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OUTCOME OF ENDODONTICALLY TREATED CRACKED TEETH

by

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A thesis submitted to the Faculty of the
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in partial fulfillment of the requirements for the degree of
Master of Science
in Oral Biology

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Bethesda, Maryland

CERTIFICATE OF APPROVAL

MASTER'S THESIS

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2020

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ABSTRACT

OUTCOME OF ENDODONTICALLY TREATED CRACKED TEETH

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Introduction: Cracked tooth is defined by the American Association of Endodontists Glossary of Terms as “a thin surface disruption of enamel and dentin, and possibly cementum, of unknown depth or extension”. Patients with a cracked tooth most often experience pain on biting and with changes in temperature. If a crack propagation compromises the pulp and causes pulpal and/or periapical pathosis, a NSRCT is required to remove disease and alleviate the patient’s symptoms. Reports of cracked teeth have been published since the 1950s, but there are still no long-term, prospective outcomes studies of endodontically treated cracked teeth. **Objectives:** To determine the outcome of teeth diagnosed with cracked tooth requiring initial NSRCT with 1-year to 5-year recall data and identify co-variant factors associated with functional outcomes. **Method:** The Naval Postgraduate Dental School Endodontics Department is conducting this research on consenting patients with a cracked tooth diagnosis that require initial nonsurgical root canal therapy. Data is collected at annual appointments up to 5-years. Two hundred and seven teeth is the estimated requirement to power this study to determine healed, survived, and functional outcomes from the analysis of clinical and radiographic data. **Results:** Thirteen teeth had verification of extraction. Of the 73 subjects with one-year data, the healed rate was determined to be 64% and the functional rate was 79%. One-year survival was 92%. Co-variant analysis was performed but no factors were found to significantly affect outcomes at this point in this study.

Conclusion: At one year, a 64% healed rate, a 79% functional rate, and a 92% survival rate was found for this interim analysis.

TABLE OF CONTENTS

	Page
LIST OF TABLES AND GRAPHS	vii
LIST OF ABBREVIATIONS.....	viii
CHAPTER	
I. INTRODUCTION	1
II. REVIEW OF THE LITERATURE	3
III. OBJECTIVE	9
IV. MATERIALS AND METHODS.....	10
V. RESULTS	13
VI. DISCUSSION.....	16
VII. CONCLUSIONS	18
APPENDIX A CRACKED TOOTH DATA FORM	19
APPENDIX B CRACKED TOOTH PRE-OPERATIVE DATA.....	20
APPENDIX C CRACKED TOOTH ACCESS DATA.....	21
APPENDIX D REGISTRY PRE-OPERATIVE DATA.....	22
APPENDIX E REGISTRY INTRA-OPERATIVE DATA	23
APPENDIX F REGISTRY FOLLOW-UP DATA.....	24
REFERENCES	25

LIST OF TABLES AND GRAPHS

Table / Graph	Page
Graph 1. 3-Year Healed/Functional Trend	14
Graph 2. Survivability Analysis.....	15

LIST OF ABBREVIATIONS

AAE	American Association of Endodontists
mm	millimeters
NPDS	Naval Postgraduate Dental School
NSRCT	non-surgical root canal treatment
PAI	periapical index
PARL	periapical radiolucency

Chapter I: Introduction

For the patient, a cracked tooth can be a painful problem that may cause nagging discomfort on chewing and possibly necrosis of the tooth necessitating endodontic intervention. For the clinician, a cracked tooth can be very difficult to diagnose and require multiple diagnostic appointments and multiple types of treatment before it is correctly diagnosed and definitive treatment is rendered [1]. Recognizing the challenges still faced with this malady, The American Association of Endodontists (AAE) organized the Special Committee on Cracked Tooth Initiative in 2015 that published “Cracking the Cracked Tooth Code: Detection and Treatment of Various Longitudinal Tooth Fractures”. In this publication they provide guidance on a standard terminology, diagnosis and treatment. They differentiate the five different types of longitudinal tooth fractures to be: craze lines, fractured cusp, cracked tooth, split tooth, and vertical root fracture [2]. The AAE now defines a cracked tooth to be “A thin surface disruption of enamel and dentin, and possibly cementum, of unknown depth or extension” [3].

While cracked teeth may currently be experiencing an increase in attention by the endodontic community, thoughtful clinicians have been attempting to describe and treat this condition for many years. Gibbs may have been the first to describe cracked teeth in 1954 when he called it “cuspal fracture odontalgia” [4]. Cameron was the first to coin the phrase “cracked tooth syndrome” in 1964 after thoughtfully noticing a pattern in some of his patients that had nagging pain only on biting, which would eventually be relieved when the cusp unexpectedly fractured off. He hypothesized that a crack in the tooth had been causing the pain on biting all along and thus when the cusp finally fractured off, the crack no longer caused biting pain [4].

Cameron, along with others, have helped elucidate the mystery of cracked tooth diagnosis and treatment options. To build upon all the thoughtful research on cracked teeth to this point, the next step is to determine the long-term outcome of endodontic treatment on these teeth to give clinicians solid evidence to base their decisions and best inform their patients. Few outcome studies have been conducted on cracked teeth and no prospective studies to five years have been conducted to our knowledge. Therefore, the purpose of this retrospective/prospective study is to determine the outcome of cracked teeth after initial non-surgical root canal treatment annually for up to five years.

