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Restorative Characteristics of Intrapulpally Cracked Teeth

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VCU

Restorative characteristics of intrapulpally cracked teeth

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

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Table of Contents

List of Tables iv

List of Figures v

Abstract vi

Introduction 3

Materials and Methods 7

Results 11

Discussion 26

List of References 36

Vita 38

List of Tables

Table 1. VCU Intrapulpal Crack Classification System 15

Table 2. Distributions of demographic data and independent variables 15

Table 3. Distributions of dependent variables Crack Direction, Crack Location, Pulpal Walls Involved, Pulpal Wall Classification, Pulpal Floor Involved, Pulpal Floor Classification, and Pulpal Orifices Involved (n=43)... 16

Table 4. Distributions of dependent variables Pulpal Diagnosis, and Periapical Diagnosis (n=43).. 17

Table 5. Bivariate analysis of the independent variables Tooth Type, Restoration Type, Restoration Surfaces, Restoration Classification, RVP, Restoration Size against dependent variables Crack Direction, Crack Location, Pulpal Walls Involved, Pulpal Wall Classification, Pulpal Floor Involved, Pulpal Floor Classification, Pulpal Orifices Involved, Pulpal, and Periapical Diagnosis (n=43). 18

List of Figures

Figure 1. Formula for calculation of Estimated Restoration Volume Proportion............ 19

Figure 2. Stacked columns illustrating the relationship between Restoration Size and Crack Location (n=40). 20

Figure 3. Stacked columns illustrating the relationship between Tooth Type and Pulpal Walls Involved (n=42). 21

Figure 4. Stacked columns illustrating the relationship between Restoration Classification and Pulpal Walls Involved (n=41) 22

Figure 5. Stacked columns illustrating the relationship between Restoration Surfaces and Pulpal Wall Classification... 23

Figure 6. Stacked columns illustrating the relationship between Restoration Size and Pulpal Wall Classification... 24

Figure 7. Stacked columns illustrating the relationship between Tooth Type and Pulpal Diagnosis... 25

Abstract

RESTORATIVE CHARACTERISTICS OF INTRAPULPALLY CRACKED TEETH

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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.

Virginia Commonwealth University, 2014

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Cracked teeth have long presented a diagnostic challenge. Previous investigators have considered possible predictive factors, many of which revolve around the tooth's restorative characteristics. Few have investigated the restorative status of teeth with cracks extending into the pulp chamber. The purpose of this investigation was to determine the prevalence of the different types of restorations present in intrapulpally cracked teeth and determine any other restorative factors that may aid in predicting the presence or extent of an intrapulpal crack. Intrapulpally cracked molars requiring endodontic therapy at the VCU Graduate Endodontic Practice were included in this study. For each tooth, the type of restorative material present and surfaces involved were recorded. The Restoration Volume Proportion (RVP) was calculated to accurately quantify the size of the restoration present. Pulpal and periapical diagnoses, and intrapulpal crack classification were also recorded. Chi squared analysis and logistic regression

were used to determine any significant associations. This study included 43 teeth. The study population was 65% female and the average age was 56. Of the various restoration types evaluated, 73% of teeth presented with amalgams, 12% with composites. Class I restorations were 61% of the sample. The most frequently occurring restoration size by volume was a "small" restoration. The most commonly involved teeth were the maxillary 1st molar and mandibular 2nd molar. A significant association was found between restoration size and crack classification suggesting that teeth with larger restorations had a higher incidence of coronal cracks while those with smaller restorations had a higher incidence of radicular cracks. Restoration classification and pulpal walls involved were also significantly associated suggesting that Class II restorations were most frequently associated with cracks involving a single pulpal wall while Class I restorations were evenly associated with one and two wall cracks. Other significant associations were found between tooth type and pulpal walls involved and between restoration surfaces and pulpal wall classification. This study found several significant associations between restoration characteristics and intrapulpal cracks. Further research may continue to reveal how a tooth's restorative status may influence its risk for the presence of an intrapulpal crack.

Introduction

Cracked tooth is defined as an incomplete longitudinal fracture initiated in the crown and extending subgingivally, usually in the mesiodistal direction (1). The detection, diagnosis, and treatment of cracked teeth have long been challenges for the dentist. Patients with cracked teeth can present with a wide range of symptoms and often have difficulty describing their pain. When clinically examining these teeth, diagnostic testing can often produce conflicting results or fail to fully replicate symptoms.

Severe sensitivity to cold food/beverages and erratic pain when chewing, especially upon release after biting, have been described by previous researchers as some of the more common signs and symptoms associated with cracked teeth (2-9). Patients will commonly report that the pain has been difficult to diagnose and that prior dental treatment has failed to permanently alleviate their symptoms. Because cracks are generally not detectable radiographically, the diagnosis is often made based on the patient's history and by ruling out any other potential sources of pain (10). Another challenge lies in the fact that it is clinically difficult to determine how advanced the crack may be and thus, it is problematic to estimate the tooth's prognosis (11, 12).

Given the challenging nature of detecting and diagnosing a cracked tooth, previous studies have aimed to determine clinical factors that may offer some predictive value in identifying cracked teeth. For example, researchers have analyzed many different factors and their possible association with cracked teeth including patient age, sex, tooth type, position of the tooth in the arch, and previous dental restorations.

Several studies have shown that patients 40 years of age or older present with the highest rates of cracked teeth (2, 4, 13, 14). Some research suggests that cracks are more commonly seen in female patients (2, 4, 13, 15), while a recent study found that both sexes are affected equally (14). Multiple studies have reported the frequency of cracks to be highest in mandibular molars (4-6, 9, 16). Cameron theorized that this was likely due to the lingual cusp of the maxillary molar wedging apart the mandibular molar during mastication (13).

Previous research has also investigated the types of dental restorations associated with cracked teeth in an attempt to provide more concrete diagnostic clues; however, they have often found varying results. Roh and Lee found that cracks primarily occur in unrestored teeth (14), while other authors noted that cracks occur mainly in teeth with previous restorations (10, 13, 17, 18). Ratcliff et al reported the risk of fracture to be 29 times greater in a restored tooth as compared to a non-restored tooth (17) whereas Hiatt reported that fractures occurred as readily in sound teeth as heavily restored teeth (5). Several researchers have concluded that teeth with large restorations are prone to fracture (9, 13, 19, 20).

Other investigations have focused on restoration classification based on the number of tooth surfaces involved and analyzed the data for possible associations with cracked teeth. Some researchers have reported that Class II restorations resulted in more cracks as compared to Class I restorations (13). Similarly, Homewood demonstrated that cracks are 3 times more likely to be present when one or two marginal ridges are restored (15). In contrast to this however, certain studies have found that Class I restorations were more commonly associated with cracks than were Class II restorations (5, 14). Other authors found no significant difference in the presence of cracks when comparing Class I vs. Class II restorations (18, 21).

In relation to the types of restorative materials used, previous investigations often suggest that teeth with amalgam or gold inlay restorations were more susceptible to cracks than those restored with bonded resin restorations or porcelain inlays (13, 18). However, Rosen and Bales both reported no difference in the prevalence of cracked tooth when comparing the various restorative materials present (9, 22).

While the impact of restoration type and materials remains unclear, the diagnostic challenges persist and prompt treatment is often required as the cracked tooth can be very painful for patients (13). In theory, when coronal cracks propagate apically into the pulp space, a pathway for bacterial violation has been established and endodontic therapy may be required in an attempt to save the tooth. At Virginia Commonwealth University Graduate Endodontics Practice, teeth with coronal cracks extending into the pulp space are considered "intrapulpally cracked teeth" (23).

