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Outcome of endodontic therapy in young permanent teeth

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THESIS

OUTCOME OF ENDODONTIC THERAPY IN YOUNG PERMANENT TEETH

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DEDICATION

I would like to dedicate the 3 years of hard work on this thesis for my 3 little angels, Abdulaziz, Sabah and Aishah. To my loving husband, Yousef, for his care, support and encouragement. Also to those that are physically very far away from here, but their presence is felt in every other way, my parents and siblings. To my country, Kuwait, that provided me with an opportunity to peruse my education.

I thank you with all of my heart ♥

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OUTCOME OF ENDODONTIC THERAPY IN YOUNG PERMANENT TEETH

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ABSTRACT

The prevalence of pulpal involvement in young permanent teeth ranges between 0.3-36%. The outcome of Endodontic Therapy (ET) has not been widely studied in children and adolescents. Published studies that evaluated Endodontically Treated Teeth (ETT) in children and adolescents had results that varied tremendously. This variation could be due to the wide age range spanning from 6-18 years. Evaluating the predictors of survival, failure, and tooth retention between smaller subgroups within this age range may be relevant. AIM: To identify and assess variables associated with the outcome of ETT in 6-18 year old subjects stratified by age and to compare the results to the general population. METHODS: Retrospective chart review along with clinical follow up of subjects that received ET at BUGSDM between 2007-2015 at age 6-18 years. RESULTS: ET of the young permanent tooth resulted in 85% tooth survival and 91% retention. Patient age and tooth type were significantly related to survival and retention of ETT. CONCLUSIONS: Survival and retention of ETT observed among children and adolescents were similar to observations in adults. ET is more likely to survive when it is performed at an older age (15-18 years), or on an anterior tooth. This suggests that the longer ET is prevented through proper oral hygiene measures and preventive dental care, the better the likelihood of survival and retention of ETT in young patients.

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LIST OF ABBREVIATIONS

CI .....Confidence Interval
ETT .....Endodontically Treated Tooth/Teeth
ET ..... Endodontic Therapy/Treatment
BUGSDM .....Boston University Goldman School of Dental Medicine
D3310 ..... Endodontic therapy in the anterior tooth
D3320 ..... Endodontic therapy in the bicuspid tooth
D3330 ..... Endodontic therapy in the molar
NHANES ..... National Health and Examination Survey
PAI ..... Periapical Index score
RCT .....Root Canal Treatment

Outcome of Endodontic Therapy in Young Permanent Teeth

INTRODUCTION

Permanent teeth erupt between 6-14 years of age, excluding the third molars [1]. During this time frame, children are prone to develop caries, since the enamel is still maturing for 2-4 years after eruption [2]. It is also during this time period when the risk of traumatic dental injuries is at its peak [3] [4]. Caries, if left untreated, may result in pulpal involvement [5] and would thus either require Endodontic Treatment (ET), or in the worst cases, extraction. Furthermore, in trauma cases, ET [6] [7] may also be required depending on the patient's age, extensiveness of the trauma, pulpal involvement, maturity of the injured tooth and other factors.

Kassam et al. [8] reported that untreated dental caries in permanent teeth was the most prevalent condition in 2010, affecting 35% of the global population, or 2.4 billion people worldwide. The most prevalent disease in childhood is dental caries; it occurs 5-8 times more often than asthma, the second most common condition [9]. In 2011-2012, 21% of U.S. children aged 6–11 years and 58% of adolescents aged 12-19 years had experienced dental caries in their permanent teeth [10]. In the children's group, about 6% of dental caries were untreated; while, 15% were untreated in the adolescent group. Brukiene et al. [11] reported that of the 15-16 year-olds in their study sample, 40% had primary caries, 12% had secondary caries and 1.79% had a need for ET.

According to the literature review by Glendor [12], one fourth of all school children have suffered of trauma involving their permanent dentition. Moreover, Guedes et al. [4] found that the highest frequency of traumatic dental injuries occurred in 6-10 year-olds followed

by 11-15 year-olds. The majority of these injuries were a result of falls, followed by traffic accidents, violence, and sports activities. Kvittem et al. [13] studied the incidence of orofacial injuries in high school athletes for soccer, wrestling and basketball. It was found that about ¼ of soccer players, ½ of basketball players and ¾ of wrestlers reported occurrence of orofacial injury and that 10% of those injuries were dental. Kaste et al. [14] described phase 1 of the National Health and Examination Survey (NHANES) III data. The data were collected through examination of clinical evidence of injury to the permanent incisors along with patient reported history of injury in 1988-1991. It was reported that 24.9% of the US population 6-50 years of age had at least a single episode of trauma to one of their permanent incisors. In the 6-20 age group, 18.4% had at least one traumatic dental injury to a permanent incisor. Among all age groups, unrestored enamel fracture (45.8%) was the most common clinical evidence of injury. This was followed by repaired fractures (20.6%), unrestored dentin fracture (17%), missing permanent incisor due to trauma (10.2%), evidence of pulpal involvement (4%), and endodontically treated due to trauma (2.4%). Bastone et al. [15] in their review of trauma literature have noted that the age groups during which trauma peaks are 18-23 years, 6-13 years, and 11-15 years.

Oral health has an impact on the general well-being of an individual. Gherunpong et al. [16] found that 89.8% of children 11-12 years of age experienced an impact on their daily life because of an oral condition. Impacts on eating, emotional well-being, teeth cleaning and smiling were most prevalent. Sensitive teeth, oral ulcers and toothache were the most common causes that lead to the impacts. Further, oral health can have an impact on children's school performance. Jackson et al. [17] found that an average of 0.5 days of school are missed for dental care per child included in their study and that 17% of these days were due to pain or infection. They also noted that absences due to pain increased the

likelihood of poor school performance, while routine dental care absences did not. Thus, improving oral health may have an impact on improving children's educational experience.

CAUSES OF PERMANENT TOOTH LOSS IN CHILDREN AND ADOLESCENTS

Loss of permanent teeth especially at an early age might lead to negative consequences. Adjacent teeth would have the chance to shift from their position and thus become prone to develop caries and periodontal disease due to difficulties in cleaning. Tooth loss might also lead to decrease in chewing ability and affect speech and esthetics as well. As a result, this would affect the social and psychological well-being of growing children and adolescents.

By age 17, more than 7.3% of U.S. children have lost at least one permanent tooth because of caries [9]. Al-Shammery et al. [18] found that the mean number of missing permanent teeth due to caries was 0.03 in the 6-7 year age group, 0.12 at 12-13 years, and 0.29 at 15-19 years.

Gossadi et al. [19] examined on the cause of tooth extraction in subjects above the age of 10 years. The mean age was not mentioned in the paper, but 19.2% of the subjects were between 10-19 year of age. In general, dental caries was responsible for 25.9% of tooth extractions, periodontal disease for 18.5%, orthodontics for 17.1 % and trauma for 9.3%. The remaining tooth loss was due to prosthodontics or a combination of the previous factors. In the 10-19 year group, orthodontics was the main cause followed by caries then trauma.

Silva et al. [20] studied the prevalence of tooth loss in a sample of 889 adolescents, 15-19 years of age. The results of their oral examination showed that 40% of the sample had at least one missing tooth due to caries. In addition, they have also demonstrated that the most

commonly missing tooth was the first molar, particularly the mandibular. Casanova-Rosado et al. [21] found that 7.3% of 7-13 year-olds suffered of tooth loss and that the permanent first molars were lost in 2.1% of cases. Sutcliffe [22] found that 8% of 17 year-olds had extracted permanent first molars.

Raducanu et al. [23] further evaluated the prevalence of permanent first molar loss in 849 children, 5-17.5 years of age. Their results showed that 5.2% had extracted permanent first molars. The cause of extraction was investigated and it was found that 87.7% were lost due to caries and 12.35% due to molar incisor hypomineralization. The mandibular molars were most frequently extracted.

Due to the role of permanent teeth in guiding the development of occlusion in children, as well as their important functional and esthetic role especially in the critical phase of childhood and adolescence, all efforts are aimed at saving these teeth at such an early age.

ENDODONTIC TREATMENT IN CHILDREN AND ADOLESCENTS

Not many studies have investigated ET in permanent teeth of the young age groups. The following are few studies that have examined ET needs or prevalence in children and adolescents.

Demirbuga et al. [24] studied the frequency and distribution ET needs of permanent first molars in a Turkish pediatric population. They evaluated panoramic radiographs and charts of patients 6-16 years of age. They found that in children (6-12 years), 0.47% of permanent first molars were endodontically treated and 4% required ET. In the adolescent group (13-16 years), 4.28% of permanent first molars were endodontically treated and 6.09% were in need of ET.

Ajayi et al. [25] investigated the frequency and reasons of ET in primary and permanent teeth of patients 16 years of age and under in Nigeria. They found that 11% of surveyed patients had some form of ET and that Root Canal Treatment (RCT) constituted 38.7% of all treatments. In permanent teeth alone, RCT was the most (80%) ET performed, followed by apexification (7.6%), pulpotomy (6.2%), and pulpectomy (6.2%). The lower first molar was the most common Endodontically Treated Tooth (ETT) in the permanent dentition followed by the maxillary central incisor. Caries was the reason for ET in all of the molar cases, while it was the cause in 62.5% of permanent central incisors. In addition to that, they have also found that trauma and failed RCT are other less frequent causes of ET in children.