Chapter II: Review of Literature

LITERATURE SEARCH

A review of the literature was conducted on 15 October 2018 in three biomedical literature databases: MEDLINE (via PubMed), Dentistry and Oral Sciences Source (via EBSCO), and Embase (via Elsevier). The literature searches in these databases included a combination of subject headings and keywords related to cracked teeth and outcomes. The following is an example of the search terms used in PubMed: (((((((("Cracked Tooth Syndrome"[MeSH] OR cracked tooth syndrome OR cracked tooth OR cracked tooth OR cracked teeth OR split Tooth OR split teeth))) OR ((incomplete fracture* OR Microcrack OR microcracks OR microfracture OR microfractures) AND (tooth OR teeth) OR (((Pulp chamber floor OR "dental pulp cavity"[MeSH]) AND (crack OR cracked OR cracks OR microcrack* OR microfracture OR microfractures)))) OR (((("root canal therapy" AND restor*) AND (crack OR cracked OR crack OR split OR splits OR microcrack OR microcracks OR fracture OR fractured OR fractures) AND ((Prognosis OR management OR manage OR success OR treatment OR therapy OR root canal therapy OR failure OR tooth extraction OR extraction OR restoration OR restore OR prognostic))). Similar searches were conducted in Dentistry and Oral Sciences Source and Embase. Date limits were not applied. Two hundred and ninety-seven unique citations were retrieved at this time. An initial screening of returned abstracts was performed and compared against the last literature search for this research project. One additional, relevant full-length article from a peer-reviewed periodical were obtained and included in this updated literature review. A similar search was conducted on 01 May 2020 and three new relevant articles were incorporated.

PREVALENCE

Krell and Rivera found the incidence of cracked teeth in an endodontic practice over 6 years to be 9.7% out of 8,175 patients [5]. Kang had similar results with an incidence of 8.9% over a five-year period in a dental hospital [6]. They also found mandibular second molars to be the most prevalent teeth with cracks [5, 6]. Signore proposed that the higher incidence in molars was due to the closer proximity to the temporomandibular joint and therefore would have greater force applied to those teeth in parafunction or if there were excursive interferences [7]. Cracks have also been seen to increase in prevalence with increasing age [4], with the mean patient age in the mid-forties [8, 9]. As to whether there is a predilection toward one sex or another, there have been differing results that do not point to a conclusive answer [4, 10]. Krell took it one step further and studied a population of 127 cracked teeth for six years, and found that 21% of those cracked teeth required NSRCT due to irreversible pulpitis or necrosis [5]. In 2019, Wu had a similar finding of 29% of vital cracked teeth that were crowned, but would still require NSRCT after 3 years [11].

ETIOLOGY

Multiple etiologies have been proposed for cracked teeth, but no single cause has been proven. Cracks almost always occur in a mesial-distal direction, through one or both marginal ridges. Large restorations have been theorized to weaken the tooth and allow a crack to form from occlusal forces, making restored teeth as much as 29 times more likely to crack than non-restored teeth [12, 13]. Additionally, repetitious thermal expansion of some restorative materials may push the tooth apart [14]. But Cameron believed that the only explanation for cracked teeth in non-restored teeth was force [4]. Excessive masticatory forces due to bruxism or clenching may force cusps apart and cause cracks, especially if there are excursive interferences or steep

cusps with deep fossae [4, 7, 15]. The trend seen that mandibular second molars are the most often cracked, lends itself to the possibility that the position in the arch closer to the temporomandibular joint and its consequent increased force during mastication, clenching, and bruxism may also be a factor [7]. What is known is that some cracks in teeth propagate until the pulp becomes involved, at which point pulpitis or necrosis may necessitate endodontic therapy [5].

DIAGNOSIS

Diagnosis of a cracked tooth, begins with a thorough patient history of their chief complaint. There will often be a history of symptoms such as sharp pain on biting or pain on release from biting that indicate a tooth is cracked. Commonly the patient will report pain on chewing and unexplained sensitivity to cold [16]. Clinical diagnosis can be accomplished by simple visualization of the crack with or without magnification that most often crosses the mesial or distal marginal ridge. Visualization can be aided by dye or transillumination [2]. Restorative material in a class II restoration will often hide a crack and must be removed to visualize it [17]. Tactile examination with a probe may allow the clinician to feel the crack. However, if the probe can be wedged into the crack and initiate flexure of the segments, the crack has propagated. If now diagnosed as “split tooth”, the prognosis becomes highly unfavorable [2]. Biting on a bite stick may reproduce the chief complaint of pain and localize to a particular cusp [4]. A deep, narrow periodontal probing depth can be indicative of a crack that has propagated apical to the gingival attachment [18]. Separate from a cracked tooth diagnosis, a pulpal and periapical diagnosis must also be made by clinical exam, sensibility testing, and radiographic analysis to determine if endodontic therapy is indicated.

HISTOPATHOLOGY

There is limited research on the histopathology of cracked teeth, but Ricucci found that out of 20 teeth with cracks, all the cracks were colonized by bacterial biofilms. If the crack reached the dentinal tubules, bacteria were found invading the dentinal tubules. Effects from bacteria within the dentinal tubules was detected in the adjacent pulp by the presence of inflammatory cells. Depending on the depth of the crack and subsequent bacterial invasion, acute inflammation or even pulpal necrosis was observed[19]. This demonstrates that bacteria invasion, facilitated by the crack can lead to irreversible pulpitis or necrosis, which necessitates an NSRCT.

