Factors Effecting Survival of Teeth with Nonsurgical Root Canal Therapy Including a Multi-State Outcome Analysis

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FACTORS EFFECTING SURVIVAL OF TEETH WITH NONSURGICAL ROOT CANAL THERAPY INCLUDING A MULTI-STATE OUTCOME ANALYSIS

By,

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ABSTRACT

FACTORS EFFECTING SURVIVAL OF TEETH WITH NONSURGICAL ROOT CANAL THERAPY INCLUDING A MULTI-STATE OUTCOME ANALYSIS

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Objective: To study the factors effecting the survival of teeth with non-surgical root canal therapy (NS-RCT) and to compare the transitions between failure states for teeth treated with NS-RCT based on initial provider type.

Methods: Insurance claims were analyzed for 438,487 initial NS-RCT procedures to determine the effect of provider type, patient age, tooth position, presence of post/core, and crown at 90 days on tooth survival. Kaplan Meier survival estimates were evaluated for 1, 3, 5, and 10 years and adjusted hazard ratios (aHR's) were calculated. A multi-state model with six transitions was created using the 'mstate' R package.

Results: Overall survival was 98.2% at 1 year, 94.4% at 3 years, 90.8% at 5 years, and 82.8% at 10 years. Ten-year survival rates were 84.5% and 81.9% for teeth treated by endodontists and other providers, respectively. In the multiple regression analysis, significant differences in survival were found comparing NS-RCT provider (other provider vs. endodontist, aHR 1.31 [1.27, 1.35]) and tooth location (molar vs. anterior, aHR 1.26 [1.21, 1.31]). Increasing age at NS-RCT was significantly associated with a greater hazard of extraction. Placement of core/post and crown within 90 days were each significantly associated with a reduced hazard of extraction (aHR = 0.74 [0.72, 0.76] and aHR = 0.53 [0.51, 0.54]).
Most teeth treated by NS-RCT had no subsequent treatment interventions. Teeth that were retreated were more likely to be extracted than teeth that did not have such an intervention. Teeth were more likely to be extracted than retreated. If a tooth had a non-surgical retreatment and subsequently a surgical retreatment, then it was more likely that the surgical intervention occurred during the first year of treatment.

Conclusion: Survival rates of NSRCT treated teeth are higher among teeth treated by endodontists, when a crown was placed within 90-days of NSRCT and among younger patients. NS-RCT failures are most likely to result in tooth extraction. When retreatment is performed, it is more likely to be non-surgical and retreatment in any form increases the likelihood for future extraction. NS-RCTs initially performed by non-endodontists also have a greater chance for non-surgical retreatment or extraction.

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INTRODUCTION

The pioneering studies in endodontics by Moller and Kakehashi demonstrated that the main etiology in the development of apical periodontitis is the presence of bacteria and their byproducts within the root canal system (1,2). These premises lead Herbert Schilder, the father of modern endodontics, to describe the mechanical and biological objectives that need to be fulfilled in order to allow for successful therapy (3). He proposed cleaning and shaping and obturation protocols, many of which are still utilized to this day. In accomplishing these objectives, it became possible to achieve predictably successful outcomes in endodontics.

The success rates of endodontic therapy have been studied extensively and demonstrate a range from 81% to 97% (4,5,6). Even though there are a myriad of studies indicating factors that affect the prognosis of the treatment, there are limited studies investigating the impact that the treating clinician has on the outcome (7,8). These studies demonstrated that tooth survival was higher when an endodontist performed the root canal therapy compared to a general dentist. However, these studies did not further evaluate the rates of retreatment based on the initial provider type. Lazarski in 2001 compared the outcomes of root canal therapy between an endodontist or a general dentist and evaluated the incidences of extraction, retreatment, and surgical retreatment (9). Lazarski was able to identify the true outcome of the endodontic therapy by evaluating the combined incidence of extraction and endodontic retreatment. However, there has not been additional research corroborating these results.

In order to further evaluate the true outcome of endodontic therapy based on the initial provider type, an insurance database study was completed. Insurance database studies are limited as they only account for treatment that has been submitted to the insurance company. However, they provide a real-world evaluation of treatment being rendered in a private practice environment encompassing a large demographic. Delta Dental of Wisconsin provided their electronic insurance claims record and enrollment database encompassing a thirteen-year period from 2000- 2013. The claims were analyzed to compare the true outcome of endodontic therapy based on if the initial provider was an endodontist or a general dentist.