Ridell et al. [26] found that the most common cause of ET in Sweden was caries followed by trauma then tooth developmental disturbances. They were investigating patients (N= 1,971) 19 years of age and found that ET had been performed in 9.1% of patients. Molars were most frequently treated, followed by anterior teeth and premolars. They however found that the most common ETT was the maxillary central incisor.

Finally, Al-Madi [27] found that the prevalence of pulpal involvement of permanent teeth in 6-18 year-olds to be 35.8% in Saudi Arabia. Of those, 15% had incomplete RCT and 3% had completed RCT. The remaining teeth required extraction or pulp capping.

Unfortunately, there were no studies that we were aware of that measured the prevalence of ET in the pediatric population in the USA. Nor were there studies reporting on ET needs in children and adolescents. The majority of available studies were interested in measuring the prevalence of caries and extractions.

ENDODONTIC TREATMENT OUTCOMES: (SURVIVAL/SUCCESS)

Despite the high prevalence of ET in children and adolescents, the success or survival rate has not been widely studied in this specific age group. Within the general population, however, multiple studies have been performed with varying outcomes. The variations depend on the outcome that is measured along with the criteria that are used to assess this outcome as well as many other factors such as the study design, the duration of follow up, the operators performing the ET, etc.

Friedman and Mor [28] studied the healing and functionality of ETT. They have chosen 15 articles that conformed to a set of criteria. The outcomes studied were healed (clinical + radiographic normalcy), healing (clinical normalcy + reduced radiolucency), and functional (healed + healing $\pm$ unchanged radiolucency). The reported percentage of healed teeth ranged from 73-97% and functional teeth, 88-91%.

Ng et al. [29] did a systematic review of 63 studies. All of the studies were longitudinal clinical studies investigating on the outcome of initial RCT with a minimum of 6 months post-operative review. All studies also included their sample sizes along with the overall success rate or provided raw data through which success could be calculated. Success was measured based on clinical and/or radiographic criteria. The reported pooled success rate of studies using strict criteria (absence of apical radiolucency) was 74.7% and those using loose criteria (reduction in size of apical radiolucency) was 85.2%.

Tables 1 and 2 summarize the studies of survival (Table 1) or success (Table 2) of ET in the general population. Studies that have examined the survival of ETT have reported a retention rate of 65-98.1% whereas studies on success have reported it to be 56-94%.

A. SURVIVAL OF ENDODONTIC TREATMENT

Mindiola et al. [30], and Salehrabi and Rotstein [31] studied survival rate by performing an electronic survey of treatments performed by both general dentists and endodontic specialist. The age was not specified in both of these studies. The finding of each of these studies is 97% of teeth were retained for 3 years after treatment and 97% retained after 8 years, respectively. Alley et al. [32] found through their chart review that 90% of cases treated by general dentists and 98% of cases treated by endodontists survived after a minimum of 5 year follow up.

Dammadchke et al. [33], and Heling and Tamse [34] studied RCT performed by dental students. In the first study, patients 18-74 years old were included. In the second study, patients were 10-60 years old. The survival rates were 85% and 93%, respectively. Friedman, et al. [35] examined RCT performed in a graduate clinic and found that 97% of teeth remained functional. Their definition of functional was an asymptomatic tooth regardless of the Periapical Index score (PAI). In this study, the age of the subjects was not mentioned.

Fonzar et al. [36] examined both survival and success rates in patients 8-86 years of age. Retreatment cases were included in their analysis as well. They have found survival to be 93%. Stoll et al. [37] analyzed RCT performed by operators of different levels of experience and included retreatment cases also. They have found a 10-year survival probability to be 0.74. They included patients 10-82 years of age.

Lazarski et al. [38], Chen et al. [39] [40], Petersson et al. [41], and Frasson et al. [42] found the survival to be 94, 92, 93, 65, and 90% respectively. In all of these studies data were taken from an insurance database. Frasson et al. [42] noted that tooth survival was influenced by the age of the patient at the time of treatment; survival was highest in the

youngest (20-29 years) age group (93%). The patients studied were 20-102 years of age. While Lazarski et al. [38] noted that patient age at time of RCT is a risk factor for experiencing untoward events. The patients were 14-90 years of age.

B. SUCCESS OF ENDODONTIC TREATMENT

While some studies measured the success of ET based on both clinical and radiographic criteria, other studies only used radiographic examination alone to determine success.

Heling and Tamse [34] determined that an asymptomatic tooth along with a normal periapical bone structure and periodontal membrane was successful. They found a 1-5 year success of 70%. Fonzar et al. [36] also determined that a comfortable tooth without periapical or lateral radiolucency is successful. They reported a 10 year success of 84%. Retreatment cases were included along with initial RCT in this study. An interesting finding in this study was that only 16% of total failures were endodontically related. The majority of the failures were actually due to periodontal causes and fractures. Another study that utilized both clinical and radiographic criteria for measurement of endodontic success was done by Friedman et al. [35]. Their definition of success was absence of apical periodontitis radiographically, using the PAI scale, and absence of signs and symptoms other than tenderness to percussion. Success rate was found to be 81% among patients seen at the graduate clinic of a university. Imura et al. [43] followed up records of patients treated by endodontic specialists and found that 94% were successful according to the European Society of Endodontology. Having an asymptomatic tooth (absence of pain, swelling and other symptoms, no sinus tract, and no loss of function) and having normal periodontal ligament space were the criteria used to assess success. Cheung [44] had a clinical and radiographic follow up exam and a phone interview of non-attending cases asking about presence of tooth and symptoms. Failure was defined as the tooth being

extracted, re-treated, or having a periapical radiolucency, and having clinical signs and symptoms. The failure rate recorded was 44%. From that information, the success rate was calculated to be 56%.

Some studies used more lenient radiographic criteria. Instead of including only cases without periapical radiolucency, these studies also included lesions that arrested in size or became smaller. Matsumoto et al. [45] determined success by having an asymptomatic tooth along with having no new radiographic lesions develop, or even an old lesion that became smaller in size and not necessarily disappeared completely. They found a 2-4 year success rate to be 75%. Endodontic staff at a dental school performed the treatments. Swartz et al. [46] defined success as absence of pain or swelling, disappearance of sinus tract, no loss of function, resolved or arrested radiolucency 1 year post-treatment. They performed a radiographic exam and included patient responses to questions about symptoms related to the tooth. Their success rate was 88%. Their analysis included both gutta percha and silverpoints. While cases that were filled with gutta percha had a higher success rate (91%), it was not statistically significant.

Some studies used radiographic criteria alone to assess the success of ET. Chugal et al. [47] considered the absence of periapical pathosis as a success. They have concluded that 80% of teeth with a permanent restoration and 60% of teeth without permanent restoration were successful. Sjogren et al. [48] used the Strindberg criteria, which considered normal contours, width and structure of periodontal margin or being widened around excess filling to be successful. They followed up 356 patients 8-10 years after having ET completed by undergraduate students. The recorded success rate was 91%. Koch et al. [49] considered success as having normal PAI status (PAI 1,2). They studied the effect of educating general practitioners on the use of Ni-Ti rotary technique. The success rate was 58% before the intervention and 64% after.

Table 1. Previously published studies that assessed survival after ET					
Authors	**Method /operator**	**Age (yrs) & no. of cases**	**Criteria**	**Survival rate**	**Findings**
Mindiola et al. (2006)	Electronic survey of insurance database General practitioners and specialists	Age: - 5460 RCT in 4500 patients	Tooth retention	97% (3-yr)	Diabetes and/or hypertension, delayed or no restoration, and increasing age, may all contribute to decreased retention
Salehrabi & Rotstein (2004)	Electronic survey of insurance database Private general practitioners and endodontists participating in Delta Dental Insurance plan	Age: - 1,462,936 teeth of 1,126,288 patients	Tooth retention in oral cavity Failure: Occurrence of untoward events (extraction, re-treatment, apical surgery)	97.1% (8-yr) 3% (failure)	Most endodontic failures occurred in the first 3 years More than 83% of extracted teeth had no full coronal coverage
Fonzar et al. (2009)	Retrospective cohort treated by a single operator with clinical and radiographic follow up records	Age:8-86 411 patients, 1,175 teeth	Probability of surviving 10-yrs post-treatment of initial endodontic treatment and re-treatment	93% (10-yr)	Causes of failure: 42.6% periodontitis 29.4% fracture 16% endodontic related 5.9% caries 5.9% replaced by implant
Dammadchke et al. (2003)	Review of radiographs + records of RCT Students	Age: 18-74 144 patients 190 teeth	Tooth still present at time of examination	85.1% (10-yr minimum)	Age, gender, jaw, quantity of root canals had no influence on success. Having apical lesion before treatment showed significantly shorter survival. Best results in root canal fillings ending 0-1 and 1-2mm before apex. Highest loss rate in overfilled teeth

Table 1. Previously published studies that assessed survival after ET					
Authors	**Method /operator**	**Age (yrs) & no. of cases**	**Criteria**	**Survival rate**	**Findings**
Heling & Tamse (1970)	Clinical + radiographic follow up of RCT Students	Age: 10-60 213 teeth	Comfortable tooth	93% (1-5yr)	15 teeth required extraction (15/213=7%)
Fransson et al. (2016)	Insurance data of completed RCT tracked 5-6 for extraction codes. Mostly general practitioners	Age: 20-102 248,299 teeth	Not extracted	89.9% (5-6yr)	Survival highest in youngest (20-29) age group (93.2%)
Petersson et al. (2016)	Clinical + radiographic follow up of cases from insurance data	Age: 21-70 104 patients 499 teeth	Remained at follow up	65% (20yr)	Periodontal status of tooth may be important determinant of endodontic treatment outcome.
Lazarski et al. (2001)	Insurance database assessment Endodontists and general dentists	Age: 14-90 44,613 (minimum 2yr follow up)	Remained functional	94.44% (3.5yr) 5.56% (extracted)	Patient age at time of RCT is a risk factor for experiencing untoward event. Incidence of extraction increases 1-2% each decade until plateauing after age 60.
Friedman et al. (2003)	Clinical + radiographic exam Graduate clinic of university	Age: - 350 patients 405 teeth	All asymptomatic teeth regardless of PAI score	97% (4-6-yr)	Apical periodontitis is the main prognostic factor in initial RCT.
Alley et al. (2004)	Chart review at 3 private general practices General dentists and Endodontists	Mean age:49-50.8 350 teeth	Presence of tooth on radiograph or restorative chart notation at or beyond 5-yr mark. Failure: Evidence of extraction on chart note or radiograph prior to 5-yr mark.	89.7% (general dentists) 98.1% (endodontists)	Endodontic treatment by specialists is significantly more successful and has a survival rate that is as high or better than implants.