Previous studies have shown 18% of cracked teeth had cracks extending into the pulp chamber (16). Additionally, Roh et al found the prevalence of cracks that require endodontic therapy to be around 42.2% (14). Being able to identify teeth that require endodontic therapy is of the utmost importance in general dentistry and endodontics alike, given the goal of preserving the natural dentition while preventing and treating oral disease. While there have been several previous investigations concerning the relationships between restoration types and cracked teeth, the research focus was on cracked teeth in general. Few, if any, studies have specifically looked at the restorative characteristics of intrapulpally cracked teeth.

The purpose of this investigation was to determine the prevalence of various restoration classifications, restoration volumes, and the different types of restorative materials present in intrapulpally cracked teeth (ie those requiring endodontic therapy) treated in the Virginia Commonwealth University Graduate Endodontics Practice. Additionally, the study sought to determine any association these restorative characteristics may have with the type of intrapulpal crack present. This involved comparing the different restoration classifications (unrestored vs. Class I vs. Class II) and the restorative materials present (amalgam vs. gold vs. composite vs. porcelain vs. temporary restorative material) in the intrapulpally cracked teeth. In order to analyze restoration size in a more quantitative fashion, a restoration was classified in terms of its estimated total surface volume. To accomplish this, a Restoration Volume Proportion (RVP) was calculated for each restoration included in this study using methods previously established by Sturdevant et al (24). In his study, tracings completed on an occlusal photograph and a bitewing radiograph could be used to calculate an estimated RVP, which proved to be an accurate method to quantify the relative volume of restorative material present in coronal tooth structure.

Materials and Methods

A prospective clinical study was conducted to analyze specific data for all teeth confirmed to be intrapulpally cracked that were diagnosed and endodontically treated in the VCU Graduate Endodontics Practice between the dates of July 1, 2012 to December 15, 2014. The subjects involved were those patients referred for evaluation and non-surgical root canal therapy (NSRCT) or retreatment (RETX) on any teeth confirmed to have an intrapulpal crack.

The VCU Graduate Endodontics Practice's established clinical protocol for evaluating and treating patients with intrapulpally cracked teeth was utilized in this study. This included gathering patient demographic data and subjective data regarding the patients' dental history. Demographic data collected included sex and age of each patient. Subjective data gathered included questions about the nature of the cracked tooth along with any associated symptoms. Specifically, the treating doctor recorded whether the tooth in question was referred because of a suspected crack, whether the tooth in question had a previously existing restoration, and the age of this restoration. If this data could not be gathered directly from the patient examination, digital progress notes (AxiUm) were reviewed for additional information when applicable. Clinic protocol also involved recording the results of routine endodontic testing such as percussion, palpation, mastication, thermal testing, and electronic pulp testing. In addition, periapical and bitewing radiographs were taken of all teeth in question. This information was then used to determine the pulpal and periapical diagnosis. In order to further diagnose cracks in these teeth, transillumination, surgical microscopic evaluation, periodontal probing, and staining with methylene blue dye were also employed and results recorded. To document the type and size of the restorations present in suspected teeth, occlusal photographs at 0.6 magnification were captured with the surgical operating microscope (Carl Zeiss Meditec, Jena, Germany) and clinicians recorded the type of restorative material present based on routine visual examination.

Existing restoration characteristics were classified into groups based first on the number of tooth surfaces they involved. The specific surfaces were recorded as M,D,F,L,O in any combination that was present for each individual restoration. The restorations were also classified as unrestored, Class I (involving the occlusal surface and/or lateral surfaces only), or Class II (involving the occlusal and at least one other proximal surface). This was referred to as the tooth's "Restoration Classification". The existing restorations were further classified based on the type of restorative materials that were present. Categories included: unrestored, amalgam, composite resin, temporary restorative material, porcelain inlay/onlay, gold inlay/onlay, gold crown, PFM crown, ceramic crown, or temporary crown. This was referred to as the tooth's "Restoration Type". This information was recorded on the "Characteristics of Intrapulpally Cracked Teeth" data collection sheet utilized in the VCU Graduate Endodontics Practice and also scanned into the electronic dental records system (axiUm).

Teeth suspected to be intrapulpally cracked and diagnosed with irreversible pulpitis, pulpal necrosis, or previously treated pulp had endodontic therapy initiated with the patients' consent to perform treatment and consent for participation in this study (IRB# HM20000900). All patients were anesthetized, access to the pulp chamber was completed after rubber dam isolation, and the tooth was stained with a unidose of Vista Blue™ (Vista Dental Products, Racine WI) methylene blue die for 1 minute, rinsed with 5.25% NaOCl to remove excess dye, and evaluated under an OPMI Pico dental microscope (Carl Zeiss Meditec, Jena, Germany) to confirm the diagnosis of an intrapulpally cracked tooth. VCU's Intrapulpal Crack Classification System, developed by Dr. Karan Replogle and Dr. Matthew Detar, was used to document the extent and location of each of the cracks. This included recording the marginal ridge(s) involved, pulpal wall(s) involved, pulpal orifice(s) involved, any pulpal floor involvement, and crack direction (M-D, B-L, or oblique). This information was used to determine each tooth's "Intrapulpal Crack Classification" which included a "Pulpal Wall Classification" and "Pulpal Floor Classification" as seen in the Table 1. For the purposes of data analysis, each cracked tooth was further grouped into one of two overall "Crack Locations" which were "Coronal Cracks" and "Radicular Cracks." "Coronal Cracks" were those only involving pulpal walls while "Radicular Cracks" were any of those involving a pulpal orifice and/or the pulpal floor.

For the purposes of this study, teeth that had visual confirmation of a crack extending to within the confines of the pulp chamber were the only ones considered to be intrapulpally cracked and thus, the only teeth included in this study.

For those teeth with a confirmed diagnosis of an intrapulpal crack, the total number of unrestored, Class I, and Class II restorations was compiled, specifically documenting the exact surfaces involved for each restoration. Also collected was the total number of unrestored teeth, amalgam, composite resin, temporary restorative material, porcelain inlay/onlay, gold inlay/onlay, gold crown, PFM crown, ceramic crown, and temporary crown restorations. For the purposes of data analysis these existing restoration groups were then collapsed and classified as either amalgam, composite, crown, or other.

In addition, the Restoration Volume Proportion (RVP) was estimated for each tooth containing a restoration. RVP was estimated from the bitewing radiograph and occlusal view, digital photograph made of each patient's tooth in the following manner. The restoration's outline and the outline of the entire coronal portion of the tooth were traced on each occlusal view and radiographic digital image view using public domain image tracing software ImageJ (1.47v National Institutes of Health, USA).

The accuracy of the image tracing software was confirmed by completing multiple tracings of the same area, yielding numbers that varied less than 2% from the mean. Four individual surface areas were traced for each tooth, the surface area of the restoration in both the occlusal and bitewing radiograph views, and the surface areas for the coronal portion of the tooth in the occlusal and bitewing radiograph view. All tracings were completed by the same investigator and each area was traced three times, with the average of the three tracings being used in the calculations to estimate the RVP. When the cemento-enamel junction was not visible, the apical extent of the restoration was taken as the apical landmark. If a sedative base was visible in the radiographic image, it was included in the tracing as part of the restoration. The surface area of the restoration was then divided by the surface area of the coronal portion of the tooth for each view and these two numbers were multiplied to calculate the overall estimate of RVP for each tooth. The formula for RVP, developed by Sturdevant et al (24) can be seen in Figure 1. From the RVP estimates, four Restoration Sizes were generated: Small RVP ≤ 0.05, Medium RVP ≤ 0.10, Large RVP ≤ 0.20, Extra Large RVP > 0.20. Data analysis included chi-square and logistic regression using JMP Pro 11.0.0, SAS Institute Inc., Cary, NC, USA.

