitioners that is driven primarily by anecdotal evidence. The purpose of this current research project was to ascertain and detail current trends in the management of invasive cervical resorption at Virginia Commonwealth University, throughout the United States, as well as in other countries. The goal is to provide useful information that may help endodontists and educators make more informed decisions, taking into consideration current trends in the field. It is hopeful that it will also serve as a tool to give guidance and direction to educators, as well as those considering clinical research on invasive cervical resorption.

Methods

This study was reviewed and declared exempt by the Virginia Commonwealth University Institutional Review Board [Study ID: HM20015697/HM20016723]. The study comprised two separate components consisting of a survey and a retrospective chart review. Survey questions and study data were collected and managed using REDCap (Research Electronic Data Capture) tools hosted at Virginia Commonwealth University. REDCap is a secure, browser-based application designed to provide a secure environment so that research teams can collect, and store highly sensitive information for research purposes. It is Health Insurance Portability and Accountability Act (HIPAA)–compliant, highly secure, and intuitive to use. The database uses instruments such as surveys and forms to capture project data. It is workflow-based and focuses on collecting data and exporting it to statistical programs and other data analysis software.(25) The survey questions administered via REDCap were all multiple-choice format to provide an efficient, user-friendly experience to participants. Historically, external surveys of this type have average response rates of 10-15%. In an attempt to improve the survey response rate, large organizational e-mail contact lists were not utilized for recruitment purposes. E-mail addresses of currently practicing endodontists throughout the United Sates and several other countries were compiled by networking with endodontic practitioners in the personal spheres of faculty, residents, and students at Virginia Commonwealth University. The initial list was comprised entirely of personal contacts but included an invitation to forward the survey to other

endodontists meeting the specified inclusion criteria. Due to the methods used to distribute the survey, a response rate was not calculated. The true denominator cannot be determined. Participants were limited to licensed dental professionals over the age of 18 years and either currently enrolled in an accredited endodontic specialty residency program or certified/licensed endodontists. General dentists who had not received specialty training and certification in endodontics, and endodontists with expired dental licenses were excluded. E-mail invitations to participate in the survey were sent two times, three weeks apart, giving participants a total of six weeks to respond. The REDCap survey link was generic and not individualized in any way, making it impossible to link a participant to a set of responses. The endodontists who participated did so voluntarily, anonymously and without compensation. Survey questions were aimed at collecting demographic information such as experience, practice location and setting, as well as philosophy regarding treatment approaches in managing invasive cervical resorption cases.

Electronic health records at the Virginia Commonwealth University School of Dentistry are maintained through the dental software program axiUm Dental (Exan Software U.S.A.). The axiUm Dental software is a HIPAA-compliant system that includes electronic health records, billing, and practice management applications.(26) Electronic health records in axiUm were queried for terms and CDT codes that indicated evaluation, diagnosis, or treatment of invasive cervical resorption. The selected charts were reviewed for inclusion in a retrospective study of treatment planning for diagnosed invasive cervical resorption cases between the years of 2010 and 2019. Cases involving other categories of root resorption were excluded from the study. Any cases that were not referred to the graduate endodontic clinic for evaluation were also excluded from the study, as the current project aimed to determine treatment philosophies and

management practices of endodontists and endodontic residents. Data collected from the electronic charts included date of initial exam, patient age and gender, tooth number, signs/symptoms, Heithersay classification,(14) treatment recommended and provided, materials used, and number of recalls obtained. No patients were contacted in an attempt to recall them for further observational study. However, historical recall radiographs were reviewed for the purpose of determining lesion progression and tooth survival. Due to the retrospective nature of the study with no further patient contact or recall required, consent for inclusion in the study was not necessary. Study data were recorded using a Microsoft Excel spreadsheet which was maintained on a secure Virginia Commonwealth University server accessible to authorized research investigators and assistants. Prior to data analysis, all records were de-identified by removing the axiUm patient chart number and assigning a random patient number from 1-80 that could not be connected thereafter to a particular patient.

STATISTICAL METHODS

For survey responses, results were summarized using descriptive statistics (counts and percentages). Differences in responses between the US-based Endodontists and International respondents were compared using Fisher's Exact test. For chart review, results were again described using descriptive statistics including counts and percentages for categorical but also included median and IQR for continuous variables (age, number of follow-up appointments). Chi-squared tests were used to determine associations among variables collected from chart review. This included comparing treatment recommended versus rendered, and the associations between patient age, whether they were experiencing symptoms, the classification of their lesion and the treatments recommended and rendered.

