2015

The prevalence, predictive factors, and classification of intrapulpal cracks in maxillary premolars requiring endodontic treatment

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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 2015

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Abstract

THE PREVALENCE, PREDICTIVE FACTORS, AND CLASSIFICATION OF INTRAPULPAL CRACKS IN MAXILLARY PREMOLARS REQUIRING ENDODONTIC TREATMENT

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Cracked teeth may be difficult to diagnose. Craze lines rarely become symptomatic or require treatment. Cracks in the enamel and dentin alone may or may not become symptomatic and require restorative treatment. However, cracks extending into the enamel, dentin, and pulp chamber provide an avenue for bacteria to establish infection and this commonly results in symptoms and the need for endodontic and restorative treatment. The published endodontic literature has limited information regarding the prevalence or predictive factors for cracks extending into the pulp chamber of teeth. The purpose of this study was to determine the prevalence and classification of intrapulpal cracks in maxillary premolars and to identify factors that may aid in diagnosing the existence and extent of a crack. The cracks were classified according to the Intrapulpal Crack Classification System proposed by Detar in 2014. All maxillary premolar teeth treatment planned for non-surgical root canal therapy (NSRCT) or retreatment (RETX) at Virginia Commonwealth University (VCU) Graduate Endodontic

Practice from January 2014 through February 2015 were included in the study after obtaining patient consent. Teeth were examined visually, stained, and examined microscopically for the presence of an intrapulpal crack. Demographic information, subjective data associated with the chief complaint, objective results of diagnostic testing (percussion, palpation, bite stick test, transillumination, probing depths), existing restorations, pulpal diagnosis, and periapical diagnosis were analyzed using chi-square and multiple logistic regression ($P<0.05$) to identify associations of these findings with the existence of a crack. A total of 19.7% (15 out of 76 teeth) of maxillary premolars evaluated for endodontic treatment were cracked. Of the 14 cracked premolars, 8 (10.5%) had an intrapulpal crack. Seven teeth (9.2%) contained cracks that did not extend to the pulp chamber. There was a higher prevalence of cracks in maxillary first premolars compared to second premolars, teeth with two or fewer surfaces restored, teeth testing positive to transillumination prior to access, and teeth with probing depths greater than 4mm ($P<0.01$).

Supported by VCU Department of Endodontics
IRB #HM20000335

Introduction

Cracked teeth are difficult to diagnose. Ritchey et al (1) first described pain on release of biting and unexplained cold sensitivity as the symptoms associated with a cracked tooth. Cameron went on to define this set of symptoms as the cracked tooth syndrome in the 1960s (2, 3). Subsequent authors have confirmed that masticatory pain and thermal sensitivity are the symptoms most often associated with cracked teeth (4-6). However, researchers agree it remains an elusive diagnosis because of the varied presentation and unclear etiology (7). Patients may report a history of examinations or treatment of the tooth without resolution of pain. Patients may also be asymptomatic, requiring the practitioner to rely on clinical signs to make a diagnosis. Cracks are usually not visible radiographically (4), so a thorough evaluation including thermal, percussion, mastication, mobility, and nerve conduction testing is required. Transilluminating the suspected tooth and its neighboring teeth has also proven useful in visualizing cracks (3, 4). A thorough history from the patient and comprehensive clinical exam are necessary to diagnose a cracked tooth.

Multiple classifications have been proposed as a way to standardize the terminology surrounding cracked teeth. Gibbs first described incompletely fractured teeth and their associated symptoms in 1954 using the term “cuspal fracture odontalgia” (5). In 1957, Ritchey provided case reports of incompletely fractured teeth with subsequent pulpitis (6). Cameron proposed the term “cracked-tooth syndrome” in 1964 with a description of signs and symptoms associated with a cracked tooth (2). He emphasized the importance of treatment to prevent the propagation

of cracks and eliminate symptoms in a follow-up paper in 1976 (3). Since then, multiple authors have continued the effort to describe, classify, and propose treatment for cracked teeth (8-10).

Early diagnosis is essential for the appropriate management of a cracked tooth (2, 3, 11). Luebke (12) suggested characterizing pain as dentinal, pulpal, or periodontal in origin to better understand the extent of a crack. The provoking factors, quality of pain, and duration are helpful in determining this origin. According to Bader (13), the majority of cracks do not involve the pulp and can be managed using direct restorative materials. However, if the crack extends to the pulp and/or radicular surface of a tooth a multi-disciplinary approach involving endodontic, periodontic, orthodontic, or surgical intervention may be necessary to appropriately treat. Cracks communicating with pulp tissue require endodontic treatment. Therefore, endodontists must establish a predictable method for diagnosing, classifying, and treating these teeth.

In an attempt to compile and standardize previously published papers on the subject, the American Association of Endodontists (AAE) published a guide to cracked teeth in 1997 with five classifications for a fractured tooth (14). In 2003, Rivera introduced the term "longitudinal tooth fracture" to suggest a distance and time component to cracks (15). This terminology was adopted by the AAE in their 2008 guide to cracked teeth. The most notable difference between the 1997 and 2008 AAE publications is the use of the term longitudinal to describe the various types of cracks (16). The 2008 publication currently serves as the most recognized guide to cracked tooth terminology. The five categories of longitudinal tooth cracks are craze line, fractured cusp, cracked tooth, split tooth, and vertical root fracture. According to this system, a practitioner classifies a crack based predominantly on its external coronal features. Associated symptoms and internal features of the crack, such as involvement of the pulp, are not described.