TREATMENT

Treatment options for a cracked tooth are predicated on a good pulpal and periapical diagnosis. If endodontic therapy is not indicated, then a direct bonded restoration or indirect full cuspal coverage restoration should be completed to resolve symptoms and prevent further propagation of the crack [2]. Direct composite restorations were investigated by Opdam who found a 6% annual failure rate of restorations without cuspal coverage, while there were no failures of restorations with full cuspal coverage. Fourteen percent of teeth with direct composite restorations progressed to need endodontic therapy, while none of the teeth in the full cuspal coverage group required an NSRCT out to seven years [17]. Signore found similar results with bonded composite cuspal coverage onlays. At 4 weeks, 93% of patients were symptom free and did not require NSRCT for the following 4 to 6 years. The remaining 7% required NSRCT by 6 months [7]. The aim of full cuspal coverage restorations is to hold the tooth together through a

ferrule effect, prevent further crack propagation, and relieve symptoms. Krell found 21% of cracked teeth that did not have indications for NSRCT and had a full cuspal coverage restoration placed would progress to irreversible pulpitis or necrosis within 6 months and require NSRCT. The remainder of the teeth did not require root canal treatment for up to 6 years [5]. In 2019, Wu found similar results with 199 vital cracked teeth treated with a crown, of which 29% required NSRCT within 3 years [11]. More research is needed in this area, however it appears that full cuspal coverage restorations are superior to direct bonded restorations in providing a longer-term solution that helps prevent pulpal involvement.

If the pulpal and periapical diagnosis indicate root canal therapy, NSRCT should be completed prior to placement of a definitive full cuspal coverage restoration [2]. The intention of a full cuspal coverage restoration following NSRCT is to provide a ferrule effect and prevent further crack propagation. Cracks that progress apically and onto the root surface result in a non-restorable split tooth. Boren investigated 420 teeth for 10 years and discovered a crown placement after NSRCT significantly increased odds of survival [20]. If symptoms do not resolve after root canal treatment and full cuspal coverage restoration, extraction may be warranted [6].

PROGNOSIS

There are few long-term outcome studies evaluating cracked teeth following NSRCT, most of which are retrospective. In a 2-year retrospective study of 49 teeth, Tan found an 85.5% survival rate with a higher rate of tooth loss for terminal teeth in the dental arch, teeth with periodontal pocketing, and teeth with multiple cracks [8]. In a two-year retrospective study of 88 teeth, Kang found a two-year survival rate of 90.0% with a probing depth of more than 6mm as a significant prognostic factor for extraction [6]. In a 5-year retrospective study of 84 teeth, Sim

reported a 92% survival rate and identified teeth with an extension of the crack onto the pulpal floor had 11 times higher odds of being extracted [9]. In a 1-year retrospective study of 363 teeth, Krell found 82% successful. The three factors he found most significant were pocket depth ≥ 5 mm, distal marginal ridge crack, and periapical diagnosis of chronic apical periodontitis, suppurative apical periodontitis, or acute apical abscess [18]. In a 2 to 4 year prospective study of 53 teeth, Davis found 91% successful up to the 4-year period and 97% survival [21]. In 2020, Olivieri published a systematic review and meta-analysis of 7 studies and found an overall survival rate of 88% and a success rate of 82% for a 1-year follow-up. The only significant factor associated with a higher risk of tooth loss was a periodontal pocket associate to a crack [22].

Chapter III: Objective*

**This study, WRNMMC IRB #410603, "Outcome of Endodontically Treated Cracked Teeth", is ongoing. The Objective section for this paper was modified from the approved protocol.*

The objective is to determine the outcome of teeth diagnosed with cracked tooth requiring initial NSRCT using clinical and radiographic data at a minimum of 12 months after receiving treatment.

This study will assess the outcome of teeth diagnosed with cracked tooth that require initial NSRCT. Radiographic Periapical Index (PAI) scoring and the presence or absence of clinical symptoms will be collected at a minimum of 12 months following treatment to establish proportions of healed and not healed teeth. Healed teeth will have a PAI score of 1 or 2 AND are asymptomatic at recall. Teeth will be classified as not healed if they are symptomatic OR have a PAI score of 3, 4, or 5.

A secondary analysis using only the presence or absence of clinical symptoms will be used to establish the proportion of teeth that are functional.

Chapter IV: Materials and Methods*

**This study, WRNMMC IRB #410603, "Outcome of Endodontically Treated Cracked Teeth", is ongoing. The Material and Methods section for this paper were modified from the approved protocol.*

This study retrospectively and prospectively collected data from subjects referred to the endodontic clinic at the Naval Postgraduate Dental School (NPDS). Inclusion criteria for the study included the following: the subject 1) was at least 18 years of age; 2) willingly provided consent; 3) was diagnosed with a cracked tooth at the NPDS endodontic clinic; 4) required endodontic treatment on the cracked tooth; and 5) all endodontic treatment was performed by a NPDS endodontic resident or faculty member.

A thorough pre-operative radiographic and clinical examination was performed. Various methods were employed to aid in the diagnosis of a cracked tooth including direct visualization (with or without the use of magnification or a dental operating microscope), transillumination, methylene-blue dye application, and Tooth Slooth® bite test. For the prospective portion of the study, subjects were enrolled when a diagnosis of cracked tooth was made. For the retrospective portion, subjects were enrolled if cracked tooth details were noted retrospectively in the patient's record during a routine follow-up examination. An associate investigator obtained informed consent from the subject and all subjects were enrolled in the NPDS Endodontic Treatment Registry; WRNMMC #352271, a database of patients maintained in the NPDS Endodontic Department. The Endodontic Treatment Registry (WRNMMC #352271) was closed in Oct 2019 but subjects that were entered into WRNMMC IRB #410603, "Outcome of Endodontically Treated Cracked Teeth" prior to this closure have been retained.