Results

A total of 153 Endodontists responded to the survey, 97 (63%) of which were US based and 56 (37%) were international. The majority of US based respondents were in Districts I (12%), V (20%), and VI (14%). International respondents represented: Australia (n=25), Italy (n=22), Germany (n=1), Ireland (n=1), Japan (n=2), Kuwait (n=1), and New Zealand (n=1). Respondents were roughly equally distributed in terms of years in practice from 0-5 years (27%) through 21+ years (30%). The majority of respondents practiced in a private practice setting (n=107, 69%). Complete demographics are given in Table 1.

Table 1: Survey Respondent Demographics

	n	%
AAE District		
District I (DE, DC, MA, MD, ME, NH, PA, VT, VA)	18	12%
District II (CT, NJ, NY, RI)	4	3%
District III (FL, GA, NC, SC, TN)	14	9%
District IV (IL, IN, KY, MI, OH, WV, WI)	2	1%
District V (AL, AR, AZ, LA, MS, NM, OK, PR, TX, VI, U.S. Armed Services, Veterans' Administration)	31	20%
District VI (AK, CO, Guam, HI, ID, IA, KS, MN, MO, MT, NE, NV, ND, OR, SD, UT, WA, WY)	22	14%
District VII (CA)	6	4%
Outside United States	56	37%
Years in Practice		
0-5 years	42	27%
6-10 years	24	16%
11-15 years	24	16%
15-20 years	18	12%

	21+ years	46	30%
Practice Setting			
	Private Practice	107	69%
	Academic	39	25%
	Military/Government	19	12%
	Resident	4	3%
	Other	8	5%

The vast majority of respondents reported treating invasive cervical resorption (96% of US respondents, 89% of international, p-value=0.1121). A smaller majority reported that their specialty training adequately prepared them to diagnose and treat ICR (59% for US, 61% for international, p-value=0.6836). There were significant differences in the responses to other questions between respondents that were US-based and those who were international. International respondents reported "Frequently" using trichloroacetic acid (TCA) 55% of the time compared to 35% for US-based respondents (p-value=0.0384). The materials used for root defects were also significantly different (p-value<0.0001). US-based had a higher rate of Geristore use (63% vs 7%) and a lower rate of MTA (9% vs 39%). The treatment philosophy was also significantly different between responding US and International endodontists (p-value=0.0047). A higher rate of international respondents reported treating immediately (69% vs 42%), and more US-based respondents elected to recall more frequently to monitor lesion progression (45% vs 22%). Complete breakdown of responses based on practice location are given in

Table 2.

Table 2: Self-Reported Treatment Practices for Invasive Cervical Resorption Based on Region of Practice

	US Based (n=97)	International (n=56)	P-value
Have you treated invasive cervical resoprtion (ICR)?			0.1121
Yes	93, 96%	50, 89%	
No	4, 4%	6, 11%	
Do you feel that your specialty training adequately prepared you to diagnose and treat ICR?			0.6836
Yes	57, 59%	34, 61%	
Somewhat	31, 32%	19, 34%	
No	9, 9%	3, 5%	
Use of TCA			0.0384
Frequently	34, 35%	30, 55%	
Infrequently	17, 18%	4, 7%	
Never	46, 47%	21, 38%	
Materials for Root Defects			<0.0001
Geristore	61, 63%	4, 7%	
MTA	9, 9%	22, 39%	
BioDentine	11, 11%	13, 23%	
Other	16, 16%	17, 30%	
Treatment Philosophy			0.0047
I treat immediately in order to halt lesion progression	40, 42%	38, 69%	
I recall the patient frequently to monitor for lesion progression prior to treating	43, 45%	12, 22%	
I rarely treat this entity	13, 14%	5, 9%	

*p-value from chi-squared test

CHART REVIEW

A total of 67 charts with 79 teeth diagnosed with ICR from 2010 through 2019 were reviewed for the study. The majority of the patients were 26 or older (73%), 56% were female. There was

a nearly equal split of posterior and anterior teeth (52% vs 48%). Complete demographics are given in

Table 3.