For the purpose of this study, a crack extending to or beyond the pulp chamber is defined as an intrapulpal crack. The term intrapulpal implies a direct communication from the external environment to the pulp chamber via a propagated coronal fracture. The term superficial crack refers to a crack extending into the enamel and coronal dentin alone and does not communicate with the pulp chamber. The Intrapulpal Crack Classification System introduced by Detar in 2014 (17) will be used to classify intrapulpal cracks identified in this study. This system characterizes intrapulpal cracks based on their extension along walls, orifices, and across the floor of the chamber.

Cracks provide an avenue for bacteria to access the pulp. Hiatt recognized bacterial invasion through a crack may lead to periapical lesions if the crack extends close enough to the pulp (11). In a healthy tooth, the enamel and dentin protect the pulp from contaminants present in the oral cavity (18). If bacteria gain access to the pulp chamber, the pulp will initiate an inflammatory response (19). This can lead to irreversible pulpitis or pulpal necrosis and/or periapical pathology.

The 2008 AAE Colleagues for Excellence publication provides a guideline for treatment planning cracked teeth based on empirical evidence. Treatment depends on the extent of the crack and the pulpal and periapical diagnoses (16). Since the extent of the crack is often difficult to identify, many times the decision to treat is made by the patient's history of symptoms. Early diagnosis and treatment of cracks is prudent to arrest bacterial invasion and re-establish a healthy periodontium to support the tooth.

An understanding of the prevalence of cracks involving the pulp may aid general dentists and endodontists with treatment planning decisions. Studies have shown mandibular molars are the teeth most commonly diagnosed with a crack (20). Teeth with intracoronal restorations are

also more likely to be diagnosed with a crack (20). Early research identified cracks as a possible etiology for pulpal pathology (1, 3). A prospective cohort study from 2006 followed 154 cracked teeth over a one year period and found 42.2 % required root canal therapy (21). These studies suggest the etiology of pulpal pathosis is bacterial infection via a crack. However, no studies have specifically focused on the prevalence or incidence of cracks in maxillary premolars extending into the pulp chamber (20). In 2014, Lawson (22) evaluated the prevalence and predictive factors of intrapulpal cracks in mandibular molars. He found that age, probing depth greater than 4mm, positive transillumination, and pain on biting were predictive factors for an intrapulpal crack. This study is based on a similar design. Information regarding the predictive factors and classification of intrapulpal cracks will provide a more objective determination for treatment of these teeth.

The purpose of this study was to evaluate the prevalence of intrapulpal cracks in maxillary premolars treatment planned for NSRCT or RETX at the VCU Endodontic Residency Practice, classify these cracks using the Intrapulpal Crack Classification System, and to investigate pre-operative clinical findings that may be predictive for an intrapulpal crack.

Materials and Methods

This study utilized a prospective dental chart review design to determine the prevalence and location of intrapulpal cracks documented during routine evaluation and endodontic treatment at VCU School of Dentistry's Graduate Endodontic Practice. The Institutional Review Board approved the study (IRB #HM20000335). Patients referred to the practice for evaluation and NSRCT or RETX of maxillary premolars from January 2014 through February 2015 were included in the study. Patients were referred from VCU's predoctoral clinic, advanced education practice, faculty practice, or private practice. No clinical protocol was altered for the sake of the study.

The endodontic practice has an established clinical protocol for treating patients with intrapulpal cracks (Appendix). This includes gathering subjective data regarding the patient's chief complaint, history of symptoms, dental treatment history, and reason for referral to an endodontic practice. The clinical diagnostic testing for a suspected intrapulpal crack involves the following: cold test, bite test, percussion test, palpation, mobility, probing, and transillumination. All diagnostic information was recorded in the electronic dental record (axiUm Dental Software, BC Canada) along with radiographs and clinical photographs (MiPACS Dental Enterprise Solution, Medicor Imaging, North Carolina). A pulpal and periapical diagnosis was made prior to initiating treatment.

If non-surgical root canal therapy was indicated, the treating endodontic resident explained the aims of the study and presented the patient with a consent form (Appendix). Once all of the patient's questions were answered regarding the study and the patient decided to be part

of the study, the patient and resident signed the consent. All residents were calibrated to present the study and obtain consent in the same manner. If the patient declined to participate in the study, the same clinical protocol was followed but the patient's information was not included in the data analysis. Three patients agreed to be part of the study, signed the consent, but elected to have his/her tooth extracted. These teeth were examined for an intrapulpal crack before or after extraction and included in the analysis. If the tooth was deemed restorable by the resident, the patient was anesthetized and the tooth isolated. The tooth was visually inspected without magnification for a crack, transilluminated, and stained using a unidose of Vista Blue™ (Vista Dental Products, Racine, WI) methylene blue stain applicator. The tooth was stained for one minute and rinsed using 5.25% sodium hypochlorite. The resident again visually inspected the tooth for a crack. If a crack was present, the resident took a clinical photograph of the crown of the tooth at a magnification of 1.0 using an OPMI pico dental microscope (Carl Zeiss Meditec, Jena, Germany). Next, the resident accessed the tooth and inspected the pulp chamber walls and floor for a crack using the same microscope at a magnification of 1.6. (The OPMI pico microscope provides 5 magnification settings: 0.4, 0.6, 1.0, 1.6, and 2.5, which correspond to the following magnifications, depending on the focal length of the objective: 250 nm: 3.40x, 5.10x, 8.50x, 13.60x, 21.25x; 300 nm: 2.83x, 4.25x, 7.08x, 11.33x, 17.71x). The pulp chamber walls and floor were stained, using the same method, and microscopically examined for a crack. If an intrapulpal crack was present, VCU's Intrapulpal Crack Classification System was used to document the location and extent of the crack. The information gathered regarding a cracked tooth was recorded on a data sheet (Appendix) and included in the patient's electronic health record.