Results

The data set contained 43 patient records and 43 total teeth. The study population included 28 (65%) females, and the mean patient age was 56 years (SD=9.1) (Table 2).

For the predictor variables, Tooth Types were relatively evenly distributed with 10 (23%) Mandibular First Molars, 15 (35%) Mandibular Second Molars, 15 (35%) Maxillary First Molars, and 3 (7%) Maxillary Second Molars. Restoration Type included predominately 30 (73%) Amalgams, 5 (12%) Composites, and 6 (15%) Other. Restoration Surfaces, which from the various clinical occurrences, were collapsed into 4 groups: 9 (22%) Mesial, 2 (5%) Distal, 4 (10%) Mesial – Distal, and 26 (63%) Other. Restoration Classification included 25 (61%) Class I and 16 (39%) Class II restorations. RVP ranged from very small of <0.01, to 0.38 in the case of a very large restoration, with a mean RVP of 0.12 (SD=0.109). Of the four Restoration Sizes generated from the RVP estimates 8 (20%) were Very Large, 12 (29%) were Large, 6 (15%) Medium, and 15 (36%) were Small (Table 2).

The dependent variables were: Crack Direction, Crack Location, Pulpal Walls Involved, Pulpal Wall Classification, Pulpal Floor Involved, Pulpal Floor Classification, Pulpal Orifices Involved, Pulpal Diagnosis, and Periapical Diagnosis. The distributions of each of these can be found in Tables 3 and 4.

In this data set, 84%(n = 36) of the cracks were mesial to distal in direction. Less than 10% (n = 4) were buccal-lingual. Greater than 50% (n = 22) of the cracks were classified as involving the radicular tooth structure, while 46% (n = 19) involved coronal tooth structure only.

Forty percent (n = 17) of the cracks involved at least one pulpal orifice and only 12% (n = 5) of the cracks involved the pulpal floor (Table 3).

Forty percent (n = 17) of cracks involved the distal wall alone, while 19% (n = 8) involved the mesial wall alone; these were considered Pulpal Wall Classification Type I. The data set included 21% (n = 9) that involved both the mesial and distal wall together; these were considered Pulpal Wall Classification Type II. In total, 64% (n = 27) of the cracks were considered Pulpal Wall Classification Type I and 36% (n = 15) were considered Type II (Table 3).

The majority of the intrapulpal cracks in this sample did not involve the pulpal floor (88%, n = 37) or any pulpal orifices (60%, n = 25). In regard to the Pulpal Floor Classification, 45% (n = 19) of the cracks involved pulpal wall only (Type A) and 43% (n = 18) involved pulpal wall and at least one pulpal orifice (Type B). Only 2% (n = 1) of the cracks extended partially across the pulpal floor (Type C) and 7% (n = 3) of the cracks extended across the entire pulpal floor (Table 3).

In regard to the Pulpal and Periapical Diagnoses, the most common Pulpal Diagnosis in intrapulpally cracked teeth was Pulp Necrosis (56%) followed by Symptomatic Irreversible Pulpitis (40%), Asymptomatic Irreversible Pulpitis (2%), and Previously Treated (2%) (Table 4). The most common Periapical Diagnosis was overwhelmingly Symptomatic Apical Periodontitis (72%), followed by Acute Apical Abscess (9%), Chronic Apical Abscess (9%), Asymptomatic Apical Periodontitis (5%), and Normal Apical Tissues (5%) (Table 4).

Bivariate unadjusted analysis ($p \leq 0.1$) revealed potential significant associations between the independent variables, Tooth Type, Restoration Type, Restoration Surfaces, Restoration

Classification, RVP, and Restoration Size; and the dependent variables Crack Direction, Crack Location, Pulpal Walls Involved, Pulpal Wall Classification, Pulpal Floor Involved, Pulpal Floor Classification, Pulpal Diagnosis, and Periapical Diagnosis as displayed in Table 5. For each outcome variable, potentially significant predicators were included in a multiple logistic regression analysis. The significant predicators ($p<0.05$) are described below.

In regard to Crack Location, the logistic regression model was found to be significant ($p=0.0244$) with the variable Restoration Size revealing an association to Crack Location illustrated in Figure 2. This demonstrates that Large and Very Large Restorations are more likely to be associated with coronal cracks while Medium and Small Restorations are more likely to be associated with radicular cracks (Figure 2). In regard to Pulpal Walls Involved, the logistic regression model was found to be significant ($p<0.0001$) and the relationships between the cofounders Tooth Type, Restoration Classification and Pulpal Walls Involved are displayed in Figures 3 & 4. Figure 3 shows that the mandibular first molar is most often associated with a distal wall crack. The mandibular second molar is also most often associated with a distal wall crack though this is closely followed by a crack of both the mesial and distal walls together. The maxillary first molar is most commonly associated with either a single mesial or distal wall crack while all maxillary second molars were associated with a crack of both the mesial and distal walls together (Figure 3). Figure 4 demonstrates that Class I restorations were relatively evenly associated with all of the various pulpal wall involvements, while Class II restorations were most frequently associated with involvement of a single pulpal wall (distal and mesial).

Pulpal Wall Classification's logistic regression model was found to be significant ($p=0.0009$) and the relationship between the variables Restoration Surfaces and Pulpal Wall Classification are displayed in Figure 5. This revealed that in a cracked tooth, when the mesial-occlusal surface alone are restored it is always associated with Pulpal Wall Class I crack. When the distal-occlusal surfaces alone are restored, it is evenly associated with Pulpal Wall Class I and Class II cracks. When both the mesial-occlusal-distal surfaces together are restored, it is always associated with a Pulpal Wall Class I crack and when any other surfaces are restored they are evenly associated with Pulpal Wall Class I and Class II cracks (Figure 5). Pulpal Wall Classification was also significantly associated with Restoration Size (p=0.049) and Figure 6 summarizes this relationship. This revealed that Very Large and Large restorations were most commonly associated with Pulpal Wall Class I cracks while Medium and Small restorations were most commonly associated with Pulpal Wall Class II cracks.

Pulpal Diagnosis' logistic regression model was found to be significant and the relationship between Pulpal Diagnosis and Tooth Type are displayed in Figure 7. Analysis of this association showed that mandibular first molars were Necrotic 80% of the time whereas mandibular second molars and maxillary first molars were equally likely to present with either Pulp Necrosis or Symptomatic Apical Periodontitis (Figure 7).

Table 1. VCU Intrapulpal Crack Classification System

	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

Table 2. Distributions of demographic data and independent variables.

	N	%
Gender		
Female	28	65%
Male	15	35%
Tooth Type		
Mand First Molars	10	23%
Mand Second Molars	15	35%
Max First Molars	15	35%
Max Second Molars	3	7%
Restoration Type		
Amalgam	30	73%
Composite	5	12%
Other	6	15%
Restoration Surfaces		
Mesial	9	22%
Distal	2	5%
Mesial/Distal	4	10%
Other	26	63%
Restoration Classification		
Class I	25	61%
Class II	16	39%
RVP Sized		
Small	15	37%
Medium	6	15%
Large	12	29%
Very Large	8	20%

Table 3. Distributions of dependent variables Crack Direction, Crack Location, Pulpal Walls Involved, Pulpal Wall Classification, Pulpal Floor Involved, Pulpal Floor Classification, and Pulpal Orifices Involved (n=43).