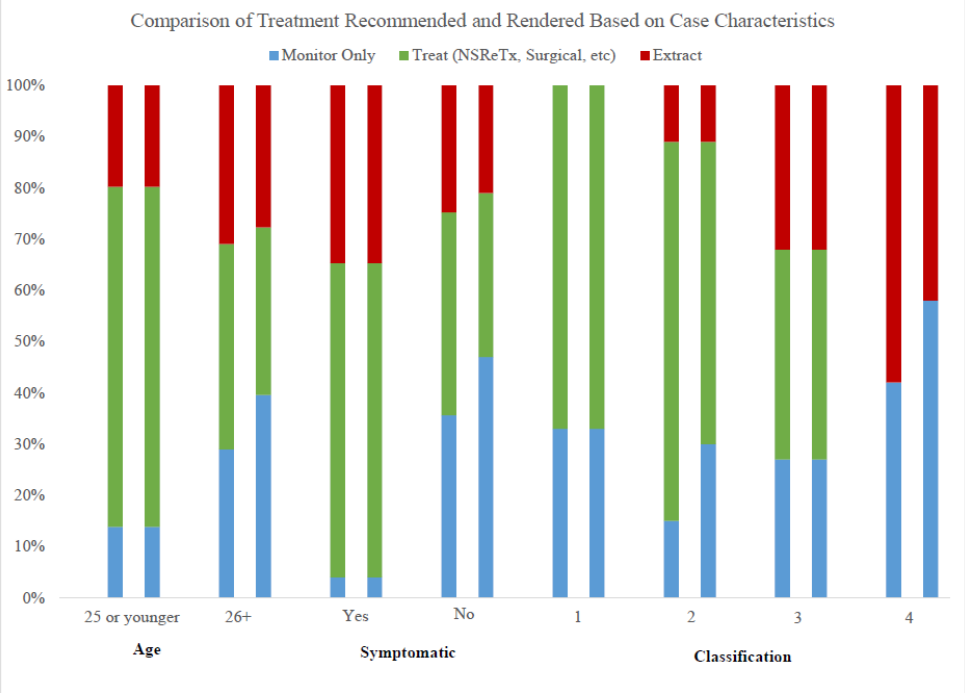
Table 3: Patient Demographics from Chart Review of Invasive Cervical Resorption

		n	%
Age			
	≤25	21	27%
	26+	58	73%
Gender			
	Male	35	44%
	Female	44	56%
Tooth Location			
	Anterior	38	48%
	Posterior	41	52%
Classification			
	1	3	4%
	2	27	34%
	3	37	47%
	4	12	15%
Number of Visits Post-Operative			
	0	53	67%
	1+	26	33%
		Median	IQR
Average Age		54	25-67
Number of Follow-Up Visits		0	0-1

Patients generally accepted the treatment plans as presented and treatment rendered was significantly associated with the treatment recommended (p-value<0.0001). All of the cases that were recommended for monitoring were only monitored (n=20). Twenty of the 22 teeth recommended for extraction were removed, whereas 2 were monitored by patient request (9%). Of the 37 teeth where treatment of some type was recommended, 33 accepted and received the planned treatment (89%).

Figure 1 details the treatments recommended and rendered based on the case characteristics (age, symptomatic, and classification).

Figure 1: Treatment Recommended and Rendered by Characteristic



Although these were significantly related, discrepancies between recommendation and treatment rendered can be seen for patients 26 and older, asymptomatic patients, and classification 2 and 4. Consultation or referral to another dental specialist occurred in 28 (35%) of the cases, with the

majority related to extractions (20, 71%) referred to oral surgery (n=14). Other disciplines included orthodontics (n=3), periodontics (n=10), and prosthodontics (n=1).

Treatment recommendations were significantly associated with presence or absence of symptoms (p-value=0.0044) and the lesion classification (p-value=0.0002). Symptomatic cases were more likely to be treated (62% vs 40%), more likely to be extracted (35% vs 25%), and less likely to be monitored (4% vs 36%). Classification 4 cases were more likely to be extracted (58% vs 0-32%) or monitored (42% vs 15-33%) than Classification 1-3. Classification 1 or 2 teeth were less likely to be extracted and more likely to be treated. There was also marginal evidence that treatment recommendation was associated with age of the patient (p-value=0.1327). Younger patients (under 25 years old) were more likely to be recommended treatment (67% vs 40%). Treatment recommendations are given in Table 4.