LITERATURE REVIEW

Nonsurgical Root Canal Therapy

The primary goals of nonsurgical root canal therapy (NS-RCT) include removing the root canal system contents, elimination of adverse signs or symptoms, promotion of healing and repair of periapical tissues, and the prevention of further breakdown of periapical tissues (10,11). In several classic studies, apical periodontitis has been shown to be the result of microorganisms and their byproducts in the root canal system (1,2,11). In these studies, it was shown that teeth will develop apical periodontitis when microorganisms are present but will not if the pulps are aseptic (1,2,11). This lead to the hypothesis that in order to have resolution of apical periodontitis, the root canal system must be disinfected to the point that the body can allow for healing. It was shown that the success rates for root canal therapy were higher in situations that bacteria were not able to be detected through culturing (12). There is now a further understanding of the presence of a biofilm in the root canal system of infected teeth and the difficulty to fully eradicate the microorganisms (13). As a result of the biofilm, bacterial resilience, and the limitations in the chemomechanical debridement, the current belief is that microorganisms cannot be completely eliminated from the root canal system regardless of techniques utilized (14,15). Fortunately, root canal therapy has still been shown to be very effective in a multitude of studies with success rates ranging from 90-96% (16,17).

There are a wide variety of opinions and techniques regarding the process of complete chemomechanical debridement although it is well accepted that a thorough cleaning and shaping will lead to the best possible success. Peters et al. found that through instrumentation alone, 35% of the root canal remained unchanged (18). This, along with a study by Bystrom and Sunqvist showed that hand instrumentation and saline did not produce a sterile canal system, led researchers to understand a chemical component was necessary to disinfect the canal system (19). The rationale for the use of files is to disrupt the biofilm mechanically while also creating a suitable shape that allows for irrigation to reach the apex of the tooth (3). Through a meta-analysis, it was found that the highest success rates were achieved when the root canal therapy terminated within 1mm of the radiographic apex (20). It has been suggested that the canal must be enlarged to a master apical size of at least 0.30mm in order to allow for irrigation to reach 1mm short of the apex, while others have argued that larger sized preparations will increase the chemomechanical debridement of the root canal system (21,22). Once the canal has been prepared to its proper size, a variety of irrigants have been suggested for proper disinfection, but the most popular remain sodium hypochlorite (NaOCl) and ethylenediaminetetraacetic acid (EDTA) (23). NaOCl is antibacterial and removes organic debris while EDTA removes the inorganic portion of the smear layer (24,25,26). This model of chemomechanical debridement does not allow for complete sterility of the root canal system (14,15). However, it represents the general practice protocol for root canal therapy, which allows for high levels of success (16,17).

Success versus Survival

There are conflicting opinions regarding what constitutes successful therapy in endodontics (27,28). Strindberg came up with stringent criteria claiming that success requires both no symptoms and no periapical radiolucency (27). Friedman has described possible outcomes of endodontic therapy as healed, healing, disease, and functional retention (28). Functional retention describes a situation where the patient is asymptomatic and functional, but a periapical radiolucency is present. Thus, it has been suggested that the primary goal of the therapy is for the tooth to be retained and asymptomatic and the secondary goal is for resolution of apical periodontitis (28). In the outcome study by Ng, patients were asymptomatic and functional in 91% of the cases but according to the Strindberg criteria the success of the therapy decreased to 83% (29). This demonstrates that the success rates will change based on the definition of success that is used, which is why it is important to have a standardized classification of successful treatment.

There have been a limited number of studies regarding the success and failure rates of root canal therapy based on the provider type (7,9). Burry found that at 5 and 10 years, the survival of teeth endodontically treated by a general dentist was lower than if they were treated by an endodontist (7). Survival was defined as a tooth that was not extracted, retreated non-surgically, or retreated surgically. That means that a tooth with an untoward event may still exhibit survival and thus the study did not measure true survival.

Nonsurgical Root Canal Treatment Failure

Even though the success rates are high in endodontic therapy, there will always be cases that will fail for a variety of reasons (15). There is a constant interaction between the human body and the infection stemming from the root canal system and goal of root canal therapy is to shift the pendulum from infection to repair. A compromised immune system is a significant predictor for endodontic treatment outcome, which shows that an individual's immune response can impact the success of the treatment (30). There are variations in the complexity and resistance of the infection present and how patients respond to the endodontic therapy. Treatments that may work on one individual might not be sufficient to fully alleviate the symptoms or allow for resolution of the infection in another individual.