At the end of the study period, the information was analyzed to determine the prevalence and classification of cracks present in maxillary premolars presenting to the Graduate Endodontic Practice for root canal therapy as well as any predictive clinical factors. Data was summarized using percentages, means, and standard deviations as appropriate. All analyses were performed using SAS software (JMP version 10, SAS Institute Inc., Cary, NC). Comparisons were done using chi-square test or multiple logistic regression. Significance was declared at alpha less than 0.05.

Results

The first section of results describes the 76 cases and the values of the variables recorded. In the second section, the associations between individual characteristics and cracked teeth are explored. In the third section, the associations between individual predictors for intrapulpal cracks are addressed.

Description of cases

Between January 22, 2014 and February 13, 2015, 76 cases met the selection criteria (Table 1). Nearly 56% of cases were from females (43 females and 33 males) and 54% of all cases were second premolars (35 first premolars and 41 second premolars). The average age of patients was 45.9 years (SD = 15.8, range = 18 to 77 years). Nearly 79% (60/76) were teeth with two canals and almost all were not the most distal tooth. Teeth with no restorations comprised 30% (23/76) of the total, and the remaining 70% (53/76) exhibited a variety of restorations. Restorations included one, two, three, or four surface fillings and full coverage crowns with 33% of teeth having 2 surface restorations and 20% with crowns.

Table 1. Description of Cases

Characteristic	N	Percent
Tooth #		
4	18	24
5	14	18
12	21	28
13	23	30
# of canals		
1	13	17
2	60	79
3	3	4
Most distal tooth		
N	73	96
Y	3	4
Type of restoration		
none	23	30
1 surface	4	5
2 surface	25	33
3 surface	6	8
4 surface	3	4
crown	15	20

Note: Percentages may not add to 100 due to rounding.

Subjective questions recorded at initial patient intake are described in Table 2 along with probing depths and the provider's ability to visualize a crack at the initial visit. Only fourteen cases (18%) were referred for the evaluation of a suspected crack. In 33 cases (43%) patients reported a history of pain provoked by chewing or biting.

Table 2. Referral and Patient History

Characteristic	N	Percent
Is this tooth being referred to you for an evaluation of a suspected crack?		
N	62	82
Y	14	18
Does the patient report a history of pain provoked by chewing/biting?		
N	43	57
Y	33	43
Has this patient ever been told there is a crack in the tooth?		
N	64	84
Y	12	16
Are there any probing depths greater than 4 mm around the tooth?		
N	65	86
Y	11	14
Can you visualize a crack, or confirm presence of an apparent crack, with transillumination?		
N	61	80
Y	15	20

Note: Percentages may not add to 100 due to rounding.

There were 45 teeth found to be necrotic (59%), 27 teeth were vital (36%), and 4 teeth were previously treated (5%). The apical diagnoses varied, with the majority of teeth (58%) presenting with symptomatic apical periodontitis. This clinical history is recorded in Table 3.

Table 3. Clinical History

Characteristic	N	Percent
Vital, Necrotic, Previously Treated		
V	27	36
N	45	59
PT	4	5
Apical diagnosis		
Symptomatic Apical Periodontitis	44	58
Asymptomatic Apical Periodontitis	7	9
Acute Apical Abscess	1	1
Chronic Apical Abscess	4	5
Chronic Apical Periodontitis	2	3
Normal	18	24
Etiology		
Caries	46	61
Recurrent caries	3	4
Caries/fracture	1	1
Crack	2	3
Fracture	1	1
Occlusal trauma	1	1
Restorative trauma	18	24
Post-treatment disease	2	3
N/A (prophylactic endo)	1	1
?	1	1

Note: Percentages may not add to 100 due to rounding.

The primary outcome of interest was the presence or absence of a cracked tooth, although there were determined to be two types of cracked teeth. There were 8 teeth with intrapulpal cracks (11%, 95% CI = 5.4 to 19.4%), including 5 that also had a superficial crack. There were 7 teeth with only a superficial crack (9%, 95% CI = 4.5 to 17.8%) and 61 with no cracks (80%).

Using the Intrapulpal Crack Classification System (Table 4), the intrapulpal cracks were categorized based on their location relative to walls and orifices. Three teeth had a crack extending down one wall (Type IA), two teeth had cracks extending down two walls (Type IIA), one tooth had a crack extending down one wall and into one orifice (Type IB), and two teeth had a crack extending down two walls and into one orifice (Type IIB).

Table 4. Intrapulpal Crack Classification

	Wall(s) only	Wall(s) and orifice	Wall(s) and partially across floor	Wall(s) and across entire floor
1 Wall	IA	IB	IC	ID
2 Walls	IIA	IIB	IIC	IID

Association between Clinical Predictors and Cracked Teeth

In order to test for characteristics that may be associated with a cracked tooth, the analysis proceeded in two stages. The first stage of preliminary analysis looked at the association between the outcome and each characteristic, ignoring all of the other characteristics. This preliminary analysis screened each characteristic to determine which characteristics may be included in the final analysis. In the final analysis, a multiple logistic regression was used to determine which of the successfully screened variables remain statistically significant when all the other characteristics are adjusted for.