Table 4: Treatment Recommendation based on Patient Characteristics

	Monitor Only	Extract	Treat (NSRCT, Surgical, etc)	P-value*
Age				0.1327
25 or younger	3, 14%	4, 19%	14, 67%	
26+	17, 29%	18, 31%	23, 40%	
Symptomatic				0.0044
Yes	1, 4%	9, 35%	16, 62%	
No	19, 36%	13, 25%	21, 40%	
Classification				0.0002
1	1, 33%	0, 0%	2, 67%	
2	4, 15%	3, 11%	20, 74%	
3	10, 27%	12, 32%	15, 41%	
4	5, 42%	7, 58%	0, 0%	

*p-value from Fisher's Exact test

Treatment rendered was significantly associated with the age of the patient. Younger patients were more likely to receive treatment (NSRCT, surgical repair, etc) than those 26+ (67% vs 33%, p-value=0.0243). Older patients were more likely to be monitored than younger patients (40% vs 14%). As expected from treatment recommendations, symptomatic patients were more likely to be treated (62% v 32%) or extracted (35% vs 21%) and less likely to be monitored (4% vs 47%) (p-value=0.0002). Treatment classification was also significantly related to treatment rendered (-value=0.0038). Higher classification cases were more likely to be monitored or extracted and lower classification cases were more likely to be surgically or non-surgically treated. Results are given in Table 5.

Table 5: Treatment Rendered based on Patient Characteristics

	Monitor Only	Extract	Treat (NSRCT, Surgical, etc)	P-value*
Age				0.0243
25 or younger	3, 14%	4, 20%	14, 67%	
26+	23, 40%	16, 28%	19, 33%	
Symptomatic				0.0002
Yes	1, 4%	9, 35%	16, 62%	
No	25, 47%	11, 21%	17, 32%	
Classification				0.0038
1	1, 33%	0, 0%	2, 67%	
2	8, 30%	3, 11%	16, 59%	
3	10, 27%	12, 32%	15, 41%	
4	7, 58%	5, 42%	0, 0%	

Several different restorative materials were commonly used in cases where some form of treatment was rendered. Geristore was used for 78% of the cases treated at VCU, which is similar to the results from the survey (63% of respondents). MTA was noted as a material used in 9% of cases, which aligns with the survey responses from US-based endodontists. Other restorative materials included amalgam, composite resin, and Biodentine. TCA was used for

35% of the cases at VCU, which aligns with the survey responses for those who indicated they "Frequently" use TCA. However, looking further into the TCA usage, 8 of the 9 cases were before 2012 (data was collected from 2010-2019).

There were 26 cases that received no treatment. Of these, 10 had at least one follow-up ranging from 3 months through 2 years. None of the teeth that were monitored were lost to extraction during the follow-up period. Only one of those teeth showed documented lesion progression at recall, which was noted at 18 months. In comparison, 31% of the cases that received treatment with subsequent recall (n=16) showed lesion progression. Lesion progression for treated cases was variable and observed between 6 months and 30 months. This difference in lesion progression between monitored and treated teeth was not significant (p-value=0.3524). Details are given in Table 6.

Table 6: Summary of Lesion Progression by Treatment Rendered

	No Treatment Rendered	**Surgical and Nonsurgical Treatment**
Total	26	33
Cases with Follow-up	10, 38%	16, 48%
Follow-up Range (months)	3-48	1-36
% with Lesion Progression	1, 10%	5, 31%
Observed Lesion Progression Range (Months)	18	6-30

Discussion

The existing body of literature on the topic of invasive cervical resorption consists mainly of case reports and series, review papers, and textbook chapters. Randomized clinical trials studying the management of ICR are sparse, which has resulted in a lack of consensus in the scientific literature regarding treatment protocols.(9) Additionally, the nature of invasive cervical resorption and ambiguity that persists regarding its etiology and pathogenesis lends itself to frustration at times when attempting to develop a management strategy. The difficulty often lies in the decision of whether or not to intervene, as many of these lesions have been demonstrated to be arrested with no sign of progression over many years. In these instances, surgical intervention could result in damage to hard and soft tissues that may result in loss of the tooth earlier than might have been expected if no treatment was rendered. Alternatively, many cases have shown rapid progression with extensive damage being sustained in a relatively short time period. The only definitive method for determining the nature of a particular ICR lesion is to review and compare historical radiographs. Unfortunately, not all patients will have adequate historical radiographs for reference during initial examination by an endodontist.