Table 2. Previously published studies that assessed success after ET					
Authors	Method/Operator	**Age (yrs) & no. of cases**	Criteria	Rate	Findings
Fonzar et al. (2009)	Recall of retrospective cohort	Age: 8-86-yr 411 patients 1175 teeth	Complete success: asymptomatic, absence of PA or lateral radiolucency on periapical radiograph Partial success: asymptomatic, radiographic improvement Partial failure: asymptomatic, no radiographic improvement or worsening, and any symptomatic teeth Complete failure: extracted	84.1% (10yr)	Causes of failure: 42.6% periodontitis 29.4% fracture 16% endodontic related 5.9% caries 5.9% replaced by implant
Mtsumoto et al. (1987)	Clinical + radiographic follow up of RCT performed by endodontic school staff	Age: - 85 teeth	Success: no symptoms, if there was no lesion initially and no area can be detected after a certain period of time, if there was a lesion initially and became smaller	75.3% (2-3yr)	Underfilled roots were highly successful Factors influencing failure: deep periodontal pockets, apical rarefactions, occlusal trauma, teeth w/ one or no adjacent teeth.
Heling & Tamse (1970)	Clinical + radiographic follow up of RCT by students	Age: 10-60-yr 213 teeth	Success: Tooth comfortable, PA bone structure + Periodontal membrane are normal Failure: develop lesion where one was not present, previous lesion not repaired, uncomfortable tooth or sensitive to percussion	70% (1-5yr)	
Chugal et al. (2007)	Clinical + radiographic follow up of RCT in postgraduate dental clinic	Age: - 200 teeth 441 roots 120 patients	Success: absence of PA pathosis Failure: presence of PA pathosis	80%(permanent restoration) 60% (temporary restoration)	
Friedman et al. (2003)	Clinical + radiographic exam Graduate clinic of university	Age: - 120 teeth	Healed: Absence of radiographic signs of apical periodontitis (PAI<3) + Absence of clinical signs and symptoms other than tenderness to percussion Diseased: Any other condition	97% (4-6-yr)	Apical periodontitis id the main prognostic factor in initial RCT.

Table 2. Previously published studies that assessed success after ET					
Authors	Method/Operator	**Age (yrs) & no. of cases**	Criteria	Rate	Findings
Imura et al. (2007)	Follow of records of patients treated by endodontic specialists in private office	Age: - 1376 teeth	European Society of Endodontology, 1994	94%	
Chueng (2002)	Recall for clinical + radiographic exam. Phone call to nonparticipating cases to ask about presence of tooth and symptoms.	Age: - 251 teeth	Fail: extraction, re-treatment, periapical radiolucency, clinical signs and symptoms.	Failure rate: 44%-→ success: 56%	Most frequent reason for extraction was tooth fracture followed by recurrent pain/swelling and mobility. Survival was influenced by tooth type, radiographic location of voids, and intracanal medicament used.
Sjogren et al. (1990)	Follow up exam of cases treated by undergraduate students	Age: - 356 patients	Strindberg criteria (normal contour, width and structure of periodontal margin or widened around excess filling	91% (8-10-yr)	Pre-operative pulp and periapical status and level of root filling affect the outcome. Age did not affect outcome.
Koch et al. (2015)	Technical quality of RCT outcome by general dentists before and after an educational intervention on the use of Ni-Ti rotary technique	Age: - 414 teeth (pre-education) 416 teeth (post-education)	Surviving with normal periapical status (PAI 1,2)	58% (pre-education) 64% (post-education)	No improvement in periapical status.
Swartz et al. (1983)	Recall radiographs + patient response on questions about symptoms for minimum of 1 yr post-treatment	Age: - 1,007 teeth 1,770 canals	Success: Absence of pain or swelling; disappearance of sinus tract; no loss of function; radiographic evidence of resolved or arrested radiolucencies after 1-yr post-treatment interval Failure: Presence of pain, swelling, or sinus tract; loss of function; increase in size or arresting of radiolucency; development of radioluncency where one was not present	89.66% (canals) 87.79% (cases) 88.44% silver points* 91.23% GP* * no significant difference	Lower success with overfilled canals, pre-existing radiolucency, no proper restoration after RCT No significant difference in age

C. ENDODONTIC TREATMENT OUTCOME IN CHILDREN AND ADOLESCENTS

When considering the young population only, analyses of success of ET are rare and usually concerned with unfinished root growth [50]. There are only a few studies that were exclusively performed on the young population to measure the success of ET.

Clarke et al. [51] assessed the technical quality of RCT performed in a pediatric population with mean age of 13.4+/-2.3. Radiographs of 100 cases were assessed using the European Society of Endodontology quality guidelines. For a satisfactory outcome, the root filling material should be less than 2mm from the radiographic apex, no canal space should be observed beyond the end of the obturation, the filling should have homogenous density without voids, and where MTA was used then a plug should be of 3mm length or greater. The study findings showed 61% of the cases to be satisfactory. Of those unsatisfactory, 21% were short of the apex, 28% had extruded material and 56% had voids. They have concluded that RCT in the pediatric population is comparable to that in the general adult population. In their study, the most common reason for RCT was dental trauma, which accounted for 84%. They have found that age did not influence the outcome.

Jordal et al. [52] studied the periapical status in permanent teeth with RCT in 9-17 year-olds using the PAI along with technical quality of root fillings. For the PAI, they considered a score of 1-2 satisfactory and also if the score changed from 4-5 to 3. As for the filling quality, they compared their radiographs to a reference and gave a score of 1-4 and only a score of 1 was considered satisfactory. They found that 25% of teeth had apical periodontitis at follow up and that only 42% were of adequate technical quality. The RCT were performed by general practitioners and had a minimum follow up of 1 year. Outcomes were determined based on radiographic evaluation only.

Ridell et al. [53] have also analyzed RCT in permanent teeth through radiographic assessment. The sample consisted of 19 year-olds that had a minimum of 1 year follow up. The PAI was also used to determine periapical status and the technical quality of root canal filling was studied based on sealing quality and distance of filling from radiographic apex. A PAI score of 1-2 was considered successful. For sealing quality to be adequate, no voids should be observed. For distance from radiographic apex, they considered 2mm or less to be satisfactory. The results showed that 48% of teeth showed healthy periapical tissue, 49% of teeth were adequately sealed and 49% were sealed within 2mm of the radiographic apex. Vojinovic et al. [50] found 86% success rate of RCT in teeth with finished root growth and 85% in teeth with unfinished root growth, when calcium hydroxide was used for treatment of apical periodontitis. The sample consisted of subjects 10-20 years of age. They considered the treatment to be successful when the following criteria were met: absence of signs and symptoms, complete loss of apical lesion with preserve lamina dura and identical width of periodontal area, preserved continuum of lamina dura with crest-like enlargement of periodontal area with signs of disappearance of bone destruction.

Peretz et al. [54] examined RCT performed in permanent molars of 18 patients 8-16 year old at the time of treatment. At the time of examination 24-77 months post-treatment time has passed. They performed both clinical and radiographic examination. They assessed sensitivity to percussion, mobility, quality of restoration (contact point reproduced, overhang, and secondary caries), periapical lesion before and after treatment, external root resorption, furcation involvement, and interproximal bone resorption). They defined success if no pathology was identified. Of the 28 examined teeth, only 36% were found successful.

While most of the studies referenced above utilized only radiographs to assess the technical quality of RCT or the periapical status of the tooth or both, some of the other studies used both clinical and radiographic criteria. Since each of the previous studies had a different design and criteria to measure the outcome, the results differed tremendously.

In our study, we utilized the absence of signs or symptoms, absence of radiolucency and also absence of untoward events (defined in methods section) as an assessment of success. We also assessed survival based on the above criteria but the only difference was disregarding the radiographic presence of a radiolucency. Failure was considered when signs and symptoms were present or when an untoward event occurred regardless of a radiographic radiolucency. We were also able to calculate the retention rate of ETT from our sample. This allowed us to compare our results with multiple different studies.

AIM OF STUDY

The purpose of this study was to examine survival, retention and failure rates of ET performed on permanent teeth of 6-18 year old patients at the Boston University-Goldman School of Dental Medicine (BUGSDM). Predictors of survival, failure and retention of such treatment in the young population were also assessed. Finally, this study compared the findings to those from the general adult population.

METHODS

IRB APPROVAL

This study was approved by the IRB committee of the Boston University Medical Campus, record # H-34766.