There was no association between a tooth's cracked status and sex ($P>0.4$, Table 5) nor was there an association with age (data not shown, $P>0.27$). First premolars were more likely to be cracked (31% vs 10% in second premolars), but there did not appear to be a difference between intrapulpal and superficial ($P = 0.02$). Although none of the teeth with 3 canals were cracked, there was no apparent association with the number of canals ($P> 0.7$). There was an association with the size of the restoration; no teeth with 3 or more surfaces restored (including crowns) were cracked ($P<0.002$). There was no apparent association with pain on biting ($P>0.6$). There was a clear association with probing depths greater than 4 millimeters (mm) ($P < 0.002$) and transillumination was associated with crack status ($P < .0010$).

Table 5. Screening predictive characteristics

	Cracked status? % (n)						
Characteristic	Intrapulpal crack		Superficial crack		No crack		Total
Gender							
F	14	(6)	7	(3)	79	(34)	(43)
M	6	(2)	12	(4)	82	(27)	(33)
Chi-square P = 0.4228							
Tooth Type							
P1	17	(6)	14	(5)	69	(24)	(35)
P2	5	(2)	5	(2)	90	(37)	(41)
Chi-square P = 0.0211							
# of canals							
1	8	(1)	15	(2)	77	(10)	(13)
2	12	(7)	8	(5)	80	(48)	(60)
3	0	(0)	0	(0)	100	(3)	(3)
Chi-square P = 0.7325							
Surfaces restored							
<=2 surfaces	15	(8)	13	(7)	71	(37)	(52)
>=3 surfaces	0	(0)	0	(0)	100	(24)	(24)
Chi-square P = 0.0015							
Pain on biting							
N	9	(4)	7	(3)	84	(36)	(43)
Y	12	(4)	12	(4)	76	(25)	(33)
Chi-square P = 0.6642							
Probing > 4mm							
N	6	(4)	6	(4)	88	(57)	(65)
Y	36	(4)	27	(3)	36	(4)	(11)
Chi-square P = 0.0018							
Did transillumination reveal crack?							
N	0	(0)	0	(0)	100	(61)	(61)
Y	53	(8)	47	(7)	0	(0)	(15)
Total	11	(8)	9	(7)	80	(61)	(76)
Chi-square P = <.0001							

Adjusted Analyses

All of the previous analyses looked at the relationship of a single predictor to the outcome of interest. The following characteristics were found to be related to cracked teeth when all other characteristics were ignored: tooth type (first or second premolar), surfaces restored, probing depth, and transillumination. Since transillumination was exactly related to the presence of a

crack, it was not included in the multiple logistic regression. A logistic regression analysis indicated that the other three factors were significantly related to crack status (P<0.01, Table 6 and 2 or less restored surfaces Figure 1).

The bar on the right of Figure 1 shows the prevalence of cracks overall. The largest proportion is no crack (the white area, approximately 80%). There are roughly equal proportions of superficial cracks (9%) and intrapulpal cracks (11%). These proportions vary by the number of surfaces restored, probing depth, and tooth type. Moving from right to left, none of the 24 teeth with 3 or more surfaces restored had either type of crack (wholly white area). Looking at the three groups of teeth with 2 or fewer surfaces restored moving from right to left, there is an increasing proportion of cracks. In the 26 second premolars with probing depths less than 4mm, 4% had an intrapulpal crack and 8% had an superficial crack. In the 17 first premolars with probing depths less than 4mm, 18% had an intrapulpal crack and 12% had a superficial crack. In the 9 premolars with probing depths greater than 4mm, 44% had an intrapulpal crack and 33% had a superficial crack.

Table 6. Risk groups

			Cracked status? % (n)						
Restored surfaces	Probing >4mm	Tooth type	Intrapulpal crack		Superficial crack		No crack		Total
2 or less	Yes	(all)	44	(4)	33	(3)	22	(2)	(9)
"	No	P1	18	(3)	12	(2)	71	(12)	(17)
"	"	P2	4	(1)	8	(2)	88	(23)	(26)
3 or more	(all)	(all)	0	(0)	0	(0)	100	(24)	(24)

Chi-square = 29.7, df=14, P=0.0085.