Cracked tooth information was collected during the initial evaluation including tooth characteristics, diagnostic methods, and fracture location along with health history, history of

present condition, and diagnostic results (see APPENDIX A, B, D). Following the collection of pre-treatment data, non-surgical root canal therapy was provided. Teeth were accessed using rubber dam isolation; information regarding crack location and extent was collected after access (see APPENDIX C). No specified instrumentation technique, irrigation technique, or obturation technique was required (obturation material required to be gutta percha or Resilon), and all were documented on standardized data forms (see APPENDIX E). Following completion of treatment and temporization, subjects were referred for the definitive restoration of the tooth. At a minimum of twelve months after the endodontic treatment, subjects returned for a follow-up clinical and radiographic examination (see APPENDIX F). Each year following treatment, subjects were asked to return for subsequent follow-up examinations with data collection for up to five years.

Assessment of the clinical and radiographic data determined the outcome. The clinical examination included percussion, palpation, periodontal probing, mobility, and sensibility testing. The radiographic examination included one periapical radiograph at a minimum. Three calibrated, board-certified endodontists individually assessed the randomized follow-up radiographs on a shared laptop with image enhancement capabilities using the Periapical Index scoring described by Orstavik [23]. A dichotomous classification system of healed or non-healed was used for each tooth. A tooth was considered healed if the following criteria were met: 1) the tooth had no signs or symptoms (mobility < class 2, probing depth < 5mm, and no swelling, sinus tract, percussion sensitivity, or palpation sensitivity) and 2) the PAI score was 1 or 2. A tooth was considered non-healed if: 1) the tooth presented with signs or symptoms or 2) the PAI score was 3, 4, or 5. In a separate analysis, all asymptomatic teeth (no percussion or palpation sensitivity), regardless of PAI score, were considered functional (clinical success). All present (non-extracted) teeth regardless of symptoms were considered survived. The data were analyzed using R statistical software.

Based on previously published literature, to estimate a healed rate of 70% at 5-years with a 95% confidence interval of 61.02% to 79.25% produced the need for 93 subjects with 5 year follow ups for analysis. Those assumptions and a 5-year recall rate assumed at 45% were used to perform power analysis giving a target sample size of 207 subjects, with an allowance of up to 250 subjects if more were lost to recall than expected.

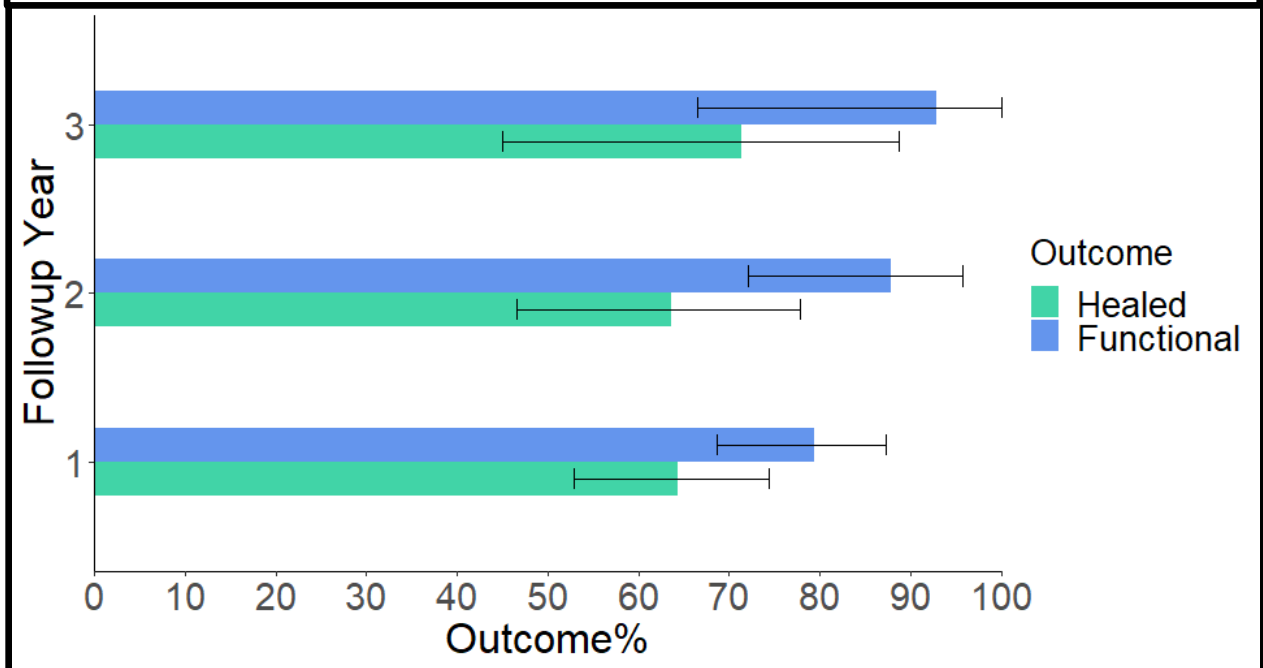
Chapter V: Results

In this interim analysis there were 128 subjects enrolled in the study - eighteen of which were retrospective and 110 prospective. Of which, thirteen were extracted and were not used in the calculation of healed and functional rates, but were used in the calculation of the survival rate. There were 73 one-year recalls, 33 two-year recalls, and 14 three-year recalls used to determine healed and functional rates. These recalls had clinical findings assessed and radiographs scored with the PAI system to determine healed and functional rates.