STUDY DESIGN

The study consisted of two parts. The first part was a retrospective review of existing data. The second part was a clinical follow up study of the outcome of ET.

STUDY SAMPLE

We identified subjects that had completed an initial RCT at the BUGSDM during the years 2007-2015. Only subjects that were 6-18 years of age at the time of treatment completion were included. The electronic records of the cases were identified by using the following Current Dental Terminology (CDT) codes: D3310, D3320, and D3330, i.e., ET in the anterior tooth, bicuspid tooth and molar, respectively.

OUTCOMES

We utilized survival, retention and failure rates as the outcomes. Outcomes were determined at < 6 months, 6-11months, 1-, 2-, 3-4 and 5+ years after treatment.

Outcomes were defined as follows:

1. Survival:

    - Absence of clinical signs or symptoms (regardless of radiographic condition)
    - Absence of untoward events

2. Failure:

    - Presence of clinical signs or symptoms (regardless of radiographic condition)
    - Occurrence of untoward event

3. Retention
    - Presence of tooth in the mouth regardless of clinical or radiographic condition

STUDY COVARIATES

The following covariates were measured to determine their association with treatment survival/failure/retention: age at time of treatment, sex, tooth type, jaw type, insurance, co-morbid medical conditions (allergies, asthma, cancer/cancer treatment, cardiovascular conditions, diabetes, epilepsy/seizures) and smoking status.

PROCEDURES

The retrospective portion of the study used existing data extracted from the electronic dental records. Data were de-identified and a study ID was used to record our findings.

The second part of this study included only patients with ETT that were not considered as failures (documentation of extraction, re-treatment or apical surgery; chart record reporting clinical signs or symptoms) during the chart review process. These subjects were contacted via telephone and asked about the presence of the tooth in the mouth and if any additional procedures were performed (retreatment, apical surgery). If the tooth was present without occurrence of untoward events then the subjects were invited for a free clinical and radiographic examination.

In the follow up visit and after written informed consents were obtained from participants or their legal guardian, the subjects were asked to fill in a questionnaire. We asked about

the patients' background information, medical conditions and smoking status. We also included specific questions about the tooth that received the ET. We asked about infection or further treatment to that tooth and if the tooth was functional and comfortable. After that each subject received a clinical and radiographic examination. We examined for visual signs of infection, sensitivity to percussion and palpation, mobility and probing depths (if premedication was not required), and the presence of fracture, caries and restorations. We took a periapical and a bitewing radiograph to examine for presence of caries, restorability and periapical lesions. All of our findings were recorded in our examination sheet that identified each participant by their study ID. We also documented the visit on the subjects BUGSDM electronic file.

All subjects received a report of the clinical and radiographic findings at the end of the visit. Subjects that required further treatment were informed to return to their dentist to address their needs. This visit was free of charge and subjects also received a gift card to compensate for their travel expenses and time.

ANALYSIS

Findings were entered in an Excel database and analyzed using SAS, Version 9.3. Descriptive characteristics of the covariates were computed. Bivariate analysis was conducted to test the associations between the descriptive characteristics and the outcomes (survival, failure, retention). Multivariate modeling included covariates that were clinically relevant and those with p-value ≤ 0.2 in the bivariate analyses. Covariates with p-value ≤ 0.05 were deemed statistically significant during bivariate and multivariate analyses.

RESULTS

DESCRIPTIVE ANALYSIS

Part 1. Retrospective Chart Review

Table 3. Descriptive characteristics of subjects (N=773)

Variable	Category	n	Mean (range)/ %	Age 6-11 years (N=97)	Age 12-14 years (N=215)	Age 15-18 years (N=461)	p=
Age at treatment		773	14.76 (6-18)	9.94 (6-11)	13.1 (12-14)	16.55 (15-18)	n/a
Gender	Female	410	54.09%	50.54%	48.31%	57.42%	0.0704
	Male	348	45.91%	49.46%	51.69%	42.58%	
Insurance	Masshealth	513	66.24%	73.20%	71.63%	62.26%	**0.0462***
	Private	64	8.28%	4.12%	8.37%	9.11%	
	Self-pay	197	25.49%	22.68%	20%	28.63%	
History of allergy	No	325	77.01%	85.71%	80.37%	74.06%	0.1295
	Yes	97	22.98%	14.29%	19.63%	25.94%	
History of lung disease	No	362	87.44%	87.76%	85.71%	88.08%	0.8248
	Yes	52	12.56%	12.24%	14.29%	11.92%	
History of tobacco use	No	367	94.59%	100%	97.89%	92.43%	**0.0348***
	Yes	21	5.41%	0	2.11%	7.52%	
ET per patient		773	1.2 (1-5)	1.11 (1-3)	1.27 (1-5)	1.19 (1-4)	**0.0298***
Operator group	Endodontic	737	95.34%	96.91%	97.67%	93.93%	.0724
	Other	36	4.66%	3.09%	2.33%	6.07%	

***P-values < 0.05 (Chi-square test)**

The chart review identified 932 teeth in 774 subjects between the ages of 6-18 years that received ET. One subject was excluded because the ET was completed at age 19 years and 2 months. The number of subjects included in this study was 773 subject and 931 teeth (Table 3). The mean age of the subjects was 14.76 years (range: 6-18 years). In general, there were slightly more females (54%) than males (46%). This is true for all age groups except for the 12-14 years age group, where male subjects (52%) slightly exceeded female subjects (48%). The majority of subjects were healthy and did not have history of allergies (77.07%) or lung disease (87.47%). Also, the great majority did not use tobacco in any form (94.59%). However, information was missing in regard to history of allergy, lung disease and tobacco use in about 50% of the subjects. Most subjects were of low socioeconomic status and had MassHealth (Medicaid) insurance (66%). The remaining

either self-paid for their treatment (26%) or had private insurance (8%). The majority of subjects had the ET at age 15-18 years (n=461) followed by 12-14 years (n=215) followed by 6-11 years (n=97). The vast majority of treatments were performed by the endodontic department of the school (95%). Other departments, such as advanced education in general dentistry, pediatric dentistry, and predoctoral students, performed only 5% of ET.

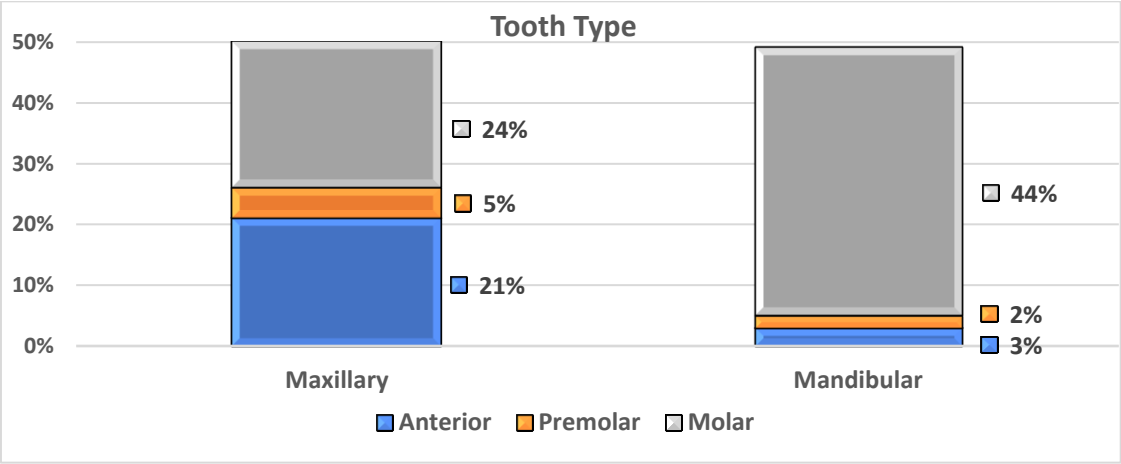
Table 4. Descriptive characteristics of ETT (N=931)

Variable	Category	N (%)	Age 6-11 (n=97)	Age 12-15 (n=215)	Age 13-18 (n=461)	P=
No. of ETT per patient	1	649 (83.96%)	90.72%	77.67%	85.47%	**0.0494***
	2	99 (12.81%)	7.22%	19.07%	11.06%	
	3	17 (2.39%)	2.06%	1.86%	2.39%	
	4	7 (0.9%)	0	0.93%	1.08%	
	5	1 (0.13%)	0	0.47%	0	
Tooth type	Anterior	220 (23.63%)	41.12%	25.77%	19.33%	**<0.0001***
	Premolar	71 (7.63%)	0	6.54%	9.57%	
	Molar	640 (68.74%)	58.88%	67.69%	71.10%	
Tooth category	Mandibular Anterior	30 (3.22%)	5.61%	1.54%	3.55%	**<0.0001***
	Maxillary Anterior	191 (20.52%)	36.45%	24.23%	15.78%	
	Mandibular Molar	413 (45.36%)	43.93%	48.08%	42.73%	
	Maxillary Molar	226 (24.27%)	14.02%	19.62%	28.37%	
	Mandibular Premolar	21 (2.26%)	0	1.54%	3.01%	
	Maxillary Premolar	50 (5.37%)	0	5.00%	6.56%	

***P-values < 0.05** (Chi-square test)

Table 4 shows the descriptive statistics for the ETT. The mean number of ETT per patient was 1.2 (range: 1-5). The majority of patients had a single ET (84%), followed by 2 (13%), 3 (2%), 4 (0.9%) then lastly 5 (0.1%). The ET were performed most often on molars (69%), followed by incisors (24%), then premolars (8%). Mandibular molars received most of the ET (44%) followed by the maxillary molars (24%), then the maxillary anterior teeth (21%), followed by the maxillary premolars (5%), mandibular anterior teeth (3%) and premolars (2%). This is shown in Figure 1.