	N	%		N	%
Crack Direction			**Crack Location**		
Mesial-Distal	36	84%	Coronal Crack	19	46%
Buccal-Lingual	4	9%	Radicular Crack	22	54%
Other	3	7%			
Pulpal Walls Involved			**Pulpal Wall Classification**		
Mesial	8	19%	I	27	64%
Distal	17	40%	II	15	36%
Mesial-Distal	9	21%			
Buccal, Lingual, Buc-Lin	4	10%			
Other	4	10%			
Pulpal Floor Involved			**Pulpal Floor Classification**		
No	37	88%	A	19	45%
Yes	5	12%	B	18	43%
			C	1	2%
			D	3	7%
			Other	1	2%
Pulpal Orifices Involved					
No	25	60%			
Yes	17	40%			

Table 4. Distributions of dependent variables Pulpal Diagnosis, and Periapical Diagnosis (n=43).

	N	%
Pulpal Diagnosis		
Asymptomatic Irreversible Pulpitis	1	2%
Previously Treated	1	2%
Symptomatic Irreversible Pulpitis	17	40%
Pulp Necrosis	24	56%
Periapical Diagnosis		
Acute Apical Abscess	4	9%
Asymptomatic Apical Periodontitis	2	5%
Chronic Apical Abscess	4	9%
Normal Apical Tissues	2	5%
Symptomatic Apical Periodontitis	31	72%

Table 5. Bivariate analysis of the independent variables Tooth Type, Restoration Type, Restoration Surfaces, Restoration Classification, RVP, Restoration Size against dependent variables Crack Direction, Crack Location, Pulpal Walls Involved, Pulpal Wall Classification, Pulpal Floor Involved, Pulpal Floor Classification, Pulpal Orifices Involved, Pulpal, and Periapical Diagnosis (n=43).

	Crack Direction			Crack Location		
	DF	Chi Square	p value*	DF	Chi Square	p value*
Tooth Type	6	6.61	0.3585	3	5.98	0.1125
Restoration Type	4	2.35	0.6726	2	1.08	0.5828
Restoration Surfaces	6	4.87	0.5606	3	3.87	0.2759
Restoration Classification	2	5.40	0.0671	1	4.83	0.0515
RVP	2	1.91	0.3854	1	2.73	0.0984
Restoration Size	6	6.66	0.3532	3	8.49	0.0369
	Pulpal Walls Involved			**Pulpal Wall Classification**		
	DF	Chi Square	p value*	DF	Chi Square	p value*
Tooth Type	12	27.62	0.0063	3	8.63	0.0360
Restoration Type	8	5.78	0.6719	2	2.21	0.3316
Restoration Surfaces	12	16.05	0.1888	3	10.99	0.0118
Restoration Classification	4	10.04	0.0398	1	6.56	0.0104
RVP	4	14.81	0.0051	1	7.81	0.0052
Restoration Size	12	16.53	0.1682	3	8.21	0.0419
	Pulpal Floor Involved			**Pulpal Floor Classification**		
	DF	Chi Square	p value*	DF	Chi Square	p value*
Tooth Type	3	4.27	0.2339	12	16.66	0.1627
Restoration Type	2	2.09	0.3521	8	3.00	0.9346
Restoration Surfaces	3	3.29	0.3497	12	5.75	0.9281
Restoration Classification	1	3.64	0.0563	4	6.70	0.1524
RVP	1	0.77	0.3793	4	6.84	0.1448
Restoration Size	3	4.19	0.2417	12	20.51	0.0581
	Pulpal Orifices Involved					
	DF	Chi Square	p value*			
Tooth Type	3	5.34	0.1488			
Restoration Type	2	1.08	0.5838			
Restoration Surfaces	3	2.06	0.5611			
Restoration Classification	1	2.17	0.1408			
RVP	1	0.46	0.4970			
Restoration Size	3	4.82	0.1852			
	Pulpal Diagnosis			**Periapical Diagnosis**		
	DF	Chi Square	p value*	DF	Chi Square	p value*
Tooth Type	9	22.54	0.0073	12	4.52	0.9721
Restoration Type	6	10.79	0.0950	8	15.24	0.0547
Restoration Surfaces	9	22.83	0.2043	12	16.46	0.1709
Restoration Classification	3	3.73	0.2927	4	5.49	0.2407
RVP	3	0.71	0.8715	4	3.26	0.5158
Restoration Size	9	9.55	0.3884	12	9.53	0.6569

*p values in red are eligible to be included in an adjusted model $\alpha < 0.10$

Occlusal Photograph **Bitewing Radiograph**

$$\left[\frac{Restoration\ Surface\ Area}{Crown\ Surface\ Area}\right] \times \left[\frac{Restoration\ Surface\ Area}{Crown\ Surface\ Area}\right] = Estimated\ RVP$$

Figure 1. Formula for calculation of Estimated Restoration Volume Proportion.

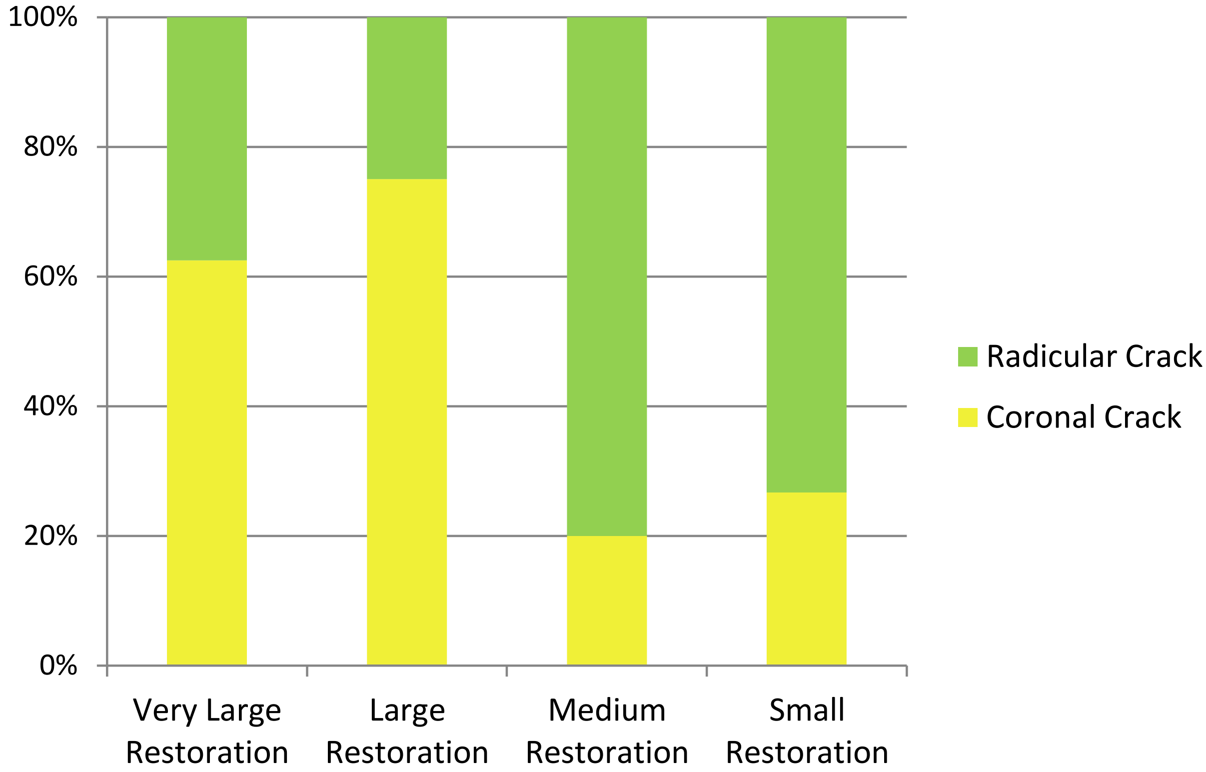

Figure 2. Stacked columns illustrating the relationship between Restoration Size and Crack Location (n=40).