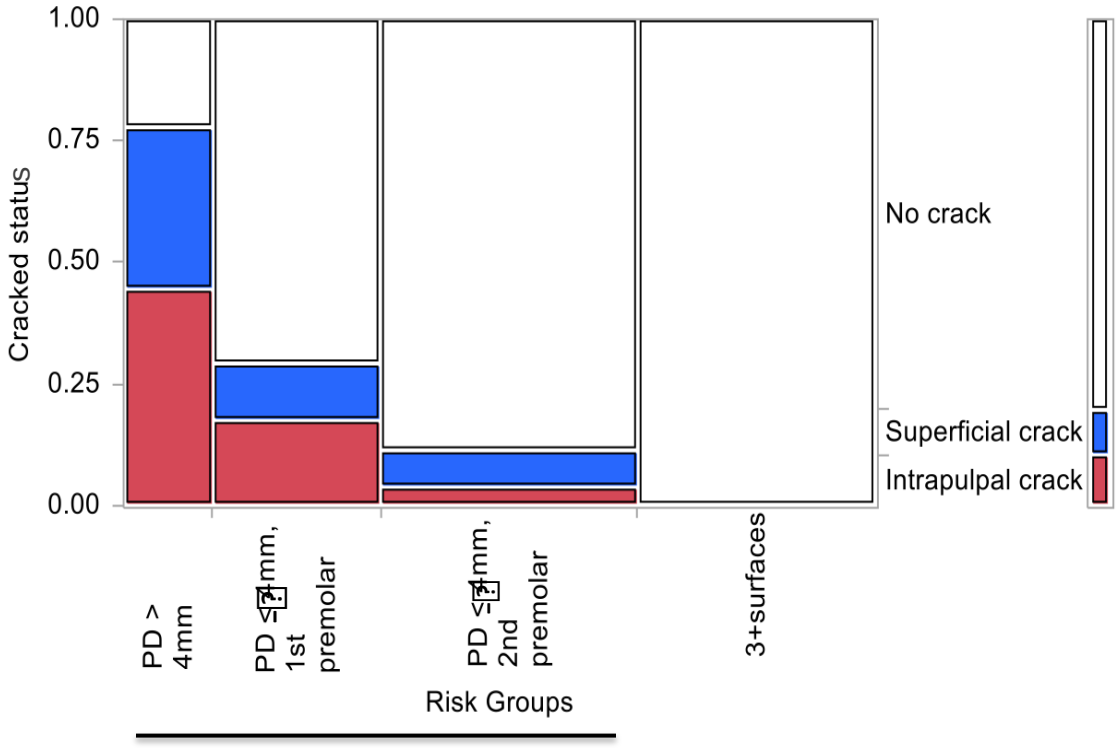

Figure 1. Logistic regression depicting relationship between restored surfaces, probing depth, tooth type and crack status

Discussion

The maxillary premolar cases included in this study represent a relatively even number of males and females as well as first and second premolars. Tooth type, surfaces restored, probing depths, and transillumination were found to be associated with the presence of an intrapulpal crack. An intrapulpal crack was present in 11% (8/76) of teeth and a superficial crack was present in 9% (7/76) of teeth with a total of 20% of teeth having cracks.

In a study by Lawson (22) evaluating predictive factors for intrapulpal cracks in mandibular molars, age greater than 40 years old, probing depth greater than 4mm, positive transillumination, and pain on biting were associated with the presence of a crack. Two of these four predictive factors (probing, transillumination) were also found to be associated with intrapulpal cracks in maxillary premolars. Abou-Rass found teeth with restorations more likely to have a crack than unrestored teeth in his 1983 survey of 120 cracked teeth (4), although he found no difference in the likelihood of a crack based on the number of surfaces restored. He also found an incidence of 19.2% for cracked maxillary premolars. This is similar to the overall prevalence of cracks (20%) in the present study. A literature review by Lubisich (20) averaged the incidence of cracked teeth from twelve studies and reported 16% of cracked teeth are maxillary premolars. This overall incidence of cracks in maxillary premolars is similar to the 20% prevalence of superficial and intrapulpal cracks found in this study. The literature to date states the incidence of cracked maxillary premolars ranges from 1-28% (20).

The published literature on associations between restorations and cracked teeth is contradictory (4, 13, 23, 24). Bader and Cavel (13, 23) found, in two separate studies, that a

greater percentage of restored tooth surface results in a greater chance of a crack. This finding is different than the current study that found teeth with fewer restored surfaces resulted in a higher prevalence of intrapulpal cracks. However, Beavers completed a study in 2015 evaluating associations between restoration volume proportion and cracks. He found small restorations were associated with more extensive intrapulpal cracks (24). Roh also found teeth with no or small restorations were more likely to be cracked than teeth with large restorations (22). These findings are in agreement with the current study.

Interestingly, tooth type but not number of canals proved to be a predictive factor in this study. Based on morphology studies (25-27), maxillary first premolars have two canals a larger percentage of the time than maxillary second molars. In this study, maxillary first premolars were cracked a larger percentage of the time than maxillary second premolars, but premolars with two canals were not more likely to be cracked than teeth with one canal. The anatomy of a premolar with two canals suggests it may be more prone to fracture due to the presence of a furcation, chamber floor, and less dentin present in the cervical region of the tooth. However, the presence of two canals does not necessarily suggest the presence of two roots. Excessive occlusal forces on maxillary first premolars due to group function may play a role in producing cracks in these teeth a higher percentage of the time than second premolars. Additional studies with larger case numbers and the ability to determine not only canal number but also root number may be necessary to tease out a potential association of two rooted premolars with the presence of a crack.

Teeth with 2 or fewer surfaces restored were more likely to have an intrapulpal crack than teeth with 3 or more surfaces restored. Instead of compromising the integrity of the remaining tooth structure, larger restorations and full coverage restorations may have a

protective effect on premolar teeth. More studies with large sample sizes need to be completed in order to support this finding.

Probing depths greater than 4mm were associated with the presence of an intrapulpal crack. Increased probing depths result from periodontal breakdown. This can be a result of bone loss in an isolated area of the tooth, generalized bone loss around the entire tooth, or hyperplastic gingiva (pseudo pockets). A crack on the root surface of a tooth compromises the periodontal ligament and associated fibrous and bony attachments to this isolated area. Based on the location of the pulp chamber relative to the level of crestal bone, intrapulpal cracks often extend to the root surface. Subsequent pocket formation would result in these areas, leading to increased probing depths.

Teeth positive to transillumination were also associated with the presence of an intrapulpal crack. Light will continue to penetrate through coronal tooth structure until it meets a space. In a tooth with a crack, this leads to the portion of the tooth next to the light illuminating, the light reflecting back when it hits the crack, and the portion of the tooth on the other side of the crack remaining dark. This represents an objective diagnostic test based on the laws of physics that may allow dentists to more predictably diagnose the presence of a crack in premolars. However, distinguishing between a superficial and intrapulpal crack using only this method is difficult.