Descriptive analysis showed that 74.4% of subjects were male and 25.6% were female. Subject's ages ranged from 20-81 years old with a median age of 47 years. The most common teeth to crack were mandibular molars that comprised 69% of the sample. The mandibular second molar was the most common tooth at 40.4% and the mandibular first molar was the second most commonly cracked at 28.5% of subjects. Forty-six percent of teeth were in the terminal position of the arch and 54% of teeth were in a non-terminal position. Recall rate at one year was 78% and at two years was 54%.

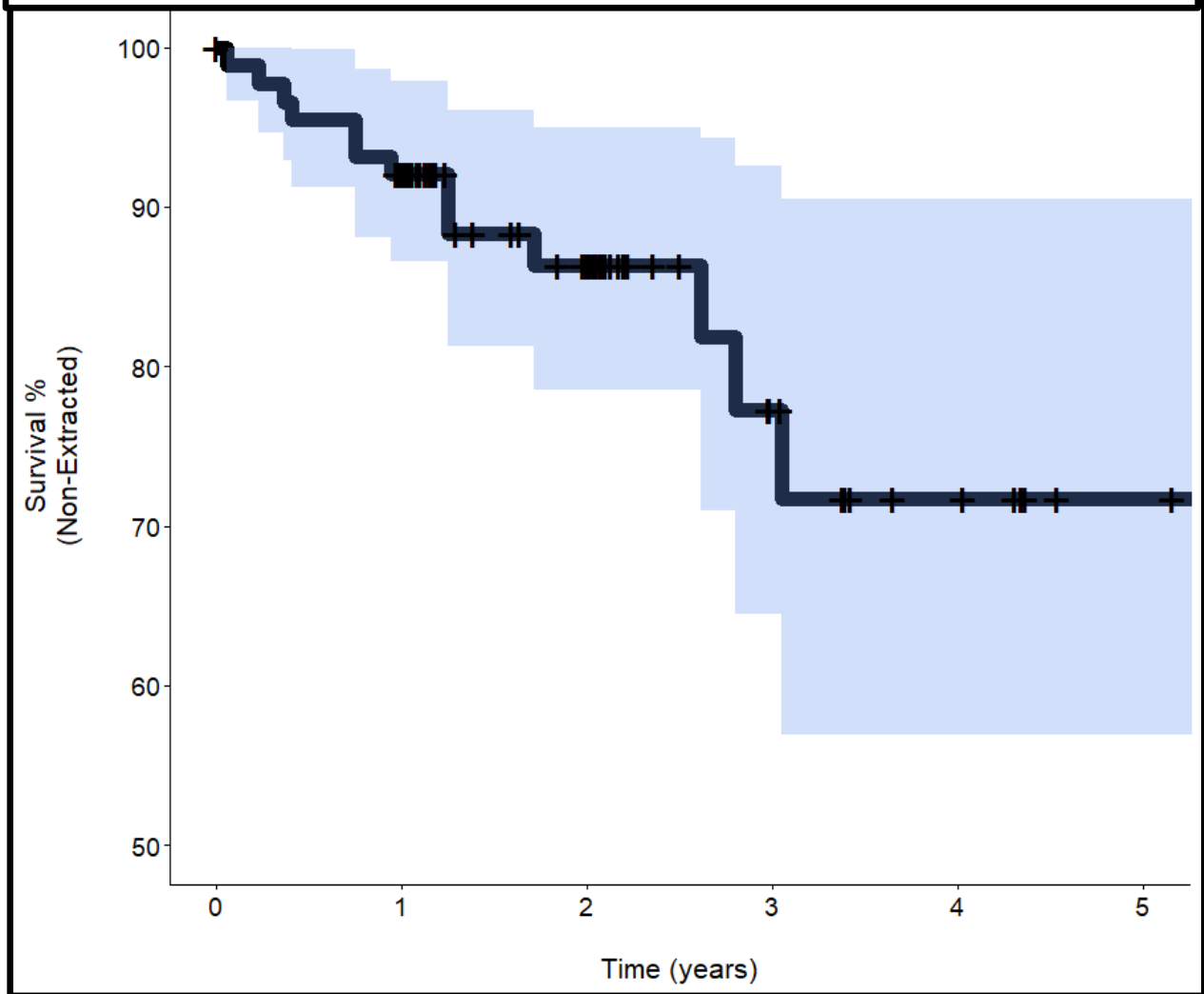
In this interim analysis, there were 73 one-year recalls available for analysis. The one-year functional rate, meaning teeth are present and asymptomatic, was 79.5%, and the healed rate which means the teeth were present, with no signs or symptoms, and had a radiographic PAI score of 1 or 2, was 64.4%. Although the recall numbers are smaller, the two-year functional rate was 87.9% with a 63.6% healed rate for 33 subjects and the three-year functional rate was 92.9% with a 71.4% healed rate (Graph 1).

Graph 1: 3-Year Healed/Functional Trend



Survivability analysis included the recalls used for healed and functional rates, with the addition of the teeth known to have been extracted. Survivability was simply defined as a tooth that was present at recall, regardless of clinical or radiographic findings. Table 2 shows the survivability of teeth out to 5 years. Each hash mark on the survivability line indicates a recall. The blue shading demonstrates the confidence interval and can be seen to expand along the x-axis as there are fewer recalls toward the 5-year mark. The one-year survivability was 92.0% and at two years it was 86.4% (Graph 2).

Graph 2: Survivability Analysis



At the time of this interim analysis, there was insufficient data for co-variate analysis of factors such as age, tooth type, gender, presence of restorations, probing depth or systemic disease that may affect outcomes of endodontically treated cracked teeth. As the project gains recalls over time, there will be a greater likelihood that factors affecting outcomes will be found.