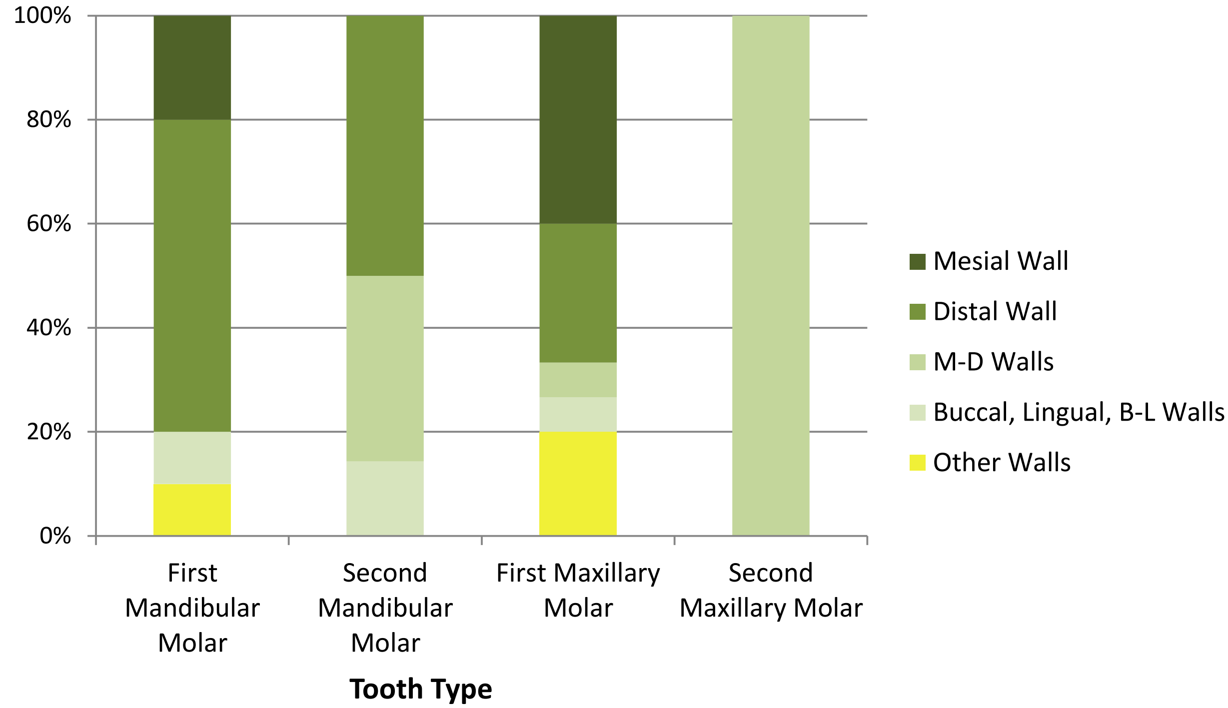

Figure 3. Stacked columns illustrating the relationship between Tooth Type and Pulpal Walls Involved (n=42).

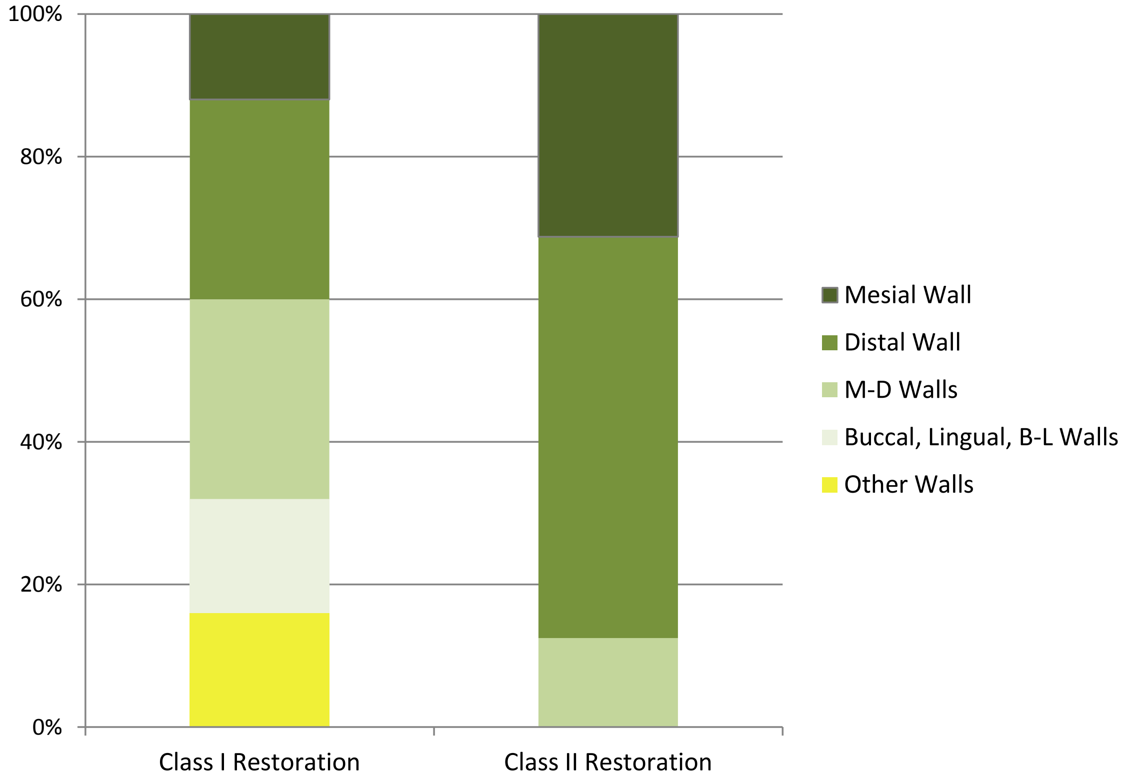

Figure 4. Stacked columns illustrating the relationship between Restoration Classification and Pulpal Walls Involved (n=41).