The preferred method for guidance on appropriate treatment planning decisions consists of a review of the current best evidence in the body of endodontic literature.(27) Given the dearth of high-level evidence on the subject, endodontic practitioners are increasingly turning to their

peers for validation of management decisions. Nearly all survey respondents reported having treated ICR during their careers, highlighting the importance of establishing appropriate management guidelines. This evaluation of current management trends among endodontic practitioners can serve as a reassurance of generally accepted protocols until such time that more compelling clinical research is published.

Use of cone-beam computed tomography(CBCT) provides for a more accurate determination of lesion location and extent.(28) It is not surprising that CBCT studies were ordered in 62.5% of cases managed at Virginia Commonwealth University over the past decade, increasing to 84.4% over the last 5 years. Considering the fact that CBCT imaging is widely accepted to be the gold standard for evaluating root resorption cases, (29) the case-based survey questions including only intraoral periapical images may not have provided sufficient information to make an informed decision regarding treatment approach. With that limitation in mind, respondents evaluated cases that were assigned according to Heithersay's classification system for ICR lesions. (20) This classification system was the first published set of criteria for assigning the level of lesion severity and it was followed by an outcome study based on this classification scheme. As may be expected, Heithersay found that smaller lesions located above the alveolar bone crest (class I and II) responded very well to treatment, with 100% reported success at 3-year recall. As lesion size increases and extends apically onto sub-crestal root structure (class III and IV), treatment prognosis was reduced, with class IV lesions having only a 12.5% success rate.(22) Most, if not all, endodontists will be familiar with this landmark classification system and the corresponding outcome study as it was the first of its kind. Accordingly, survey respondents reported higher likelihood of recommending interventional treatment in cases where lesion progression was limited in its apical extent. Each successive case presented in the survey demonstrated a more

extensive lesion and yielded a smaller percentage of respondents who selected immediate intervention as part of the initial treatment strategy. At VCU, a similar trend in initial treatment strategy was identified.

One aspect of the management of ICR that could drive the decision of whether to treat or monitor lesions is the presence of symptoms. Most practitioners will be likely to provide some manner of treatment to a patient with symptoms that limit their ability to carry out normal daily activities. This is evidenced by the finding that patients presenting at VCU with symptomatic ICR lesions were recommended some form of treatment in 96.1% of cases. However, even in the absence of symptoms the majority of survey respondents as well as endodontic practitioners at VCU opted to immediately treat ICR lesions once diagnosed. A smaller segment of practitioners opted to place patients on a frequent recall schedule and monitor for either progression of the lesion or emergence of symptoms. There seems to be precedent for both management strategies depending on the particular situation. In any case, involvement of the patient in the decision-making process is critical to addressing the chief complaint.

Patient age at the time of ICR diagnosis may also influence treatment decisions. In the younger patient demographic (under 25 years of age), maintenance of the natural tooth is of more strategic importance in considering long-term treatment planning. Intervention with either NSRCT or external surgical repair was more often recommended in younger patients at VCU, while extraction or monitoring the lesion was recommended significantly less often.

Location of affected teeth in the dental arch may be a consideration during treatment planning, particularly in the esthetic zone. Although posterior and anterior teeth were equally likely to be treated with either NSRCT or surgical repair, anterior teeth were more frequently monitored and posterior teeth were more frequently recommended for extraction. In cases where endodontic

intervention was not deemed to be appropriate, practitioners at VCU were more likely to simply monitor anterior teeth rather than recommend immediate extraction. This suggests that esthetic considerations play a large part in the decision of how and when to treat ICR lesions.