Figure 1. Tooth category of ETT



Of the total 931 teeth, only 424 (46%) had at least one follow up. The endodontic department performed the ET in 92% of the cases and other departments treated the other 8%. The mean follow up duration was 22.54 months (range: 1-99 months). The total number of failures were 63 (15%) and total number of survivals were 361 (85%).

Figure 2. Outcome assessment at final follow up

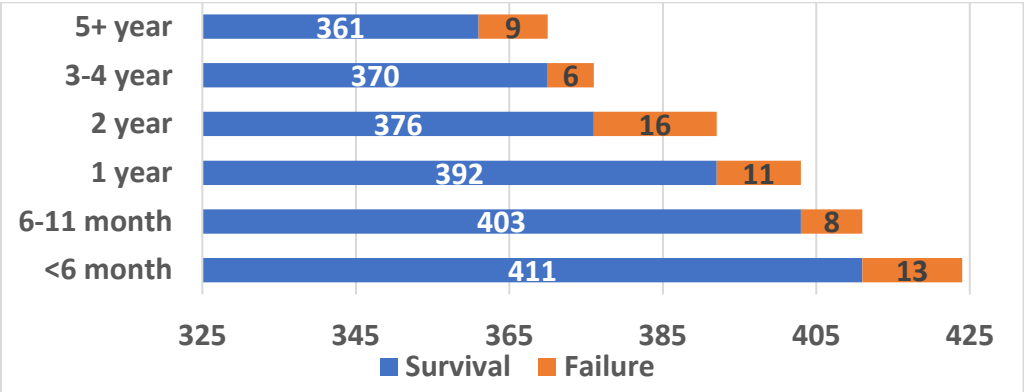


Table 5. Outcome calculation based on last follow up (tooth-based)

	n	Survival	Failure
<6 months	424	411	13
6-11 months	411	403	8
1 year	403	392	11
2 year	392	376	16
3-4 year	376	370	6
5+ year	370	361	9

Figure 2 and Table 5 show ETT that survived or failed at each follow up period. The majority of failures occurred at the 2 years period (25%) followed by the < 6 months period (21%). The least number of failures occurred at the 3-4 years follow up period (10%). Of the total 361 ETT that survived, 97 (27%) had there last follow up at less than 6 months, 70 (19%) had their last follow up at 6-11 months, 76 (21%) had their last follow up at 1 year, 37 (10%) had their last follow up at 2 years, 49 (14%) had their last follow up at 3-4 years, and finally 32 (9%) had their last follow up at 5 or more years.

Table 6. The causes of failure in ETT

N=63	Cause		Actual treatment received
29	Planned for extraction	Non-restorable= 15	Extraction=8
		Orthodontics= 7	Extraction=7
		Unknown= 7	Extraction=7
24	Signs and symptoms	Extraction= 14	Extraction=11
		Retreatment= 6	Retreatment=5
		Apicoectomy= 2	Apicoectomy=1
		Other= 2	
8	Planned for retreatment		Retreatment=7 (1 received 2 apicoectomies then was extracted)
			Extraction=1
2	Planned for apical surgery		Apicoectomy=2

Of the total 63 cases that failed, 59 (94%) cases were performed by the endodontic department and 4 (6%) were performed by other departments. In total, 29 (46%) cases were extracted or required extraction due to non-restorability, orthodontic reasons, or for unknown reasons (Table 6). The reason is unknown if the tooth was not present on subsequent radiographs or if the record was old and cannot be obtained electronically (prior to October 2010). Another 24 (38%) cases were having symptoms of pain or signs of infection or were seen at the emergency department. For the remaining failed cases, 8 (13%) required re-treatment and 2 (3%) needed apical surgery.

When further looking into the cases that failed due to infection or pain, 14 required extraction, 6 required retreatment, 2 needed periapical surgery. The remaining 2 cases did

not fit any of the above categories. One patient was advised to return for follow up but the subject never came back; another had an old record and the nature of the emergency could not be determined. Appendix 1 shows the detailed information of all of the failed ET.

When considering the time that the failure occurred in, 13 (21%) cases failed in less than 6 months after the ET (Figure 2); 8 (13%) cases failed between 6-11 months t; 11 (17%) cases failed at 1 year; 16 (25%) cases failed at 2 years; 6 (10%) cases failed at 3-4 years; 9 (14%) failed at 5 or more years after the ET.

Part 2. Clinical Follow Up

After exclusion of the discharged subjects (n=117), 656 subjects were eligible to be contacted. Also 32 subjects were excluded because they were failure cases and did not have any other teeth with ET that required a follow up. Another subject was excluded because there was no phone number on file. This left us with 623 subjects to contact. The primary investigator made all of the phone calls. In the event that the call was not answered, a second attempt was made at a different day and time from the first phone call. If the second call was not answered, it was recorded that there was no response. We were able to speak to only 67 subjects, which is about 11% of the sample size. The remaining subjects either did not respond (n=302) or were unreachable (n=253) for various reasons (Table 7).

Table 7. Reasons why some subjects did not answer when contacted via telephone

No response		302
Unreachable N=254	Call restriction/no coverage/out of service	87
	Wrong number	70
	Automatic voicemail	40
	Cannot accept calls/busy	37
	Away from home	11
	Does not speak English	6
	Hang up	3
Total		556

Of the 67 subjects that were contacted, 8 subjects were considered as failures and were not eligible for a follow up appointment. These patients either had extraction (3), retreatment (3), infection (1) or the tooth fell out (1). This left us with 59 subjects, of which 27 refused to participate in this study. Only 32 subjects approved to participate. Of those that approved, only 15 subjects actually attended the follow up appointment, which comprised 25% of the contacted eligible sample (n=59).

The age of the patients ranged from 14-26 years at the time of examination. There were 5 males and 10 females. The majority of subjects had a clear medical history with the exception of 4. One subject had food allergies and the other 3 had asthma. With regard to smoking, 3 subjects were previous smokers and only 1 was a current smoker. All subjects had dental insurance with the exception of 1. Seven subjects had MassHealth insurance; while the rest had private insurance. Time from treatment to follow up ranged from 19-108 months (1-9 years). Seventeen teeth were examined and the majority were molar teeth. There were only 2 incisors and 1 premolar. None of the examined subjects had swelling or discharge. Only 1 patient was uncomfortable while biting or chewing on the tooth and another subject had pain or discomfort from the tooth. The same 2 subjects along with one more asymptomatic subject had caries and all of these teeth were non-restorable and were considered as failures. One tooth did not have any restoration, one tooth had a broken metal alloy restoration, and the last tooth had a metal reinforced temporary restoration. All the other remaining cases were successful. These teeth had either a permanent intracoronal restoration or a crown. Only one tooth had a temporary crown over a permanent intracoronal restoration. None of the subjects had retreatment or apical surgery.

Retention rate and failure due to extraction for parts 1+2 (during retrospective chart review and clinical follow up)

Table 8. Descriptive characteristics of subjects with retained teeth (N=329)

Variable	Category	n	Mean (range)	%
Age at treatment		329	15.09 (7-18)	100%
	6-11 years	32	10.03 (7-11)	9.73%
	12-14 years	76	13.18 (12-14)	23.1%
	15-18 years	221	16.48 (15-18)	67.17%
Gender	Female	181		55.02%
	Male	148		44.98%
Insurance	Masshealth	195		59.27%
	Private	36		10.94%
	Self-pay	98		29.79%

Table 9. Descriptive characteristics of the retained ETT (N=402)

Variable	Category	N (%)
Tooth type	Anterior	115 (28.61%)
	Premolar	35 (8.71%)
	Molar	252 (62.69%)
Jaw type	Maxillary	214 (53.23%)
	Mandibular	188 (46.77%)
Tooth category	Mandibular anterior	17 (4.23%)
	Maxillary anterior	98 (24.38%)
	Mandibular premolar	12 (2.99%)
	Maxillary premolar	23 (5.72%)
	Mandibular molar	159 (39.55%)
	Maxillary molar	93 (23.13%)

When retention rate was calculated for the entire population with retrospective chart review along with the population contacted and examined, it was found to be 91% (N=402/441). Table 8 shows the demographics of subjects (N=329) with retained ETT. The mean age for the subjects was 15.09 years (range: 7-18 years). More teeth were retained in the older age group. There were more females with retained ETT than males and the majority had MassHealth insurance. Table 9 shows demographics for the retained ETT (N=402). The

majority of teeth were molars and maxillary teeth showed slightly more retention than mandibular teeth.