Chapter VI: Discussion

The outcomes of the current study are largely in line with other published literature with the exception of the healed rates. This study has a very strict criteria to be considered healed that other studies may not prescribe to. For instance, in the current study a recall radiograph must be scored as a PAI 1 or 2 in order to be classified as healed. A PAI score of 3, 4, or 5 is considered non-healed. Other studies such as Krell in 2018 omitted any subjects with unsure radiographic healing (PAI 3) from “success” calculations and found an 82% success at one year [18]. This study found a one year healed rate of 64.4%. Additionally, to be considered healed in the current study, there must be an absence of clinical signs or symptoms to include: no percussion sensitivity, no palpation sensitivity, no sinus tract, no swelling, and no probing depth greater than 4mm. Other studies, to include Krell in 2018 and the Olivieri meta-analysis in 2020, do not define their criteria for signs and symptoms used to categorize a tooth as healed and may use less stringent definitions. For these reasons, more of the teeth in this study may be deemed non-healed, whereas they may have been deemed healed using other studies’ criteria.

Davis in 2019 published a prospective outcome study of 53 subjects that found a success rate of 90.6% in the 2- to 4-year term. While this study also had strict criteria to be considered healed, they also had a unique protocol that may have allowed for an increased success rate. The protocol included placement of a glass ionomer intraorifice barrier at the depth of the crack in the canal. Their rationale for this step was to bond the dentin and potentially provide a more effective barrier against reinfection through the crack. Additionally, each tooth was taken out of occlusion after NSRCT was completed to prevent crack promulgation before a permanent crown could be placed. After crown placement by a general dentist, the author personally checked the occlusion

to ensure there was not excessive occlusion or excursive interferences. He reported occlusal adjustments of the final restoration in 78.7% of subjects. If a crown was not placed in a reasonable amount of time or if the patient did not return for an occlusion check, they were excluded from the study [21]. This protocol may prove to be advantageous in the treatment of cracked teeth, but may also account for the higher success and survival rates when compared to the current study.

With regards to survival, Tan, in a retrospective study of 50 teeth found a 2-year survival of 85.5% [8]. Kang, in a two-year retrospective study of 88 teeth, found a two-year survival rate of 90.0% [6]. Sim, in a five-year retrospective study of 84 teeth found a five-year survival rate of 92%. For survival, the current study found a 92% survival at one-year and an 86.4% at two-years, which is consistent with these other published studies on survival of endodontically treated cracked teeth.

With regards to demographic analysis, this study found the mandibular 2nd molar to be the most commonly cracked tooth requiring NSRCT at 40.4%. This is consistent with other literature such as Cameron at 34% [4] and Krell at 36% [18] that also reported the mandibular second molar most common. As for the age of patients, this study consisted of patients aged 20-81 with a median age of 47. Roh found a similar predilection toward middle aged patients with most patients in their 40s or 50s [10].

Chapter VII: Conclusions

In this interim analysis of retrospective and prospective data, endodontically treated teeth diagnosed with “cracked tooth” had a functional rate of 79%, a healed rate of 64%, and 92% survival rate at one year. While our 2- and 3-year data is not yet as robust, the trend toward increased healing over time may be indicative of what other research has shown in that the healing of radiographic lesions occurs on a continuum that takes place over more than one year. Many practitioners continue to deem teeth with cracks as non-restorable, this practice is purely anecdotal and not evidence based. Cracked teeth, as described here, can be successfully retained. This study will continue to collect data for further analysis to provide greater insight into the outcome of cracked teeth following NSRCT.

Appendix A

Subject# _____

Cracked Tooth Data Collection Form

1a. Tooth # _____

1b. Position of tooth in arch: Terminal
 Non-terminal

1c. Existing Restoration? Y/N
 (Material and surfaces):

1d. Can Crack be visualized? Y/N (cont'd pg 2)

1e. Method of crack diagnosis: Tooth Slooth
 Transilluminator
 Dye/Stain
 _____ Other: (List)

2a. Was treatment performed on day of diagnosis? Y/N

2b. Treatment performed: Band placed
 Occlusal adjustment
 Provisional Crown
 NSRCT
 Permanent full coverage restoration
 _____ Other: (List)

3a. Does the patient have a history of Cracked Tooth on another tooth? Y/N

3b. What was the treatment provided?

3c. What was the outcome of cracked tooth listed in 3a?

Date	Is tooth present?	Symptomatic Y/N	What tx has been performed since last visit?	RCT completed? (If yes, date)	Recall Method (phone, dental visit, or other)

Appendix B

Subject# _____

Visualization of Cracks in Tooth Pre-Treatment (at Evaluation)

Tooth number _____

Check the appropriate boxes/fill in blanks

Please fill in probing depths (mm)

	M	Mid	D
B			
L			

Date: _____

Did you visualize a crack at examination (Circle one)?

NO

YES



Location of Fracture (check all that apply)

- Mesial Marginal ridge
- Distal Marginal ridge
- Occlusal Surface
- Buccal Groove
- Lingual Groove
- Other _____

Appendix C

Subject# _____

Visualization upon endodontic ACCESS

Tooth number _____

Check the Appropriate boxes/Fill in blanks

Please fill in probing depths

	M	Mid	D
B			
L			

Date: _____

Did you visualize a crack upon access (circle one)?

NO

YES

Location of Fracture (check all that apply)

- Mesial Marginal ridge
- Distal Marginal ridge
- Axial Wall _____
- Floor of chamber
- Other _____

Did the crack enter a canal?