The categories describing causes for persistent apical periodontitis include intraradicular infection, extraradicular infection, foreign body reactions, and true cysts (31). The primary cause of endodontic failure is persistent bacterial infection resulting from inadequate aseptic control, missed canals, inadequate chemomechanical disinfection, leaking restorations, and extruded debris infected with microorganisms (17,31,32). It has been shown that bacteria are often organized in a biofilm, which makes them much less susceptible to the chemomechanical disinfection utilized in root canal therapy (33,34). Also, certain bacteria are more virulent than others and can be a primary reason for endodontic failure. For example, Enterococcus faecalis has been shown to be present in higher concentrations relative to other bacteria in cases of persistent disease (35). E. faecalis has been shown to aggressively invade dentinal tubules, suppress lymphocytes, and be resistant to calcium hydroxide ($Ca(OH)_2$) (36,37,38,39). These virulence factors in combination with the limitations of our ability to address the entire root canal system are possible reasons for endodontic failure.

Along with microbial factors, the patients' providers can have a direct impact on endodontic success by the quality of treatment rendered. Temporary restorations leak over time and if the tooth is not restored promptly, the success of the root canal therapy decreases (29,40). Iatrogenic complications such as fractured instruments, untreated canals, perforations, or extrusion of materials decrease the likelihood for endodontic success (41). The provider type has also been implicated in affecting endodontic survival (7).

Nonsurgical Retreatment

Despite the many causes for endodontic failure, root canal therapy still achieves success rates of 86-96% (7,13,16). In these situations where root canal therapy is not successful, the patient and provider decide if the best course of treatment is for extraction or endodontic retreatment. The goal for the retreatment is the same as the initial therapy, which is to remove the causative factor for the infection and allow for healing to occur (10). Stabholz and Friedman developed a rationale for deciding further treatment on a previously endodontically treated tooth that included surgery, re-treatment, follow-up, or no treatment (42). One of the critical factors in deciding if a tooth with failing root canal therapy is going to undergo surgical or a nonsurgical retreatment is the quality of the previous filling (42). This is because the main objective of nonsurgical retreatment is to correct deficiencies in the initial treatment. If the provider determines that they can increase the quality of the root canal therapy and navigate previously unaddressed canal space without drastically weakening the tooth structure, then the treatment decision would be to retreat non-surgically (42). Nonsurgical retreatment has demonstrated survival rates of 82-93% and should be considered as the first line treatment for an endodontic failure if the tooth is restorable (4,43,44,45).

Surgical Retreatment

Even though orthograde retreatment is typically the treatment of choice for recurrent endodontic infection, endodontic microsurgery is a very successful and valuable procedure in resolving such an infection (46). The rationale for surgical treatment remains the same as in traditional therapy in that the goal is to reduce the presence of microorganisms in the root canal space (47). One difference is that through surgical intervention, the provider can address the extraradicular infection with curettage and removal of the inflamed periapical tissues.

In situations where materials are extruded outside of the root canal system, they can harbor microorganisms that can result in a chronic inflammatory reaction (48). The lesions that arise are of inflammatory origin and are the result of chronic irritation from the microorganisms residing in the root canal system or extraradicularly (47). It has even been found that paper points can induce chronic apical periodontitis (49). Even though most lesions of endodontic origin are granulomas, roughly 15% of the lesions are cysts (50). Cysts are the result of proliferation of epithelial rest cells of the periodontal ligament (51,52). These cells proliferate as a result of an inflammatory stimulus in which they encompass the irritant (53). If they are a true cyst and not a pocket cyst, surgical endodontic therapy will not resolve the infection and they will need to be surgically removed (54, 55).

When the quality of the initial treatment is unlikely to be improved or when a nonsurgical retreatment would compromise critical tooth structure, then surgical retreatment is preferred. It is at this junction where the provider must make the decision that both allows for the best chance of resolution of the infection while also balancing long term prognosis, patient finances, desires, risks, and benefits of each treatment.

Core/Post and Core

It has been well established that the quality of the coronal restoration has a direct impact on the success of the endodontic therapy (56,57,58). A restoration not only prevents bacterial contamination into the root canal space, but also replaces broken down tooth structure. The most commonly used materials for core buildups are dental amalgam and composite. Along with being user friendly, amalgam has the benefits of high compressive strength, wear resistance, and stiffness (59). However, amalgam is brittle and has a lower tensile strength than composite, which is why they must have sufficient bulk in order to decrease their chances of fracture. Fortunately, core buildups typically require greater than 2mm of material, which is sufficient enough to provide adequate strength for the material. Dental amalgams also have the benefit of undergoing slight corrosion, which creates a seal between the restoration and tooth structure preventing leakage (60).