Table 10. Descriptive characteristics of subjects with extracted teeth (N=36)

Variable	Category	n	Mean (range) %	%
Age at treatment	6-18 years	36	14.33 (7-18)	100%
	6-11 years	7	10.14 (7-11)	19.44%
	12-14 years	10	13.2 (12-14)	27.78%
	15-18 years	19	16.47 (15-18)	52.78%
Gender	Female	26		72.22%
	Male	10		27.78%
Insurance	Masshealth	23		63.89%
	Private	5		13.89%
	Self-pay	8		22.22%

Table 11. Descriptive characteristics of the extracted ETT (N=39)

Variable	Category	N (%)
Tooth type	Anterior	3 (7.69%)
	Premolar	3 (7.69%)
	Molar	33 (84.61%)
Jaw type	Maxillary	18 (46.15%)
	Mandibular	21 (53.85%)
Tooth category	Mandibular anterior	0 (0%)
	Maxillary anterior	3 (7.69%)
	Mandibular premolar	0 (0%)
	Maxillary premolar	3 (7.69%)
	Mandibular molar	21 (53.85%)
	Maxillary molar	12 (30.77%)

As for the extractions (Tables 10 and 11), the mean age for the subjects was 14.33 years (range: 7-18 years). The majority of the extractions were in the subjects that received ET at 15-18 years of age, subjects that were females and subjects that had MassHealth insurance. The majority of extracted teeth were molars and slightly more mandibular teeth were extracted than maxillary; The most extracted tooth was the mandibular molar (54%), comprising of a little over half of the extracted teeth. None of the extracted teeth were mandibular premolar or mandibular anterior teeth.

Figure 3. Time of retention/extraction assessment of cases with follow up

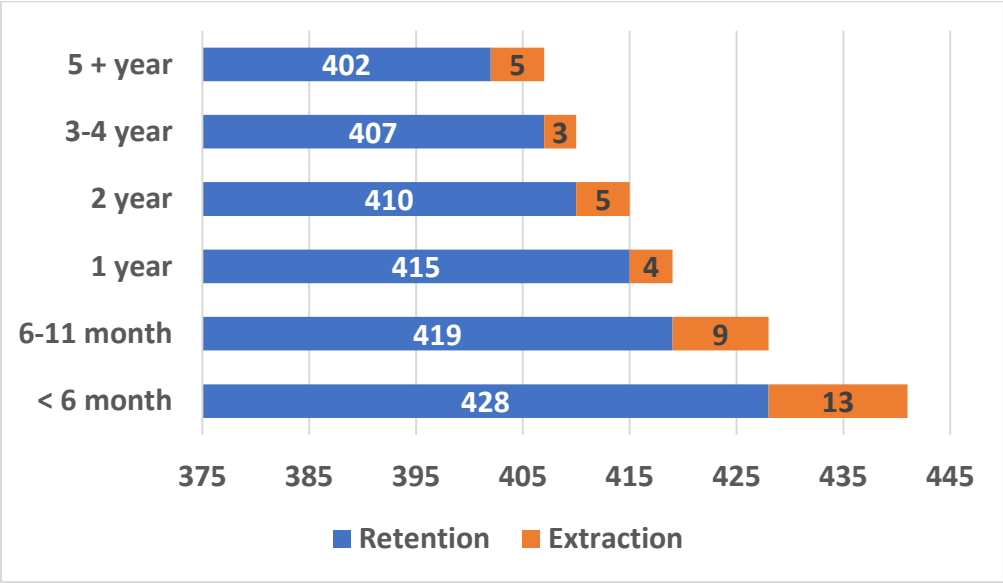


Figure 4. Age group at time of ET of subjects with extracted ETT

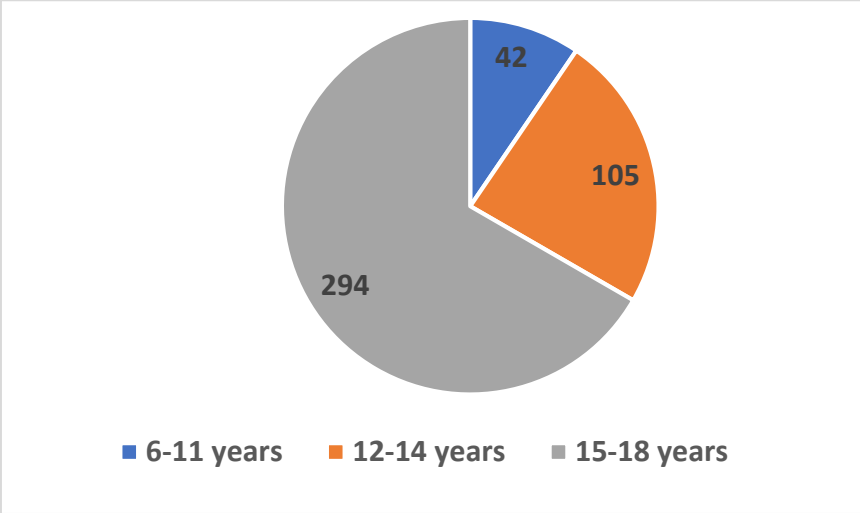


Figure 3 demonstrates tooth retention/extraction at the time of follow up. The majority of extractions occurred at less than 1 year after the ET. Figure 4 illustrates the age group at ET of subjects that had extracted ETT. The majority of extractions were in subjects that received the ET at 15-18 years followed by 12-14 years.

BIVARIATE NAD MULTIVARIATE ANALYSES

SURVIVAL

Table 12. Bivariate analyses of descriptive characteristics and their relationship with the outcome survival (N=367)

Variables	Parameter estimate	Standard error	p	Odds ratio (95% Confidence Interval (CI))
Age	0.1544	0.05	**0.002**	1.167 (1.058,1.287)
Age group at treatment (15-18)	0.9913	0.3833	**0.0097**	2.695 (1.271,5.712)
Age group at treatment (12-14)	0.3001	0.4131	0.4676	1.350 (0.601,3.034)
Sex(Male)	0.27	0.2602	0.2993	1.310 (0.787,2.181)
Insurance type (MassHealth)	-0.1298	0.266	0.6258	0.878 (0.521,1.480)
Tooth type (Maxillary)	0.1905	0.255	0.455	1.210 (0.734,1.994)
Tooth type (Anterior)	0.5275	0.3186	**0.0978**	1.695 (0.908,3.164)
Number of ETT	0.1995	0.1581	0.207	1.221 (0.895,1.664)
Duration (months)	-0.0132	0.00424	**0.0018**	0.987 (0.979,0.995)

***p-values < 0.2** (Logistic regression)

Table 13. Multivariate logistic regression of descriptive characteristics and survival (N=367)

Variables	Parameter estimate	Standard error	p	Odds ratio (95% CI)
Age group at treatment (15-18)	1.1037	0.4099	**0.0071**	3.015 (1.350,6.733)
Age group at treatment (12-14)	0.3320	0.4342	0.4444	1.394 (0.595,3.264)
Sex (Male)	0.2074	0.2701	0.4425	1.230 (0.725,2.089)
Insurance type (MassHealth)	-0.1815	0.2832	0.5215	0.834 (0.479,1.453)
Tooth type (Maxillary)	-0.1237	0.2918	0.6717	0.884 (0.499,1.566)
Tooth type (Anterior)	0.6974	0.3364	**0.0381**	2.009 (1.039,3.883)
Number of ETT	0.1478	0.1693	0.3825	1.159 (0.832,1.616)
Duration (Months)	-0.0120	0.00438	**0.0062**	0.988 (0.980-0.997)

***p-values < 0.05** (Multivariate logistic regression)

Bivariate analysis showed that age group at time of treatment, tooth type and follow up duration were the only covariates significantly related to survival (Table 12). Other covariates that were included in the multivariate analyses (Table 13) because of their clinical relevance were: sex, insurance type, jaw type and number of ETT.

Multivariate analysis revealed participants in the older age group (15-18 years) were significantly more likely to experience the outcome survival of the ETT. The odds of ETT

survival in 15-18 year group is about 200% higher than in 6-11 year group (p= 0.007). In addition to that, having an anterior ETT was significantly related to survival (p= 0.0381). The odds of survival of an anterior tooth was 100% more than a posterior tooth with ET. Another factor that showed a statistically significant association with the outcomes assessed was follow up duration. Our analysis showed that follow up duration was inversely associated with survival (p= 0.0062). This was further assessed by looking deeper into the follow up duration as a categorical variable rather than a continuous one, while controlling for age, sex, insurance, tooth and jaw type. This is shown in Table 14. It was found that the 2 years and ≥5 years groups had a statically significant relationship to survival. At 2-3 years after treatment, the odds of survival of ETT is reduced by 64% (p=0.0011) and at ≥5 years (5-8 years) after treatment, the odds of survival of ETT is reduced by 65% (p=0.0018).

No significant association was found between the survival of an ETT and sex, insurance type, jaw type, or number of ETT in this study.

Table 14. Multivariate analysis – Follow up duration and survival (N=367)

Variable	Parameter	Standard error	**p**	Odds ratios (95% CI)
Duration (6-11 months)	0.0325	0.4940	**0.9475**	1.033 (0.392, 2.720)
Duration (12-23 months)	-0.0728	0.4482	**0.8710**	0.930 (0.386, 2.238)
Duration (24-35 months)	-1.1208	0.3428	**0.0011**	0.36 (0.167, 0.638)
Duration (35-59 months)	0.1947	0.5204	**0.708**	1.215 (0.438, 3.369)
Duration (60+ months)	-1.0467	0.3355	**0.0018**	0.351 (0.182, 0.689)

***p-values < 0.05,** Logistic regression model controlling for age, sex, insurance, tooth and jaw type.

FAILURE

Bivariate analysis showed that age at time of treatment, tooth type and follow up duration were of significantly associated to the outcome failure (Table 14). The multivariate analysis (Table 15) shows that the odds of failure of an ETT in 15-18 year group is about 67% lower than failure in 6-11 year group (p = 0.007). In addition to that, the odds of failure of an anterior ETT was 50% less

than a posterior tooth (p = 0.0381). Another factor was follow up duration; it was positively associated with failure (p = 0.0062).. No significant association was found between failure and sex, insurance type, jaw type, or number of ETT in the study.