NO

YES

Canal: _____
Y/N Apical Extent visualized

Canal: _____
Y/N Apical Extent visualized

Canal: _____
Y/N Apical Extent visualized

Appendix D

Subject #: _____

REGISTRY PREOPERATIVE

Tooth type: single root multiple root

Does patient have any of the following conditions (circle):

Hypertension: B/P _____ Smoker Coronary Heart Disease Diabetes Type: _____

Symptoms: Y/N

- | | |
|--|---|
| <input type="checkbox"/> Pain (0-10) (Y/N)
<input type="checkbox"/> Can locate pain by quadrant (Y/N)
<input type="checkbox"/> Can locate pain by tooth (Y/N)
<input type="checkbox"/> Tooth #
<input type="checkbox"/> /80 Electric pulp tester
<input type="checkbox"/> Palpation sensitivity
<input type="checkbox"/> Sinus tract (Y/N)
<input type="checkbox"/> Swelling (Y/N)
<input type="checkbox"/> History of Ortho tx (Y/N)
<input type="checkbox"/> History of external resorption (Y/N)
<input type="checkbox"/> Post (Y/N)
<input type="checkbox"/> Caries | <input type="checkbox"/> Cold sensitivity (R/NL; R/L; NR)
<input type="checkbox"/> Percussion sensitivity (S/NS)
<input type="checkbox"/> Mobility (Miller's Class)
<input type="checkbox"/> Bleeding on probing
<input type="checkbox"/> History of bleaching (Y/N)
<input type="checkbox"/> History of internal resorption (Y/N)
<input type="checkbox"/> Retreatment (Y/N)
<input type="checkbox"/> Surgical/nonsurgical treatment
<input type="checkbox"/> Open margin (Y/N)
<input type="checkbox"/> Restoration present (Y/N)
<input type="checkbox"/> Duration of symptoms (mos.)
<input type="checkbox"/> Fracture (Y/N): Type _____ |
|--|---|

PPD (mm)	Buccal	Lingual
Mesial		
Direct		
Distal		

Preoperative Radiographic findings:

Intact lamina dura (Y/N) Radiolucency (Y/N) Size _____ x _____ mm

Preoperative Diagnosis:

- | | |
|---|---|
| Pulpal:
<input type="checkbox"/> Normal pulp
<input type="checkbox"/> Reversible pulpitis
<input type="checkbox"/> Symptomatic irreversible pulpitis
<input type="checkbox"/> Asymptomatic irreversible pulpitis
<input type="checkbox"/> Pulp necrosis
<input type="checkbox"/> Previously treated
<input type="checkbox"/> Previously initiated therapy | Apical:
<input type="checkbox"/> Normal apical tissues
<input type="checkbox"/> Symptomatic apical periodontitis
<input type="checkbox"/> Asymptomatic apical periodontitis
<input type="checkbox"/> Acute apical abscess
<input type="checkbox"/> Chronic apical abscess
<input type="checkbox"/> Condensing osteitis
<input type="checkbox"/> Lesion of non endodontic origin |
|---|---|

History of Trauma to tooth _____

Was CBCT Taken? _____

Appendix E

Subject #: _____

REGISTRY INTRAOPERATIVE

Working length established using electronic apex locator: **Y/N**

Patency Achieved:

____ Canal Y/N
____ Canal Y/N
____ Canal Y/N
____ Canal Y/N
____ Canal Y/N

Was patency maintained throughout the procedure? ____
How often? _____

Anesthetic used (Carpules):

2% Lidocaine w/1:100,000 epi ____
.5% Marcaine w/1:200,000 epi ____
4% Articaine w/1:100,000 epi ____
3% Mepivacaine ____

Procedure

Irrigants used, quantity (ml):

Method of irrigation: __ Side-vented tip __ Passive ultrasonic __ Neg. pressure

Ca(OH)₂ used as interappointment medicament: Y/N

Procedural complications: Y/N Type:

Intraorifice barrier placed: Y/N Type:

Number of treatment sessions: single multiple

Obturation:

____ Flush (≤2 mm from apex)
____ Overextension (beyond apex)
____ Underextension (>2 mm short of apex)

Type of obturation material:| _____
Sealer used: _____

Retreatments:

Type of obturation material removed: _____
Method of removal: _____

Post treatment Diagnosis

Pulpal:

____ Normal pulp
____ Reversible pulpitis
____ Asymptomatic irreversible pulpitis
____ Symptomatic irreversible pulpitis
____ Pulp necrosis
____ Previously treated
____ Previously initiated therapy

Apical:

____ Normal apical tissues
____ Symptomatic apical periodontitis
____ Asymptomatic apical periodontitis
____ Acute apical abscess
____ Chronic apical abscess
____ Condensing osteitis
____ Lesion of non endodontic origin

Date of Treatment Completion: _____

EVALUATOR USE ONLY

Final treatment radiographic Periapical Index (PAI) score: 1 2 3 4 5

Appendix F

Subject #: _____

Registry Follow-up Data

Date of follow-up evaluation: _____

Does patient have any of the following conditions (circle):

Hypertension: B/P _____ Smoker _____ Coronary Heart Disease _____ Diabetes Type: _____