Once the decision has been made to intervene, endodontists face a new set of decisions in terms of how resorptive defects will be accessed and restored. The aim of treatment for restorable teeth diagnosed with ICR is to retain them in a healthy and functional state and improve esthetics when indicated. The objectives of treatment are excavation of the resorptive tissue, sealing of the hard tissue defect with an esthetic, biocompatible material, and prevention of recurrence.(30) This may involve surgical reflection of a mucoperiosteal flap with excavation of the resorptive defect and placement of a restoration. Alternatively, non-surgical root canal therapy (NSRCT) may be completed with excavation of the resorptive defect and restoration placement from an internal approach. In some cases, both treatments will need to be rendered in order to completely repair the damaged tooth root and restore full function to the patient. Supraosseous lesions that have not extended to or perforated the circumpulpal dentin are typically able to be managed by an external surgical approach. An internal approach involving NSRCT is indicated when the portal of entry is small and apical to the epithelial junction, ICR is close to or has perforated the circumpulpal dentin, where surgical repair is expected to result in pulp exposure, and cases of limited surgical accessibility.(31)

With two-thirds of survey respondents reporting completing repairs internally wherever possible, this sheds light on another possible factor in the treatment planning process. Hesitancy to undertake procedures involving creation of a mucoperiosteal flap may be a consideration for some endodontists. This could be due to insufficient surgical training or patient-related factors. When asked about interdisciplinary treatment planning, many endodontists reported

collaborating with periodontists to manage ICR cases. Given their expertise in surgical management of bone and gingival tissues, it is likely that periodontists are being called on to complete external repairs that are deemed necessary. In addition, some respondents reported including orthodontists in the dental management of ICR lesions. Orthodontic extrusion of teeth with ICR lesions is often undertaken in an attempt to facilitate repair of the defect externally, without raising a flap. These data seem to indicate that endodontists are currently opting to complete fewer surgical procedures in managing these cases.

In those cases where an external repair is completed as part of the overall treatment plan, it is critical that all resorptive tissues be removed in the process in order to halt lesion progression. Use of a handpiece and bur to mechanically debride and prepare the root surface is common practice. However, it is not always possible to completely remove the resorptive tissues by mechanical means alone. Application of 90% TCA to the resorptive cavity causes coagulation necrosis of any remaining tissue as it penetrates the smaller, more inaccessible recesses and resorptive channels which may not be identified and debrided by mechanical instrumentation.(15,31,32) Although very effective at removing residual resorptive tissue from root defects, TCA is very caustic and can cause damage to adjacent soft tissues if accidental contact occurs. For this reason, use of TCA remains controversial as an adjunct to traditional mechanical debridement techniques. This sentiment is mirrored in the finding that just over one-third of survey respondents reported frequent use of TCA during external repair procedures. Additionally, TCA was used in a similar percentage of cases repaired externally at VCU. It is worth noting that the classic outcome study on ICR published by Heithersay that was referenced earlier included use of TCA as a critical element of the treatment protocol.(22) Although similar outcomes may be possible without the use of TCA, assumption of prognosis based on the results

of this study should not be extrapolated to treatment modalities that don't include use of this agent.

Selection of restorative materials for root defects is critical to the overall success of an external repair. Historically, materials such as amalgam, composite resins, and glass ionomer cements were the only available options.(33) More recently, bioactive materials such as MTA, EndoSequence Root Repair Material (RRM), and BioDentine have been employed in place of, or as an adjunct to the aforementioned materials.(24,34,35) One of the main determining factors in material selection is the location of the lesion, specifically whether or not the cavity communicates with the oral environment. Use of a material that has an adequate bond to tooth, good sealing ability, and is impervious to moisture is necessary for a successful long-term outcome.(21) In cases where the lesion is located on a facial surface in the anterior esthetic zone, use of a material that can be closely matched to tooth shade and will not lead to staining of coronal tooth structure is also important. The material of choice in both survey respondents and endodontic practitioners at VCU was Geristore, which is a biocompatible resin-modified glass ionomer. This material combines many of the desirable properties of both glass ionomer and resin materials. When an external repair of an ICR defect that approximates the pulp space is to be completed without prior non-surgical root canal therapy, bioceramic materials such as MTA, RRM, or BioDentine may be used as pulp capping agents. These materials have the advantage of being biocompatible and antimicrobial, as well as promoting reparative dentin formation.(31) However, due to their susceptibility to breakdown in the presence of saliva, they should be used in a sandwich technique with one of the materials discussed previously.(24) When an internal repair with NSRCT is completed and the defect does not communicate with the oral environment, use of bioceramic materials is preferable due to their superior biocompatibility and