Composite restorations, also known as resin-based composites, are used to replace missing tooth structure and provide increased esthetics compared to amalgam (61). There are definitive benefits and drawbacks to using composite in dentistry, so it is up to the dentist to decide which is the best material for the specific situation. Composite core buildups utilize a bonding system so that the restoration will have micromechanical retention to the enamel and dentin (59). However, composite does undergo polymerization shrinkage, which can lead to a gap between the restoration and the tooth structure allowing for leakage and recurrent caries (61). Additional disadvantages include exhibiting more occlusal wear, more time consuming to place, and they are more technique sensitive as the operating site needs to be properly isolated in order to prevent fluid contamination (60). Newer composite materials have been developed that diminish the drawbacks that the earlier generations had including having superior durability, wear resistance, and decreased shrinkage (61). With all of the advances in materials and techniques, it is critical that the dentist stays up to date in their knowledge base in order to utilize the best possible material to address the specific situation that the patients present with.

Teeth that are endodontically treated are typically structurally compromised as a result of previous restorations or caries. When there is extensive loss of coronal tooth structure, post placement is valuable for the retention of the core and crown (62). There are a variety of categories of posts including active or passive, parallel or tapered, prefabricated or custom, metal or fiber or ceramic. They each have their own indication but the primary goal is to retain the restoration and the crown when there is not enough remaining tooth structure to do so. Placement of a post can be a technique sensitive procedure and previous studies have shown that success rates are increased 20% when a rubber dam is used (63). Post placement involves creating space for post placement but it is critical to minimize the enlargement of the canal as it does weaken the root (64). An oversized post preparation space along with use of a rigid post will predispose the tooth to fracture (65). However, posts with an elastic modulus closer to dentin, such as fiber posts, can more evenly distribute the force within the root. Fiber posts typically fail from debonding which reduces the risk of root fractures (66). However, if a metal post is placed in an overly enlarged canal, then the tooth is highly predisposed to suffering a fracture (64,65). The most critical factor in preventing root fractures is preserving natural tooth structure in both the coronal and radicular areas.

Regardless of the final restoration chosen, it is also critical that such restoration takes place in a timely fashion as to prevent microbial leakage into the canals (67). Leakage studies have shown that temporary filling materials will allow for bacterial contamination of the root canal space within 30 days and bacterial endotoxin will present even sooner (68,69). That is why if there is obvious contamination, a retreatment maybe considered prior to the final restoration placement (70,71). Successful endodontic therapy relies heavily on the presence of a quality restoration placed in a timely fashion (56).

Crown

Teeth that require endodontic therapy typically have weakened tooth structure prior to therapy a result of trauma, caries, or previous restorations. In a long-term study at an endodontic specialist's office, it was determine that the main causes of tooth loss after root canal therapy are crown and root fractures (4). Additionally, in a study by Vire investigating the cause of endodontically treated tooth failure, he found that 59% of the teeth were extracted as a result of a prosthetic failure whereas only 8% were extracted due to endodontic reasons. Vire also found that teeth survived almost twice as long if a crown was placed after the root canal therapy (72). It has been shown that an MOD preparation can weaken the tooth significantly and decrease the fracture resistance by 40-60% (73). Endodontically treated teeth are weaker, but it was demonstrated that endodontic procedures and access cavity only decrease the relative stiffness by 5% whereas merely an occlusal cavity preparation has a 20% effect (74). Based on this data, it seems that the loss of tooth structure from caries or previous restorations is going to be a more significant factor on the likelihood of fractures when compared to the endodontic treatment.

Aquilino found that teeth that did not have a crown placed subsequent to the root canal therapy were lost at a rate six times those teeth that had a crown placed (75). This could be explained that teeth without a proper restoration were more prone to leakage and they are more likely to have catastrophic loss of tooth structure. Aminoshariae and others found that an endodontically treated tooth that did not have a permanent restoration had a survival rate of 58%, but if a core build-up was placed without a crown it increased to 71%. However, if a core was placed along with a crown, then the survival jumped up to 84%. Additionally, if that crown was placed within 4 months of the root canal therapy, the tooth was three times more likely to survive than if the crown was placed after four months (76). It is clear that prompt restoration with a core build-up followed by crown placement has a significant effect on tooth survival after root canal therapy.

MATERIALS AND METHODS

The data for this study was obtained from the electronic insurance claims record and enrollment database for Delta Dental of Wisconsin. The database included 491,915 initial nonsurgical root canal therapies that occurred between January 1, 2000 and December 31, 2013. Of the total number of NS-RCTs, 438,487 were completed on permanent teeth and had a 90-day continuous follow-up without failure. Ninety days after the initial therapy was used as a landmark in order to assess the presence or absence of a post/core and or crown. This study excluded 34,616 teeth that did not have at least 90 days of continuous follow-up and the 3,376 that failed within the 90 days. Survival times were calculated from the landmarked 90 days after the NS-RCT (Table 1).