Symptoms: Y/N

- | | |
|---|---|
| <input type="checkbox"/> Pain (0-10)
<input type="checkbox"/> EPT
<input type="checkbox"/> Palpation sensitivity (S/NS)
<input type="checkbox"/> Sinus tract (Y/N)
<input type="checkbox"/> Swelling (Y/N)
<input type="checkbox"/> Time Elapsed Between Initial Tx and Permanent Restoration
<input type="checkbox"/> Duration of symptoms | <input type="checkbox"/> Cold sensitivity (R/NL, R/L, NR)
<input type="checkbox"/> Percussion sensitivity (S/NS)
<input type="checkbox"/> Mobility (Miller's Classification)
<input type="checkbox"/> Periodontal Screening Record (PSR)
<input type="checkbox"/> Bleeding on probing |
|---|---|

PPD (mm)	Buccal	Lingual
Mesial		
Mid		
Distal		

Follow-up Radiographic findings:

Intact lamina dura Y/N _____ Radiolucency (Y/N) Size _____x_____ mm

Follow-up diagnosis: (Apical)

- | | |
|---|---|
| <input type="checkbox"/> Normal apical tissues
<input type="checkbox"/> Symptomatic apical periodontitis
<input type="checkbox"/> Asymptomatic apical periodontitis
<input type="checkbox"/> Acute apical abscess
<input type="checkbox"/> Chronic apical abscess
<input type="checkbox"/> Condensing osteitis
<input type="checkbox"/> Lesion of non endodontic origin | Caries present? Y/N _____
Permanent coronal restoration present? Y/N _____
Intracanal post present? Y/N _____
Open Margin Y/N _____
Surgical or Nonsurgical Treatment _____ |
|---|---|

EVALUATOR USE ONLY
 Final treatment radiographic Periapical Index (PAI) score: 1 2 3 4 5

REFERENCES

1. Stanley, H.R., *The cracked tooth syndrome*. J Am Acad Gold Foil Oper, 1968. **11**(2): p. 36-47.
2. Excellence, A.C.f., *Cracking the Cracked Tooth Code: Detection and Treatment of Various Longitudinal Tooth Fractures*. aae.org, 2008.
3. AAE, *AAE Glossary of Terms version 6*. aae.org, 2018.
4. Cameron, C.E., *CRACKED-TOOTH SYNDROME*. J Am Dent Assoc, 1964. **68**: p. 405-11.
5. Krell, K.V. and E.M. Rivera, *A six year evaluation of cracked teeth diagnosed with reversible pulpitis: treatment and prognosis*. J Endod, 2007. **33**(12): p. 1405-7.
6. Kang, S.H., B.S. Kim, and Y. Kim, *Cracked Teeth: Distribution, Characteristics, and Survival after Root Canal Treatment*. J Endod, 2016. **42**(4): p. 557-62.
7. Signore, A., et al., *A 4- to 6-year retrospective clinical study of cracked teeth restored with bonded indirect resin composite onlays*. Int J Prosthodont, 2007. **20**(6): p. 609-16.
8. Tan, L., et al., *Survival of root filled cracked teeth in a tertiary institution*. Int Endod J, 2006. **39**(11): p. 886-9.
9. Sim, I.G., et al., *Decision Making for Retention of Endodontically Treated Posterior Cracked Teeth: A 5-year Follow-up Study*. J Endod, 2016. **42**(2): p. 225-9.
10. Roh, B.D. and Y.E. Lee, *Analysis of 154 cases of teeth with cracks*. Dent Traumatol, 2006. **22**(3): p. 118-23.
11. Wu, S., H.P. Lew, and N.N. Chen, *Incidence of Pulpal Complications after Diagnosis of Vital Cracked Teeth*. J Endod, 2019. **45**(5): p. 521-525.
12. Silvestri, A.R., *The undiagnosed split-root syndrome*. J Am Dent Assoc, 1976. **92**(5): p. 930-5.
13. Ratcliff, S., I.M. Becker, and L. Quinn, *Type and incidence of cracks in posterior teeth*. J Prosthet Dent, 2001. **86**(2): p. 168-72.
14. Abou-Rass, M., *Crack lines: the precursors of tooth fractures - their diagnosis and treatment*. Quintessence Int Dent Dig, 1983. **14**(4): p. 437-47.
15. Hiatt, *Incomplete crown-root fracture in pulpal-periodontal disease*. J Periodontol, 1973. **44**: p. 369-79.

16. Cameron, C.E., *The cracked tooth syndrome: additional findings*. J Am Dent Assoc, 1976. **93**(5): p. 971-5.
17. Opdam, N.J., et al., *Seven-year clinical evaluation of painful cracked teeth restored with a direct composite restoration*. J Endod, 2008. **34**(7): p. 808-11.
18. Krell, K.V. and D.J. Caplan, *12-month Success of Cracked Teeth Treated with Orthograde Root Canal Treatment*. J Endod, 2018. **44**(4): p. 543-548.
19. Ricucci, D., et al., *The cracked tooth: histopathologic and histobacteriologic aspects*. J Endod, 2015. **41**(3): p. 343-52.
20. Landys Boren, D., P. Jonasson, and T. Kvist, *Long-term survival of endodontically treated teeth at a public dental specialist clinic*. J Endod, 2015. **41**(2): p. 176-81.
21. Davis, M.C. and S.S. Shariff, *Success and Survival of Endodontically Treated Cracked Teeth with Radicular Extensions: A 2- to 4-year Prospective Cohort*. J Endod, 2019. **45**(7): p. 848-855.
22. Olivieri, J.G., et al., *Outcome and Survival of Endodontically Treated Cracked Posterior Permanent Teeth: A Systematic Review and Meta-analysis*. J Endod, 2020. **46**(4): p. 455-463.
23. Orstavik, *The periapical index: A scoring system for radiographic assessment of apical periodontitis*. Endod Dent Traumatol, 1986. **2**: p. 20-34.