the higher likelihood for complete healing of the periodontal ligament adjacent to the restorative material. Survey respondents reported using MTA less frequently than glass ionomer cements. Similarly, practitioners at VCU used MTA significantly less. This finding may be a reflection of the more limited indications for use of this material in these cases, as well as the propensity of most endodontists to complete NSRCT as part of the overall treatment plan as discussed previously. Biodentine is a newer bioceramic, bioactive material that has been developed to provide many of the advantages of MTA with improved mechanical and handling properties to facilitate it's use as a restorative material. Whereas MTA is not indicated for use in cases where the defect has direct communication with the sulcus, Biodentine has been suggested as a suitable all-in-one material.(36) Although this material was introduced more recently, endodontic providers reported using it with slightly less frequently than MTA. Given it's more broad indications for use, it is likely that use of this material to repair ICR defects will continue to increase.

When the decision has been made to monitor a tooth with untreatable ICR, the endodontist must make a decision as to the appropriate interval for recall examinations. There is no established, generally accepted timeframe for follow-up of untreated ICR lesions. However, one year recall visits have been suggested in the literature.(31) With 36% of survey participants espousing a more conservative treatment philosophy involving frequent recall of untreated ICR lesions, the question of preferred recall interval would have provided valuable insight. Unfortunately, this data was not collected in the survey but is suggested to be included in any subsequent follow-on research. One quarter of the ICR cases managed at VCU were only monitored, and the most common recall interval was 6 months, followed by 12 months. Regardless of the recall interval chosen, patients need to be made aware of the associated risks and sequelae of lesion

progression. When properly informed, patients are more likely to be compliant with prescribed recall visits and may avoid some complications in the future.

While providing some valuable information regarding currently accepted management protocols for ICR, this study had several limitations that should be mentioned. The survey format of this research study lends itself to the possibility of response bias, which may skew the data. The distribution of survey participants was not uniform, and recruitment was targeted to some degree. This may have introduced some sampling bias, leading to results that may not adequately represent a true cross-section of endodontists. Due to the ability of survey participants to forward a non-specific REDCap link to other associates, there was no way to verify that each participant met the specified inclusion criteria and only entered a single data set. The many nuances of ICR make it difficult to adequately assess a treatment philosophy with a multiple-choice question including limited responses. Some participants reported not answering questions because they felt that none of the included responses adequately described their management philosophy. Complicating this even further, participants were asked to make a treatment decision without the use of CBCT imaging. As noted previously, CBCT imaging has become the gold standard for evaluating ICR lesions and many survey respondents commented that they could not confidently make a treatment decision without the diagnostic information provided therein.

Conclusion

Invasive cervical resorption can be aggressive and can progress in the absence of symptoms in many cases. It is often only identified once it has extended to the point of causing coronal discoloration or frank radiolucency on routine radiographic examination. Considering the challenges in treating these lesions and the unfavorable prognosis of advanced lesions, every effort should be made to identify lesions in the early stages. A knowledge of the predisposing factors combined with a thorough medical and dental history should assist clinicians with early detection. Proper radiographic examination, including intraoral and CBCT imaging, is essential to aid in proper identification of lesion origin and extension. With proper surgical technique and selection of materials, successful maintenance of affected teeth can be expected. Understanding treatment limitations and outcomes is necessary in determining if the benefits of treatment will outweigh the risks. In some cases, the treatment of choice will be to simply monitor the lesion until symptoms develop or progression threatens adjacent structures. In either case, frequent recall for re-evaluation is an essential element of successful management.

The findings of this study have reinforced the fact that there is no consensus in the endodontic community regarding a specific protocol for managing ICR lesions. While the majority of clinicians currently prefer to provide some form of treatment quickly after discovering teeth with ICR, some still prefer to take a more conservative approach and monitor lesions for progression prior to intervening. Treatment approaches vary among clinicians around the world and there

seems to be more than one method for effectively managing this entity. Treatment approaches should be thoughtfully considered after thorough examination and treatment plans formulated on a case-by-case basis, including the patient in the decision-making process along the way. More long-term, outcome-based clinical research is necessary to provide endodontic specialists with additional scientific evidence to guide their decision-making process.

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