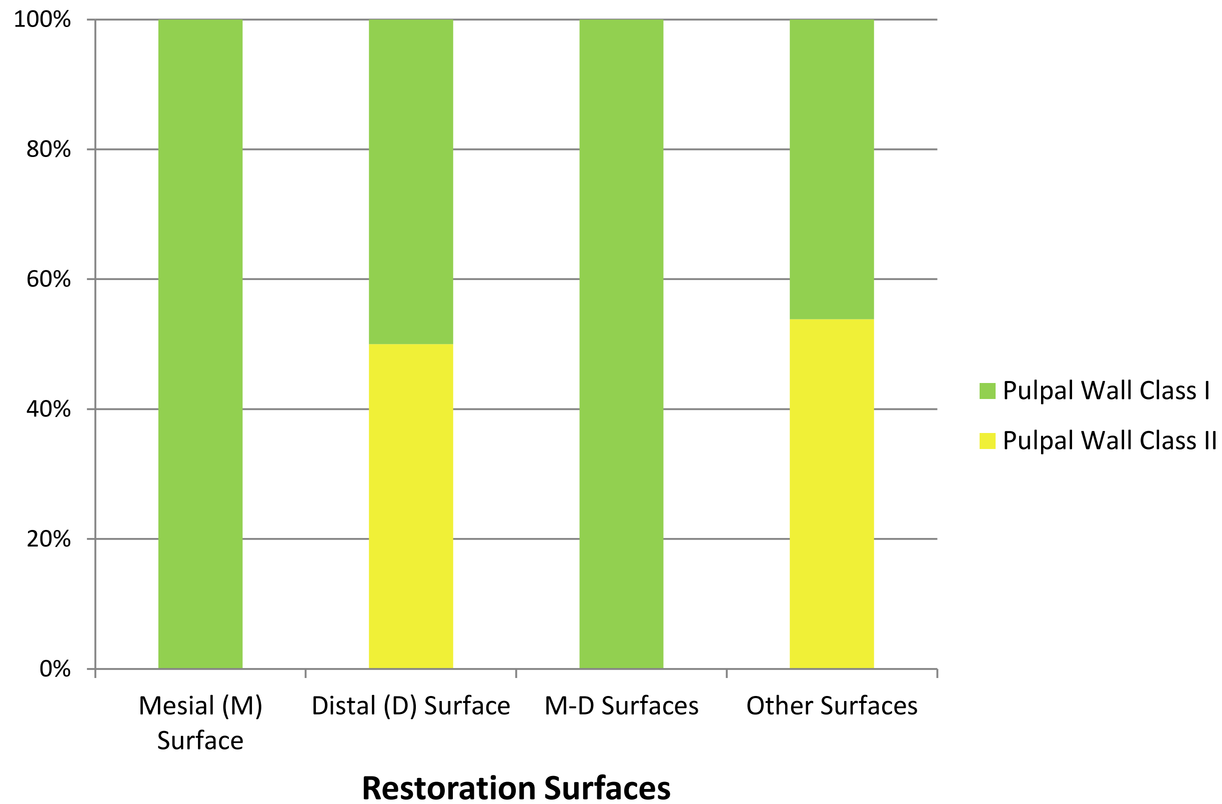

Figure 5. Stacked columns illustrating the relationship between Restoration Surfaces and Pulpal Wall Classification.

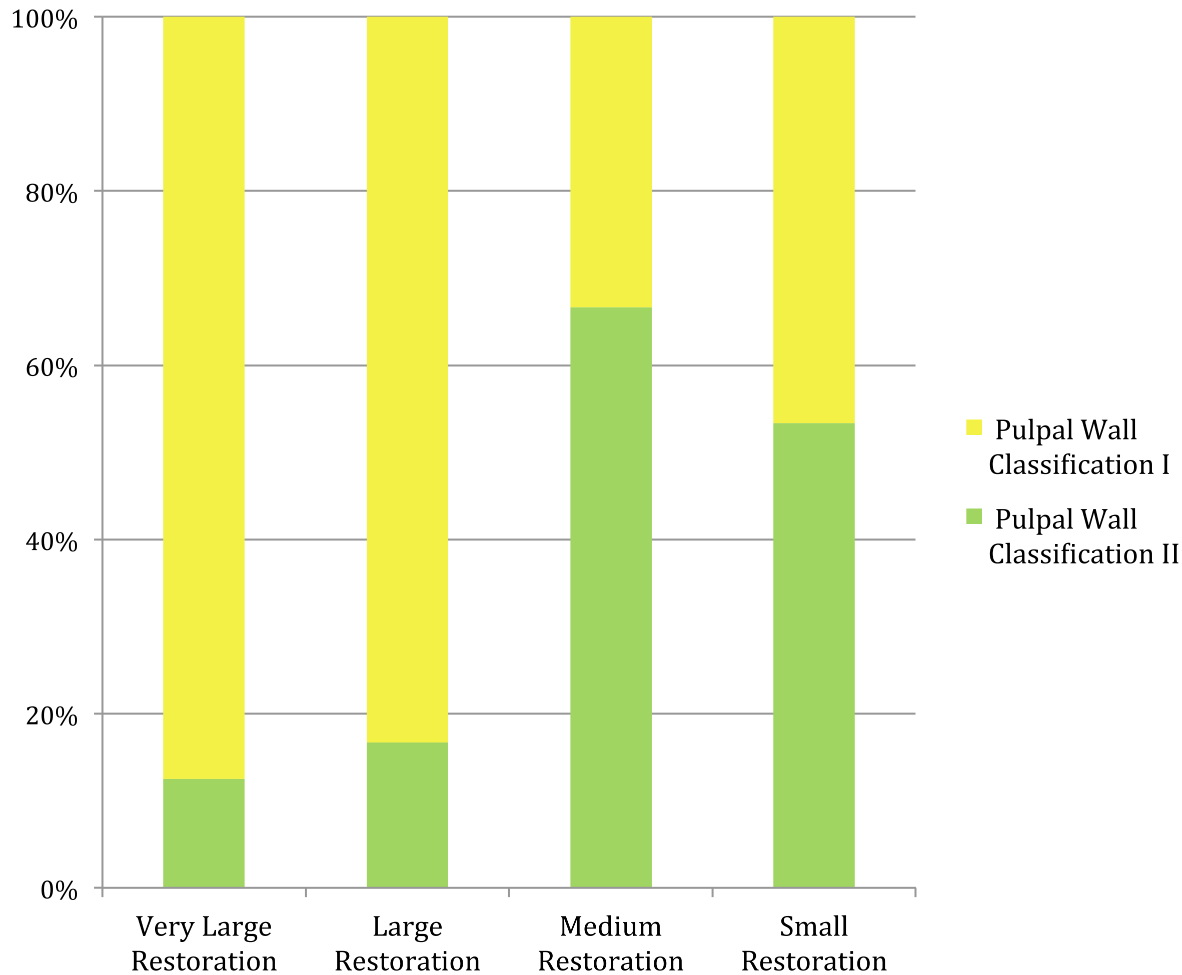

Figure 6. Stacked columns illustrating the relationship between Restoration Size and Pulpal Wall Classification.