Table 15. Bivariate analyses of descriptive characteristics and their relationship with failure (N= 74)

Variables	Parameter estimate	Standard error	p	Odds ratio (95% CI)
Age	-0.1544	0.05	**0.002**	0.857 (0.777,0.945)
Age group at treatment (15-18)	-0.9913	0.3833	**0.0097**	0.371 (0.175, 0.787)
Sex (Male)	-0.27	0.2602	0.2993	0.763 (0.458,1.271)
Insurance type (MassHealth)	0.1298	0.266	0.6258	1.139(0.676,1.918)
Tooth type (Anterior)	-0.5275	0.3186	**0.0978**	0.590 (0.316,1.102)
Jaw type (Maxillary)	-0.1905	0.255	0.455	0.827 (0.501,1.363)
Number of ETT	-0.1995	0.1581	0.207	0.819 (0.601,1.117)
Duration (1-5 months)	0.0132	0.00424	**0.0018**	1.013 (1.005,1.022)

***p-values < 0.2** (Logistic regression)

Table 16. Multivariate logistic regression of descriptive characteristics and failure (N= 74)

Variables	Parameter estimate	Standard error	p	Odds ratio (95% CI)
Age group at treatment (15-18)	-1.1037	0.4099	**0.0071**	0.332 (0.149, 0.741)
Age group at treatment (12-14)	-0.3320	0.4342	0.4444	0.717 (0.306,1.680)
Sex (Male)	-0.2074	0.2701	0.4425	0.813 (0.479,0.779)
Insurance type (MassHealth)	0.1815	0.2832	0.5212	1.199(0.688,2.089)
Tooth type (Maxillary)	0.1237	0.2918	0.6717	1.132 (0.639,2.005)
Tooth type (Anterior)	-0.6947	0.3364	**0.0381**	0.498 (0.258,0.963)
Number of ETT	-0.1478	0.1693	0.3825	0.863 (0.619,1.202)
Duration (Months)	0.012	0.00438	**0.0062**	1.012 (1.003,1.021)

***p-values < 0.05** (Multivariate logistic regression)

RETENTION

Bivariate analysis (Table 17) showed that age, sex and tooth type were significantly related to tooth retention. Other covariates that were included in the multivariate analyses because of their clinical relevance were: insurance type, jaw type, number of ETT and follow up duration. Table 16 shows the multivariate analysis. Only age group (15-18 years) and tooth

type were of significant relationship to tooth retention. Being in the older age group increased the odds of tooth retention by 150% (p= 0.0336). Also anterior ETT had almost 200% higher odds of being retained in the mouth than posterior ETT (p = 0.0102).

Table 17. Bivariate analyses of descriptive characteristics and their relationship with retention (N= 402)

Variables	Parameter estimate	Standard error	p	Odds ratio (95% CI)
Age	0.1294	0.064	**0.0432**	1.138 (1.004,1.290)
Age group at treatment (15-18)	1.0081	0.4744	**0.0336**	2.74 (1.081, 6.944)
Age group at treatment (12-14)	0.4384	0.5153	0.3949	1.550 (0.565,4.256)
Sex (Male)	0.6514	0.3611	**0.0712**	1.918 (0.945,3.893)
Insurance type (MassHealth)	-0.0822	0.3493	0.8139	0.921(0.464,1.826)
Tooth type (Anterior)	1.5703	0.611	**0.0102**	4.808 (1.452,15.924)
Jaw type (Maxillary)	0.2837	0.3364	0.3991	1.328 (0.687,2.568)
Number of ETT	0.0671	0.2069	0.7458	1.069 (0.713,1.604)
Duration (Months)	0.00116	0.00649	0.8587	1.001 (0.989,1.041)

***p-values < 0.2** (Logistic regression)

Table 18. Multivariate logistic regression of descriptive characteristics and retention (N=402)

Variables	Parameter estimate	Standard error	p	Odds ratio (95% CI)
Age group at treatment (15-18)	0.9219	0.3459	**0.0077**	2.514 (1.276, 4.953)
Age group at treatment (12-14)	1.0137	0.5818	0.0815	2.756 (0.881,8.619)
Sex (Male)	0.6244	0.3796	0.1000	1.867 (0.887,3.929)
Insurance type (MassHealth)	0.0157	0.3851	0.9675	1.016(0.478,2.161)
Jaw type (Maxillary)	-0.3379	0.3783	0.3717	0.713(0.340,1.497)
Tooth type (Anterior)	1.7657	0.6183	**0.0043**	2.846 (1.740,19.639)
Number of ETT (2)	-0.5548	0.4482	0.2157	0.574 (0.239,1.382)
Number of ETT (>2)	-0.5999	0.6197	0.3330	0.549 (0.163,1.849)
Duration (6-11 months)	-0.1790	0.4919	0.7160	0.836 (0.319,2.193)
Duration (12-23 months)	0.7640	0.6145	0.2137	2.147 (0.644,7.159)
Duration (24-35 months)	0.0940	0.5873	0.8729	1.099 (0.347,3.473)
Duration (36-59 months)	0.9927	0.7081	0.1609	2.698 (0.674,10.810)
Duration (60+ months)	0.3237	0.5867	0.5811	1.382 (0.438,4.365)

***p-values < 0.05** (Multivariate logistic regression)

DISCUSSION

The majority of studies that looked into survival of ETT have defined survival as tooth retention. In our study, we identified 63 failures from the chart review. These failures were due to having any signs and/or symptoms, root canal re-treatment and apical surgery as well as extraction. Of these 63 cases, only 35 were extracted eventually. In addition to that, 8 failures were identified when subjects were contacted via phone during part 2 of the study. Of those cases only 3 stated that they had the tooth extracted and 1 subject stated that this tooth fell out. During the clinical recall examination, none of the teeth were extracted, due to the inclusion criteria used for subject selection (not having any untoward event). As a result, retention rate was 91% and failure due to extraction was 9% (n=39/441). These findings are comparable to the findings of other studies (Table 1). Fransson et al. [42] showed about 90% survival in cases that were followed up for 5-6 years. They looked for extraction codes for completed ET from insurance data for subjects 20-102 years of age. Lazarski et al. [38] found that 94% of teeth remained functional after ET by looking into insurance database. Alley et al. [32] found that about 90% of ET performed by general practitioners survived. They also found that 98% of ET completed by endodontists survived which was higher than our study. Their data was collected through chart review from 3 private general practices and defined survival as evidence of tooth present on a radiograph or clinical chart. In our study, if we depended only on the clinical and radiographic charts we would have only identified 35 subjects and not the other 4 subjects which we called. So, we would have had a slightly higher survival rate (92%).

Heling and Tamse [34], Fonzar et al. [36], Petersson et al. [41], Friedman et al. [35] all had a clinical follow up component to their survival definition. We were able to have clinical and radiographic follow up of 15 subjects only with 17 ETT and all of the teeth were present

at 1-9-year follow up, but only 82% (n=14/17) survived. Heling and Tamse [34] found that 93% of their cases had a comfortable tooth at 1-5-year follow up (N=213). Fonzar et al. [36] found that 93% cases survived at 10-year follow up (N=1,175). They have included retreatment cases in their data as well. Petersson et al. [41] found that 65% of ETT remained at 20-year follow up (N=499). Friedman et al. [35] found 97% of their cases were asymptomatic at 4-6-year follow up regardless of the PAI score (N=405). We had a very small sample size and that could have contributed to the difference in our survival rate and that of the other studies mentioned.

In our study, age, tooth type and follow up duration were significantly related to the outcomes, while insurance, sex, arch, and number of ETT had no influence. Dammaschke, et al. [33] has also reported that sex and arch had no influence on the outcome along with age as well. While Lazarski et al. [38] and Caplan and Weintraub [55] have reported that an association exists between the patients age and the survival of ETT. Chueng [44] reported that tooth type had an influence on survival. They have identified that anterior ETT are more likely to survive, which was similar to our finding.

As for the follow up duration, we found that at 2 years and $\geq$5 years groups, the odds of survival were reduced. This can be explained clinically, because the majority of failures occur 2-3 years after ET [31] [55]. In our study, 17 failures occurred at 24-35 months, which is 23% (n=17/74) of all failures. As for the $\geq$ 5 years group, we think that this is due to the large number of subjects that were lost to follow up, which lead to loss of information during this time period. We only had 62 teeth in 62 subjects with a follow up at $\geq$ 5 years after treatment. We also think that this is due to the fact that patients with failed ETT tend to return for clinical evaluation even at a longer time after the treatment, while patients with surviving ETT do not tend to return for follow ups long after completion of the treatment. The mean follow up duration for survival was 25 months (range: 1-109), while

it was 36 months (range: 1-117) for failure. A total of 18 failures were identified at $\geq$ 5 years after treatment. In 7 of the subjects, failure was determined during patient contact via phone call. Also in 2 other subjects, failure was determined by absence of tooth on a radiograph; however, in these 2 cases, the exact time of failure is unknown. For the remaining 9 subjects, in which the timing of failure was known, the majority had a fractured tooth or a fractured restoration, 1 tooth had history of perforation and 1 had history of trauma. Only 2 teeth had a crown and 3 teeth had no restoration, while the remaining had a permanent restoration.