This study, like any other study, has limitations inherent in the design. Despite the residents' ability to identify intrapulpal cracks present on the walls or floor of a pulp chamber, a crack extending through the roof of the pulp chamber but not down any walls is difficult to identify as an intrapulpal crack. If this situation was present in teeth included in the study, it would have been classified as a superficial crack. This suggests the percentage of intrapulpal

cracks may be higher than 11%. Additionally, the Intrapulpal Crack Classification System categorizes a crack based on its presence or absence on the walls, floors, and orifices of a pulp chamber. Three teeth had a Type IA crack, two teeth had a Type IIA crack, one tooth had a Type IB crack, and two teeth had a Type IIB crack. The three teeth with cracks present on two walls were extracted. All others were endodontically treated and definitively restored. Since a number of premolars do not have a true chamber floor, this system may not be appropriate for classifying premolars. Perhaps a system including a comprehensive look at the surfaces restored, periodontal health, and ability to visualize a crack could be developed to better predict the prognosis of these teeth instead of relying solely on a dentist's ability to visualize the extent of cracks in teeth.

Etiology of disease was recorded for each patient, but this also had limitations. Many teeth requiring NSRCT or RETX have an unclear etiology of disease. Restorative trauma, occlusal trauma or a crack may be considered in cases where primary or recurrent caries are not evident in the tooth. However it is difficult to definitively categorize etiology, therefore, that information was omitted from the analysis.

Transillumination was found to be exactly related to the presence of a crack. This is likely due to the sample size. A study performed with a larger sample size would inevitably show variability in the association of transillumination with the presence of a crack.

Unlike the results found from Lawson's 2014 study, pain on biting was not identified as a predictive factor for the presence of a crack. He found that a positive result from the bite stick test was associated with the presence of a crack in mandibular molars receiving NSRCT. The results of the bite stick test in the present study were not comprehensive and were omitted from the final analysis. The subjective results of questioning the patient as to whether or not they were

experiencing pain on biting were used in the data analysis. Resident compliance with performing the bite stick test could be improved in future studies.

In conclusion, intrapulpal cracks were found in 11% of premolars treatment planned for NSRCT or RETX. Predictive factors associated with the presence of an intrapulpal crack included tooth type, surfaces restored, probing depths, and transillumination. Additional studies with larger sample sizes are needed to better understand methods to predictably diagnose and project the prognosis of teeth with intrapulpal cracks allowing dentists to make evidence based treatment decisions.

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Appendices

RESEARCH PARTICIPANT INFORMATION AND CONSENT FORM

TITLE: The prevalence and classification of intrapulpal cracks in maxillary premolars requiring non-surgical root canal therapy
VCU IRB PROTOCOL NUMBER: HM20000335
INVESTIGATOR: Dr. Karan Replogle

If any information contained in this consent form is not clear, please ask the study doctor to explain it to you. You may take home an unsigned copy of this form. In this consent, "you" always refers to the research participant.

PURPOSE OF THE STUDY
The purpose of this research study is to count the number of teeth with cracks treated in the Virginia Commonwealth University Graduate Endodontic Clinic. Only a certain kind of tooth will be included in the study – upper premolar teeth. You are being asked to participate in this study because you have an upper premolar tooth requiring a root canal.

DESCRIPTION OF THE STUDY
This study aims to identify the number of upper premolar teeth with cracks requiring non-surgical root canal therapy or retreatment. The care provided to you in our clinic is the standard of care. Your dental care will be the same as it would have been without the research study. All of the information used for this research is normally recorded for your dental care. For this study, your information will be analyzed at the end of the study period to understand how many upper premolar teeth treated in our clinic have cracks.

PROCEDURES
If you decide to be in this research study, you will be asked to sign this consent form after you have had all your questions answered. Treatment will not be altered due to this study.

Your tooth will be visually examined for a crack before initiating endodontic treatment using a blue dye. The dye stains cracks and makes them easier to see. The tooth will be examined for a crack again, using a microscope and dye, during treatment. Information regarding the presence of a crack, diagnosis, depth of pocket between gum tissue and tooth, and clinical findings will be recorded in your electronic dental health record and analyzed. This information is normally collected in our clinic for all teeth with cracks. The study will analyze the recorded measurements for a group of these teeth (upper premolars).

RISKS AND DISCOMFORTS
There are no risks or discomforts associated with this study.

BENEFITS TO YOU AND OTHERS
Knowing how often cracks occur can help endodontists diagnose and make treatment decisions in the future. This information may offer the dental community a better understanding of the outcome for these teeth.

COSTS
There are no costs to the study subject for this research.

PAYMENT FOR PARTICIPATION
Participants will not be compensated for their participation in this study.

CONFIDENTIALITY
Data is being collected only for research purposes. Your data will be de-identified. A random code will be assigned to your information, and the key to this code will be kept in a locked research area. The key will be destroyed at the end of the study. Access to all data will be limited to study personnel.

Although results of this research may be presented at meetings or in publications, identifiable personal information pertaining to participants will not be disclosed.

VOLUNTARY PARTICIPATION AND WITHDRAWAL
Your participation in this study is voluntary. You may decide to not participate in this study. Your decision not to take part will involve no penalty or loss of benefits to which you are otherwise entitled.

QUESTIONS
If you have any questions, complaints, or concerns about your participation in this research, contact:

Sarah Krygowski
Virginia Commonwealth University
School of Dentistry
Department of Endodontics
520 North 12th Street
Richmond, VA 23298-0566
Phone: (804) 628-1552
Fax: (804) 828-1373

If you have general questions about your rights as a participant in this or any other research, you may contact:

Office of Research

Virginia Commonwealth University
800 East Leigh Street, Suite 3000
P.O. Box 980568
Richmond, VA 23298
Telephone: (804) 827-2157

Contact this number for general questions, concerns, or complaints about research. You may also call this number if you cannot reach the research team or if you wish to talk to someone else. General information about participation in research studies can also be found at http://www.research.vcu.edu/irb/volunteers.htm.