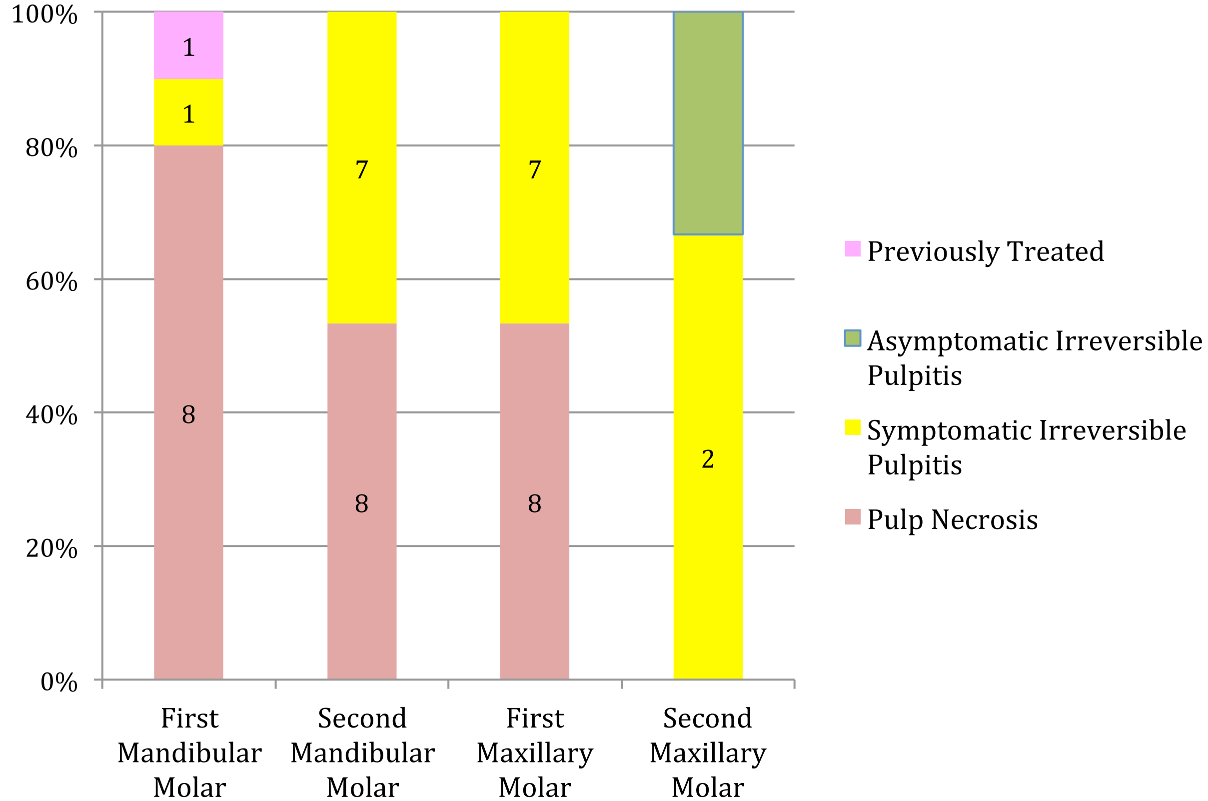

Figure 7. Stacked columns illustrating the relationship between Tooth Type and Pulpal Diagnosis.

Discussion

The demographic characteristics of this data set were similar to those found in previous cracked tooth studies (Table 2). The average patient age was 56 years old which agrees with the findings of previous authors that patients 40 years or older present with the highest rates of cracked teeth (2, 4, 13, 14). In this study, the majority of the patient population was female, which was similar to the findings of several studies (2, 4, 13, 15) but different from the findings of Roh et al who found that the sexes were equally affected (14). Similar to previous research findings (4-6, 9, 16), mandibular molars were overall more commonly cracked than maxillary molars. However, maxillary first molars and mandibular second molars shared the highest individual prevalence of cracks, both at 35%.

When considering the type of restorative material present in intrapulpally cracked teeth, amalgams were found to be the significant majority (73%) (Table 2). This falls in line with the findings of previous studies (13, 18) but contrasts the findings of Rosen and Bales who reported no difference in the prevalence of cracked teeth when comparing the various restorative materials present (9, 22). When evaluating the restorative characteristics of cracked teeth one must consider the properties of the specific restorative material used. For example, previous research has shown that teeth restored with amalgam are no stronger than teeth with unrestored cavity preparations while acid etching and composite resin restoration provides an increase in strength when subjected to impact forces (25). This could explain why the current intrapulpal crack study population had such a high prevalence of amalgam restorations, however it may simply be related to the more common use of amalgam as a restorative material in this area over time. This study was unable to prove a true causal relationship between a specific restorative material and intrapulpal cracks.

In this study, all except for 2 of the teeth presenting with intrapulpal cracks had previously existing restorations. This finding is similar to that of other authors who found cracks to occur more frequently in teeth with restorations as compared to unrestored teeth (10, 13, 17, 18). The idea that the presence of a restoration puts a tooth at risk for fracture has been well supported in the literature. Biomechanical studies of tooth fracture have shown that the preparation and subsequent restoration of a tooth allows the buccal and lingual cusps to act as cantilever beams that deflect upon load, which can ultimately lead to fracture (25). It is interesting to note however, that there were two teeth in the study population that presented with cracks and had no previous restoration whatsoever. This was similar to the findings of Roh and Lee who found that the prevalence of cracked tooth was highest in intact teeth with no restoration (14). When considering why an unrestored tooth may crack, previous research has discussed the thought that occlusal fissures that penetrate into enamel can act as a class I restoration thereby increasing flexibility of the cusps and putting the tooth at risk for fracture (25). Hiatt also noted possible areas of internal structural weakness in the occlusal fossa or grooves that allow for crack initiation when subjected to occlusal forces (5). In this study, both of the unrestored cracked teeth were mandibular molars that presented with signs and symptoms consistent with irreversible pulpal involvement. In each case, the patients elected to have the teeth extracted instead of pursuing endodontic therapy. Because these teeth were not accessed to confirm the presence of a true intrapulpal crack, these teeth were excluded from the data analysis. The exclusion of these two teeth with no restorations may have led to overestimation of the average restoration size and volume presenting in the data set.

In relation to Restoration Classification (Class I vs. Class II), the majority of the cracked teeth in this study presented with Class I restorations (61%, Table 2). This agrees with the findings of both Hiatt and Roh et al who found that Class I restorations were more commonly associated with cracks than were Class II restorations (5, 14). This disagrees with the findings of both Cameron and Homewood who reported that Class II restorations resulted in more cracks as compared to Class I restorations (13, 15). The findings of the current study would also contradict previous studies on the biomechanics of tooth fracture. For example, Reeh et al found that a reduction in tooth stiffness occurred due to restorative procedures with the greatest reduction being in MOD restorations followed by MO and then O restorations respectively. The reduction in stiffness was 63% for MOD restorations, 46% for MO restorations, and only 20% for O restorations leading to the conclusion that Class II restorations put teeth at greater risk for fracture than Class I (26). Additionally, it was concluded in Reeh's study that the loss of marginal ridge integrity was the greatest contributor to the loss in tooth strength (26). The finding of the current study, that Class I restorations had the highest prevalence in intrapulpally cracked teeth, does not support these conclusions.

When considering the size of a restoration as related to its volume, the prevailing thought has been that the larger the restoration volume, the higher the risk for fracture. Hood found that as restoration depth and width increased progressively, so did cusp flexibility and the associated risk for cracking the tooth (25). Other than Hood's study, most cracked tooth studies did not account for the actual volume of the restoration present. For this reason, the author wanted to use a novel approach to evaluate restoration volume, which was to measure the RVP. The thought was that by accurately quantifying volume in each restoration this might shed some light on the role it plays in intrapulpally cracked teeth. The RVP findings of this study, however, were somewhat conflicting (Table 2). The average RVP from the entire data set was found to be 0.12 which, based on the classifications set forth by Sturdevant during his original study on the use of RVP, equates to a Large restoration (24). In contrast to this, the overall distribution of the restoration sizes present in the study population was fairly even with Small restorations being the largest group. The distribution of restoration sizes was as follows: 20% Very Large, 29% Large, 15% Medium, 36% Small (Table 2). This could be used to either support or refute the conclusion of several previous studies that teeth with large restorations are more prone to fracture (9, 13, 19, 20). The author hoped that RVP would prove to be a reliable and clinically useful tool for predicting a tooth's likelihood to fracture; however this was not the case.