In our study, the majority of failures were extractions (68%) followed by retreatment (22%) and apical surgeries (6%). This was also similar to Chen et al. [40]. In their study extraction was the most common untoward outcome (61.5%) followed by retreatment (36%) then apical surgery (2.5%). The majority of failures did not have a permanent restoration. The mean follow up duration for failure in ETT without a permanent restoration was 23 months, while it was 55 months for teeth with permanent restoration. This finding is consistent; the importance of having a permanent restoration has been evaluated and shown by multiple studies [56] [57].

In our chart review if a tooth survived, it was assumed that it continued to survive at subsequent time periods unless otherwise stated in the clinical notes or it was absent on a subsequent radiograph. Only if data suggestive of failure were present, the ETT was removed from the survival category at subsequent follow up time periods.

The majority (54%) of the cases did not have any clinical or radiographic records after completion of the ET. This could be because the patients did not require any further treatment and the treatment would be considered successful. However, this could also be because the patients were not comfortable with the treatment and sought further treatment elsewhere. More likely this could be a combination of both. We do invite our patients for

a 6 month and 1 year follow up. In some cases, we ask for an even closer follow up depending on the treatment rendered. However, not all patients chose to attend those follow up appointments. Patients should be motivated and educated on the importance of returning for follow ups after having RCT. The earlier disease can be detected the better the treatment, the prognosis and the overall dental experience.

CONCLUSIONS

In conclusion, ET performed on permanent teeth of 6-18 year-olds at a university clinic showed high survival and low failure rate over a period ranging from 1 month to 8 years. Tooth retention rates were high as well. Survival and retention of ETT observed among children and adolescents were similar to observations in adults. Our study also concluded that ET is more likely to survive when it is performed among older children (15-18 years), or on an anterior tooth. Our study results suggests that the longer ET is prevented through proper oral hygiene measures and preventive dental care, the better the likelihood of survival and retention of ETT in young patients.

LIST OF ABBREVIATED JOURNAL TITLES

J Am Dent Assoc ..... Journal of the American Dental Association
Arch Oral Biol ..... Archives of Oral Biology
Dent Traumatol ..... Dental Traumatology
Braz Dent J ..... Brazilian dental journal
Intl J of Pediatr Dent ..... International journal of paediatric dentistry
Clin Oral Invest ..... Clinical oral investigations
J Dent res ..... Journal of dental research
Stomatologija, Baltic Dental and Maxillofacial J ... Stomatologija, Baltic Dental and Maxillofacial Journal
J public health dent ..... Journal of public health dentistry
Aust Dent J ..... Australian dental journal
Health Qual Life Outcomes ..... Health and quality of life outcomes
Am J Public Health ..... American journal of public health
Community Dent Health ..... Community Dental Health
IOSR-JDMS ... International Organization of Scientific Research-Journal of Dental and Medical Sciences
J Int Oral Health ..... Journal of International Oral Health
Community Dent Oral Epidemiol ..... Community Dentistry and Oral Epidemiology
OHDMBSC .....Oral Health and Dental Management in the Black Sea Countries
Eur J Dent ..... European Journal of Dentistry
Nig Q J Hosp Med .....Nigerian Quarterly Journal of Hospital Medicine
Swed Dent J ..... Swedish dental journal
Int Dent J ..... International Dental Journal
J Calif Dent Assoc ..... Journal of the California Dental Association
Int Endod J ..... International Endodontic Journal
J Endod ..... Journal of Endodontics
Oral Surg Oral Med Oral Pathol Oral Radiol Endod Oral Surgery, Oral Medicine, Oral Pathology, Oral Radiology, and Endodontology
Oral Surg Oral Med Oral Pathol ..... Oral Surgery, Oral Medicine, Oral Pathology, Oral Radiology, and Endodontology
Eur J Oral Implantol..... European Journal of Oral Implantology
J Formos Med Assoc ..... Journal of the Formosan Medical Association
Contemp Mater I ..... Contemporary Materials I
Eur Arch Paediatr Dent ..... European Archives of Paediatric Dentistry
Acta Odontol Scand ..... Acta Odontologica Scandinavica
J Clin Pediatr Dent ..... Journal of Clinical Pediatric Dentistry
Endod Dent Traumatol ..... Endodontics and dental traumatology

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APPENDIX 1:

Failure Analysis (Chart review cases)

RED= extraction performed GREEN= retreatment performed BLUE= apicoectomy performed

EXTRACTION (n=29)

Non-restorable (n=15)	
5	No restoration, caries
170	No restoration, caries
215	No restoration, caries
223	No restoration, Fracture, OS consult for extraction (no records of extraction)
354	Proximity to adjacent tooth and sub-gingival crown margins, has amalgam and temp crown, planned for extraction (no record of extraction)
366	Emergency: sharp edges, lost temp restoration, caries
374	External referral for extraction of root tip
409a	No restoration, caries
409b	No restoration, caries
481	Temp restoration, PARL, Fracture ML cusp (no record of extraction)
516	Pain, swelling, broken temporary restoration, abx prescribed (tooth later extracted after about 2 years due to nonrestorability as pt never replaced the temporary restoration and had caries)
575	Restoring would compromise adjacent teeth, agreed to place implant
595	No restoration, caries, PARL (no record of extraction)
735	Fracture, MOD amalgam
748	No restoration, caries
Unknown (n=7)	
21	No records available to determine case (old)
61	Most likely for orthodontic reasons (but no records to confirm)
71	No records available to determine case (old)
233	Tooth not showing on subsequent radiograph
391a	Tooth not showing on subsequent radiograph
391b	Tooth not showing on subsequent radiograph
506	Tooth not showing on subsequent radiograph
Orthodontics (n=7)	
188	Referred to OS from ortho (had SSC)
297	Had alloy restoration and was crown prepped without crown
404a	Temp restoration, treatment planned for extraction by ortho and extraction done in outside office
404b	Temp restoration & SSC, treatment planned for extraction by ortho. Extraction done in outside office
418	Agreed on extraction, but pt never returned to clinic (no record of extraction)
493a	Has permanent restoration but no crown, referred for OS by ortho
493b	Has permanent restoration but no crown, referred for OS by ortho

PAIN/INFECTION/EMERGENCY (n=24)

40	Emergency for pain and furcation RL F/U recommended, pt did not return for F/U
50	Emergency, temp restoration, no records of treatment (old record)
79	Emergency, Later extracted
86	Emergency, Later extracted
190	Deep probing, mobility, external root resorption (cosult from ortho to endo, perio, prosth)
228	Emergency, pain, broken to furcation, no restoration, remaining root, extraction done
256	Emergency, pain, No restoration, caries, mobility, deep probing, scheduled for extraction (no record of extraction)
258	Emergency, pain, broken tooth (sub-g DL fracture), no restoration, extraction done
262	Emergency, tender to percussion, temp restoration. Later had retreatment.
275	Pain and PARL, has crown. Apico done (detected unfilled middle canal). Later came with swelling (I&D+Abx) and later had a 2nd apico.
314a	Pain, permanent restoration never placed, no restoration, re-tx recommended. Later deemed nonrestorable and for extraction. Pt wants to wait on tooth (No record of extraction)
314b	Recurrent decay, pain, temp restoration, PARL, referred for extraction. Later extraction was done.
360	Pain, fracture, no restoration, unrestored post space. (No record of re-tx)
361	Pain on chewing, leaky temp restoration, caries, ML subgingival fracture, nonrestorable. Later extracted.
424	Hx of avulsion. After RCT done ankylosis noted on f/u. 2nd trauma lead to GIII mobility and deep probing. Atraumatic extraction and GBR done on same day of ortho bracket placement
549	Pain, cracked tooth, still in temp restoration, caries. Extraction done.
570	Pain, leaky temp restoration, caries, retreatment recommended and was later completed.
588	Pain and discoloration. Seems to be in temp restoration. Later had retreatment.
596	Deep probing, sinus tract, temp restoration, furcation RL. Retreatment missed canal, no fracture detected.
716	Swelling, I&D, Abx, has composite restoration, planned for apico (Apico never done, on F/U PARL is healing)
721a	External resorption, sinus tract, retreatment done
721b	External resorption, Grade III mobility, extraction done
738	Sinus tract, then emergency with pain, exploratory perio sx detected fx line, for extraction (no record of extraction)
755	No restoration, pain, never restored, no restoration, fracture

RE-TREATMENT (n=8)

98	Re-tx done, Later received 2 apicos then was surgically extracted
106	Old record cannot determine cause of failure
110	Cracked amalgam + short M obturation, re-tx done
146	Incomplete coronal obturation, (Re-tx not initiated)
475	Temp restoration not replaced and was partly missing, recontamination, re-tx done
654	Broken D wall, caries, planned for re-tx. came again with fx and tooth non-restorable (re-tx not done)
680	Never placed permanent restoration, No restoration, Re-tx done, no restoration even after re-tx
772	Not restored

APICOECTOMY: (n=2)

345	Internal resorption, thin dentinal walls, PARL increased, apico done and later for extraction and implant
466	Unsuccessful MTA obturation so apico done later

Abbreviations:
OS= oral surgery department
Ortho= orthodontics department
Endo= endodontics department
Perio= periodontics department
Prosth= prosthodontics department
RL= radiolucency
PARL= periapical radiolucency
M= mesial
D= distal
ML= mesiolingual
MOD= mesial occlusal distal
SSC= stainless steel crown
Apico= apicoectomy
Re-tx= retreatment
GBR= guided bone regeneration
I&D= incision and drainage
Abx= antibiotics
Temp= temporary
MTA= mineral trioxide aggregate
Sx= surgery
Fx= fracture
Hx= history
Pt= patient
F/U= follow up

CURICCULUM VITAE:

[redacted]