Do not sign this consent form unless you have had a chance to ask questions and have received satisfactory answers to all of your questions.

CONSENT

I have been provided with an opportunity to read this consent form carefully. All of the questions that I wish to raise concerning this study have been answered.

By signing this consent form, I have not waived any of the legal rights or benefits, to which I otherwise would be entitled. My signature indicates that I freely consent to participate in this research study. I will receive a copy of the consent form once I have agreed to participate.

_____
Participant Name, printed

_____ _____
Participant Signature Date

_____ _____
Study Doctor Signature Date

Maxillary Premolars Requiring NSRCT or RETX

Resident: _____ Date: _____
Pt Axium #: _____ Tooth #: _____

SUBJECTIVE QUESTIONS

Is this tooth being referred to you for evaluation of a suspected crack? **Yes No**
Does the patient report a history of pain provoked by chewing/biting? **Yes No**
Has this patient ever been told there is a crack in the tooth? **Yes No**
Do you, as the resident, expect to find a crack in the tooth? **Yes No**

CLINICAL EXAM

Is this the last tooth in the arch? **Yes No**
Are there any probing depths greater than 4 mm around the tooth? **Yes No**
Can you visualize a crack? **Yes No**
Can you visualize a crack, or confirm presence of an apparent crack, with transillumination? **Yes No**

MICROSCOPE AND STAINING

After rubber dam placement and prior to access, take clinical photograph of occlusal surface of tooth at magnification of 0.6.

After cleaning and shaping the root canal system, inspect the chamber for an intrapulpal crack under magnification of 1.0. Is one present? **Yes No**

Stain pulp chamber with methylene blue for 1 minute. Rinse with NaOCl, dry, and inspect chamber for crack under magnification of 1.0. Did staining reveal or confirm presence of crack? **Yes No**

Do you think staining helped identify a crack? **Yes No**

If a crack is present, please classify according to chart below: _____
Intrapulpal Crack Classification

	Wall(s) only	Wall(s) and orifice	Wall(s) and partially across floor	Wall(s) and across entire floor
1 Wall	IA	IB	IC	ID
2 Walls	IIA	IIB	IIC	IID

Data Listing

#	Tooth	Gender	Age	Suspect crack?	Pain on Biting?	Pt told a crack present?	Probing > 4mm	Did trans reveal crack?	Type of restoration	Pulpal diag	Apical diag	Crack before staining?	Crack after staining?	most distal tooth
1	5	F	45	N	Y	N	N	N	2 surface	Necrotic	SAP	N	N	N
2	13	F	23	N	N	N	N	N	none	SIP	SAP	N	N	N
3	4	F	59	N	N	N	N	N	2 surface	AIP	Normal	N	N	N
4	13	F	61	N	Y	N	N	N	3 surface	PIT	SAP	N	N	N
5	4	F	29	N	Y	N	N	N	none	SIP	SAP	N	N	N
6	13	F	45	N	Y	N	Y	N	none	Necrotic	AAA	N	N	N
7	12	M	52	N	N	N	N	N	crown	Necrotic	SAP	N	N	N
8	12	M	57	N	Y	N	Y	N	2 surface	Necrotic	CAA	N	N	N
9	5	M	57	N	Y	Y	Y	Y	2 surface	Necrotic	CAA	Y	N	N
10	13	F	57	N	N	N	N	N	crown	Necrotic	SAP	N	N	N
11	13	M	77	N	N	N	N	Y	none	Normal	Normal	Y	N	N
12	5	M	53	N	N	N	N	N	2 surface	PIT	AAP	N	N	N
13	4	F	31	N	N	N	N	N	none	SIP	SAP	N	N	N
14	5	M	56	Y	N	Y	Y	N	crown	PIT	SAP	N	N	N
15	13	F	24	N	N	N	N	N	2 surface	Necrotic	SAP	N	N	N
16	4	F	30	N	N	N	N	N	none	AIP	Normal	N	N	N
17	12	F	34	N	N	N	N	N	none	AIP	Normal	N	N	N
18	13	F	30	N	N	N	N	N	none	AIP	SAP	N	N	N
19	4	F	34	N	Y	N	N	N	none	AIP	SAP	N	N	N
20	13	M	32	N	Y	N	N	N	none	SIP	SAP	N	N	N
21	12	F	44	N	Y	N	N	N	3 surface	PIT	SAP	N	N	N
22	4	F	48	N	N	N	N	N	1 surface	PIT	SAP	N	N	N
23	13	M	67	N	Y	N	N	N	3 surface	Normal	SAP	N	N	N
24	13	F	66	N	N	N	N	N	crown	Necrotic	SAP	N	N	N
25	13	M	18	N	N	N	N	N	none	Necrotic	CAA	N	N	N
26	12	F	49	N	N	N	N	N	crown	Necrotic	AAP	N	N	N