Interestingly, the findings of this study suggest that the size of the restoration was associated with the extent or severity of the intrapulpal crack based on involvement of either coronal tooth structure alone or both coronal and radicular tooth structure (Table 5). Data analysis revealed a significant association between Restoration Size and Crack Location which demonstrated that teeth with Small and Medium restorations were more likely to have cracks involving the pulpal orifices or pulpal floor (radicular cracks) while teeth with Large or Very Large restorations were more likely to have cracks only involving pulpal walls (coronal cracks) (Figure 2). There was also a significant association found between Restoration Size and Pulpal Wall Classification (Table 5). Data analysis revealed similarly that Large and Very Large restorations were more commonly associated with cracks involving only 1 pulpal wall while Small and Medium restorations were more commonly associated with cracks involving 2 pulpal walls (Figure 6). Taken together, all of this would suggest that the smaller the restoration, the more extensive the intrapulpal crack is likely to be. Given that the extent of crack involvement is often anecdotally thought to be indicative of a cracked tooth's overall prognosis, this would certainly be an area worthy of further investigation and could potentially hold clinical relevancy. When examining why a smaller restoration may lead to a more extensive crack with involvement of the pulpal orifice or pulpal floor, there are several things to consider. First off, as discussed previously, any restoration whatsoever can weaken the tooth and provide an area for crack initiation to occur (5, 25). Secondly, Roh and Lee discuss the possibility that cracks in unrestored or minimally restored teeth tend to occur more centrally and often closer to the pulp chamber (14). In contrast to this, teeth with large restorations occupying a significant amount of the occlusal surface would direct the occlusal forces on the remaining natural tooth more laterally towards the CEJ leading to more of an oblique-type cuspal fracture as opposed to a crack travelling centrally into the pulp chamber or pulpal floor (14, 25). This may be a valuable consideration and explanation that would be supported by the findings of the current study.

Another significant association identified was between Tooth Type and Pulpal Walls Involved (Table 5). Analysis of this relationship showed that mandibular first and second molars were most often associated with a crack of the distal wall alone. Maxillary first molars most often had involvement of a single pulpal wall and this was relatively evenly distributed between mesial and distal wall cracks, with cracks of the mesial wall being the most frequent (Figure 3). However, all of the maxillary second molars involved in this study had cracks of both the mesial and distal pulpal walls (Figure 3). The observed tendency towards distal wall cracks in the mandibular molars may be related to the normal occlusion of the maxillary palatal cusps in the central fossa and distal marginal ridges of mandibular molars. This occlusal relationship effectively applies the occlusal forces towards the distal half of the tooth in mandibular molars.

This is in agreement with the explanation provided by Cameron in his discussion of the high frequency of cracks appearing in mandibular molars (13). Similarly, that may explain the trend towards mesial wall cracks in maxillary first molars as seen in this study also. This, however, assumes a normal Class I occlusal relationship in all cases, which was not evaluated in this study. The finding that all maxillary second molars included in this study had 2 wall intrapulpal cracks may be related to the specific biomechanical forces accepted by this tooth during occlusion or may simply be due to the low number of teeth involved in that there were only 3 maxillary second molars evaluated.

A significant association was also found between Restoration Classification and specific Pulpal Walls Involved (Table 5). Data analysis here revealed that Class I restorations had intrapulpal cracks evenly associated with the mesial, distal, mesio-distal, and bucco-lingual pulpal walls. Class II restorations, however, were typically involved with cracks of a single pulpal wall only, which was most commonly the D wall (Figure 4). This finding is closely related to the significant associations between both Restoration Size and Pulpal Walls Involved and also Tooth Type and Pulpal Walls Involved as discussed above. This further supports the previously discussed conclusions that conservative restorations may lead to more extensive intrapulpal cracks and that distal pulpal wall involvement may occur commonly because of natural occlusal relationships.

Another interesting association that was found was between Restoration Surfaces and Pulpal Wall Classification (Table 5). This association demonstrated that when the mesio-occlusal tooth surfaces alone, or the mesio-occlusal-distal surfaces together were restored, the intrapulpal crack involved only 1 pulpal wall in every single case. In contrast, when the disto-occlusal surfaces alone were restored, cracks were equally likely to involve either 1 or 2 pulpal walls

(Figure 5). While this draws much of the same conclusions discussed above, it also raises some unique questions. Most notably, is the extension of a restoration to involve an additional surface of a tooth ever protective against an intrapulpal crack? For example, in light of this study's findings, when a D surface requires restoration in a mandibular molar, might it be prudent to restore the mesial surface as well? This could theoretically limit the extension of a potential crack that could develop and protect the tooth. This idea would contradict the thoughts of previous biomechanical studies on tooth fracture (ie that restoration extension increases the risk for fracture), but it is certainly something that may be interesting to investigate with further research and a larger study population.

This study also documented the pulpal and periradicular diagnoses that presented in intrapulpally cracked teeth and found a significant association between Tooth Type and Pulpal Diagnosis (Table 5). Analysis of this association showed that mandibular first molars with intrapulpal cracks primarily presented with Pulpal Necrosis (80%) whereas mandibular second molars and maxillary first molars were equally likely to present with either Pulp Necrosis or Symptomatic Apical Periodontitis (Figure 7). While this finding does not directly relate to the restorative characteristics of intrapulpally cracked teeth, it is still interesting to consider the high prevalence of Pulp Necrosis in teeth evaluated in the current investigation. Previous authors have advocated for extraction of a tooth presenting with pulpal necrosis and no restorations or minimally deep restorations (3). However, we do not have any other evidence based data to support that recommendation and the overall prognosis or outcome of intrapulpally cracked teeth was not evaluated in this study.

There were several limitations in this study that could be improved upon in future investigations of the topic. Most notably, over the time period of this study, only 43 teeth fit all of the inclusion criteria and thus our sample size may have been too small to be representative of the overall population. There were several teeth in which the intrapulpal cracks that were only discovered after access into the pulp chamber had been completed. Because these teeth had not had pre-operative photographs taken to document the original restorative presentation, they were excluded from this study. There were also multiple instances where a crack traveled all the way down to the roof of the pulp chamber but once unroofed did not travel down any of the pulpal walls. These teeth were also excluded from the study because a crack of the pulpal roof does not currently fit the intrapulpal crack classification used in this study. In theory however, a crack travelling to the roof of the pulp chamber still provides an avenue of bacterial communication with the pulp that explains the etiology of the pulpal disease present. It may thus be useful to modify our current intrapulpal crack classification system to include these types of pulpal roof cracks. Another factor that may have contributed to the low sample size in this study was that all intrapulpally cracked teeth with crowns had to be excluded. This was mostly due to the fact that the RVP tracings and calculations were developed to analyze intra-coronal restorations and thus would not accurately quantify the volume of an extra-coronal restoration such as a crown. There were 12 teeth total that presented with intrapulpal cracks and full coverage crowns. All were excluded from the data analysis.

The overall design of this study was limiting in that the only teeth evaluated were those with intrapulpal cracks. Because no intact teeth or teeth with cracks not extending into the pulp chamber were included, only associations could be determined not a true measure of causality. A further study of that design may ultimately allow us to determine if one specific restorative material or a restoration of a particular size or volume actually causes intrapulpal cracks.

It must be kept in mind that when comparing the findings of this study to previous cracked tooth research that these may not be parallel comparisons. All of the historical cracked tooth research focuses on teeth that have coronal cracks in general and not necessarily only those involving the pulp chamber. Because the current study only evaluated intrapulpally cracked teeth, this may account for some of the differences seen when compared to prior cracked tooth research findings.

In conclusion, the current study found several significant associations between restoration characteristics and intrapulpally cracked teeth. Most notably, there appeared to be a trend demonstrating that more conservative restorations were commonly associated more extensive intrapulpal cracks. While RVP proved to be a clinically useful tool for measuring restoration volume, it was hoped that this may be a predictor for the likelihood of fracture and this was not the case. Given the findings of the current study, further research investigating a causal relationship between cracked teeth and restoration characteristics as well as long term outcome studies would be most valuable. The only study to date that has evaluated outcomes of endodontically treated cracked teeth found an 85.5% 2-year survival rate (12). Further research on the long term prognosis and endodontic success rates of cracked teeth treated with NSRCT and RETX will be paramount in making evidence based treatment decisions in the future. Understanding how a tooth's restorative history plays into that will be critical to the overall body of knowledge. Further investigation is absolutely necessary.

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List of References

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Vita

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