#	Tooth	Gender	Age	Suspect crack?	Pain on Biting?	Pt told a crack present?	Probing > 4mm	Did trans reveal crack?	Type of restoration	Pulpal diag	Apical diag	Crack before staining?	Crack after staining?	most distal tooth
27	12	F	57	N	N	N	N	N	2 surface	SIP	Normal	N	N	N
28	13	F	66	Y	Y	Y	Y	Y	none	Necrotic	SAP	Y	N	N
29	13	F	60	N	N	N	N	N	4 surface	SIP	SAP	N	N	N
30	4	F	24	N	N	N	N	N	none	AIP	SAP	N	N	N
31	4	M	48	N	N	N	N	N	crown	PIT	SAP	N	N	N
32	13	M	36	Y	Y	Y	N	N	3 surface	PT	SAP	N	N	N
33	5	F	29	Y	N	N	N	Y	2 surface	PIT	Normal	Y	N	N
34	5	M	33	N	Y	N	N	N	2 surface	Necrotic	AAP	N	N	N
35	4	F	38	N	N	N	N	N	2 surface	AIP	Normal	N	N	N
36	4	F	67	Y	Y	N	N	N	crown	Necrotic	SAP	N	N	N
37	4	F	43	N	N	N	N	N	none	SIP	Normal	N	N	N
38	4	M	42	N	N	N	N	N	none	Necrotic	SAP	N	N	N
39	12	F	35	N	N	N	N	N	1 surface	PIT	Normal	N	N	N
40	12	M	71	Y	Y	Y	Y	Y	2 surface	Necrotic	SAP	Y	N	N
41	5	M	57	Y	Y	N	Y	Y	2 surface	Necrotic	SAP	Y	N	N
42	5	F	24	N	Y	N	N	N	none	SIP	Normal	N	Y (IA)	N
43	12	M	55	N	Y	Y	N	Y	2 surface	PIT	SAP	Y	Y (IIA)	N
44	12	F	36	Y	N	Y	N	Y	1 surface	PT	Normal	Y	N	N
45	4	M	43	N	N	N	N	N	2 surface	Necrotic	SAP	N	N	N
46	12	M	44	N	N	N	N	N	4 surface	Necrotic	CAA	N	N	N
47	13	F	24	N	N	N	N	N	2 surface	PIT	Normal	N	Y (IA)	N
48	4	F	56	Y	N	Y	N	Y	2 surface	Normal	Normal	N	Y (IA)	N
49	5	F	39	N	N	N	N	Y	none	Necrotic	AAP	Y	N	N
50	13	M	75	N	Y	N	N	N	crown	Necrotic	SAP	N	N	N
51	12	F	30	N	Y	N	N	N	2 surface	SIP	SAP	N	N	N
52	5	M	62	N	N	Y	N	N	none	AIP	Normal	N	N	N
53	13	F	44	N	Y	N	N	N	2 surface	Necrotic	Normal	N	N	N
54	13	M	49	N	N	N	N	N	2 surface	AIP	Normal	N	N	N
55	12	F	20	N	Y	N	N	N	3 surface	SIP	SAP	N	N	N

#	Tooth	Gender	Age	Suspect crack?	Pain on Biting?	Pt told a crack present?	Probing > 4mm	Did trans reveal crack?	Type of restoration	Pulpal diag	Apical diag	Crack before staining?	Crack after staining?	most distal tooth
56	12	M	77	N	Y	N	N	N	4 surface	Necrotic	SAP	N	Y (IIA)	N
57	5	F	49	Y	N	Y	Y	Y	2 surface	PIT	SAP	Y	N	Y
58	13	M	42	N	N	N	N	N	3 surface	Necrotic	AAP	N	N	N
59	5	M	57	Y	Y	Y	Y	Y	none	Necrotic	CAP	Y	N	N
60	12	M	25	N	Y	N	N	N	crown	Necrotic	CAP	N	N	N
61	12	F	35	N	Y	N	N	N	2 surface	Necrotic	SAP	N	N	N
62	4	M	49	N	Y	N	N	N	crown	PIT	SAP	N	N	Y
63	12	F	67	Y	Y	Y	Y	Y	None	Necrotic	SAP	Y	N	N
64	13	M	56	N	N	N	N	N	1 surface	Necrotic	AAP	N	N	N
65	13	F	36	N	N	N	N	Y	2 surface	PT	Normal	Y	N	N
66	5	F	67	N	N	N	N	N	crown	Necrotic	SAP	N	N	N
67	12	F	21	Y	Y	N	N	Y	None	SIP	SAP	Y	N	N
68	13	M	40	N	N	N	N	N	None	SIP	SAP	N	N	N
69	12	F	31	N	Y	N	N	N	2 surface	Necrotic	SAP	N	N	N
70	12	F	58	N	N	N	N	N	None	AIP	Normal	N	N	N
71	4	M	22	N	N	N	N	N	2 surface	SIP	SAP	N	N	N
72	4	M	27	N	Y	N	N	N	2 surface	Necrotic	SAP	N	N	N
73	4	M	70	Y	Y	N	Y	N	crown	SIP	SAP	N	N	N
74	12	F	44	N	N	N	N	N	crown	PT	AAP	N	Y (IIB)	N
75	5	M	70	N	N	N	N	N	crown	Necrosis	SAP	N	Y (IB)	Y
76	13	M	62	N	Y	N	N	N	crown	Necrosis	SAP	N	Y (IIB)	N

Vita

Dr. Sarah Krygowski was born on March 4, 1983 in Arlington, Virginia and is a United States citizen. She received a Bachelor of Arts in Art History and a Bachelor of Arts in Mathematics from Williams College in 2005. Following graduation, she worked at an art gallery in New York City for two years before completing the pre-dental requirements for application to dental school. Dr. Krygowski subsequently earned a Doctor of Dental Medicine degree from Harvard School of Dental Medicine in 2013 graduating Cum Laude. She is a member of the American Dental Association and the American Association of Endodontists. Dr. Krygowski will graduate from Virginia Commonwealth University with a Master of Science in Dentistry and a Certificate in Endodontics and plans to join a private practice in western Massachusetts.