	N	Inclusion/exclusion
step 0:	491915	Total NS-RCT's
step 1:	488943	Include: First NS-RCT per patient/tooth
step 2:	476479	Include: Permanent teeth numbers 1-32
step 3:	438487	*Include: At least 90 days continuous follow-up

Table 1: Inclusion/Exclusion Criteria

The initial event was a NS-RCT on an anterior, premolar, or molar tooth as defined by the Code on Dental Procedures and Nomenclature (CDT). The D3310 code includes initial NS-RCT of a maxillary or mandibular central incisor, lateral incisor, or canine. The D3320 code includes initial NS-RCT of a maxillary or mandibular first or second premolar. The D3330 code includes initial NS-RCT of a maxillary or mandibular molar.

Extraction, nonsurgical retreatment and surgical retreatment of the tooth that had the initial NS-RCT were considered untoward events. The cases were followed and considered successful until the CDT codes representing extraction, nonsurgical retreatment, or surgical retreatment (apicoectomy) were encountered. If the tooth was retreated, either non-surgically or surgically, it continued to be followed and further interventions were recorded.

The presence of the core, post and core, and crown was recorded at 90 days after initial NS-RCT. It was determined by the presence of the CDT code indicating that a core, post and core, or cast post and core had been placed. Presence of the CDT code for the placement of a metallic, non-metallic, or stainless steel crowns was evaluated at 90 days after the initial NS-RCT.

For each of the initial encounters, information was obtained regarding the tooth location (anterior, premolar, molar), age of the patient, and the provider type. Provider types were divided into endodontists, whom graduated from an American Dental Association accredited United States endodontic residency program, and non-endodontists (or other providers).

Once the variables were defined, the data was analyzed using SAS version 9.3 (SAS Institute Inc., Cary, NC). A statistical significance level (alpha) of 0.05 was used throughout. The survival time is taken as the time from landmark (90 days post-procedure) to extraction. Kaplan-Meier survival estimates were evaluated for 1, 3, 5, and 10 years (Figure 1, Table 3). Clustering within subject (the same patient may have multiple teeth with root canals) was accounted for by using the sandwich estimator to obtain robust standard error estimates. Cox proportional hazards regression was used to compare survival distributions between categories for each predictor; this p-value is not adjusted for other variables or multiple testing (Tables 4,5,6,7,8, Figures 2,3,4,5,6).

In regards to the multiple Cox proportional hazards regression analysis, the survival time was taken from the 90-day post-RCT landmark to extraction. Adjusted hazard ratios (aHR's) were calculated using multiple Cox proportional hazards regression analysis; sandwich estimator was used to obtain robust standard errors that adjust for within-subject correlation. Each hazard ratio estimate is adjusted for all other variables in the model (Table 9).

Cumulative incidence plots were constructed demonstrating the incidence of the first failure event to occur following NS-RCT (nonsurgical retreatment, surgical retreatment, extraction). An additional plot demonstrated the probability of untoward events comparing the initial provider type (Figures 7,8).

A multi-state model with six transitions was created using the 'm-state' R package (only transitions to a higher level of re-intervention were allowed). The cumulative hazard and transition probabilities from the model were plotted for all NS-RCT procedures and separately by initial provider type (Figures 9,10,11). The plot of transition probabilities demonstrates the probability of a tooth with NS-RCT transitioning to a failure state and compares them based on the provider types (Figures 12,13).

RESULTS

After the inclusion/exclusion criteria were applied to the dataset, there were 438,487 patient encounters that resulted in nonsurgical root canal therapy. Table 2 demonstrated 138,655 procedures were completed by an endodontist and a non-endodontist completed 299,832. Endodontists completed 31.6% of the procedures while non-endodontists completed 68.4% of the procedures. Of the cases where NS-SRCT was performed by endodontists, 99,205 (71.5%) were molars, 25,220 (18.2%) were premolars, and 14,230 (10.3%) were anteriors. Of the cases where a provider other than an endodontist performed NS-RCT, 141,877 (47.3%) were molars, 96,600 (32.2%) were premolars, and 61,355 (20.5%) were anteriors. Based on a Chi-squared analysis, there was a significant difference in tooth location between the different provider types ($p<0.001$).

The mean age of the patients in this study was 44.7, while age of the patients of endodontists was 46.4 and the age of the patients of non-endodontists was 43.9

years old. The median age of the patients in this study, patients of the endodontists, and patients of the non-endodontists were 46, 48, 45, respectively. Based on a T-test analysis, these results are a significant difference ($p<0.001$).

Subjects were categorized based on age in five groups. Subjects in the age group 0-17 years constituted 16,123 (3.7%) cases, ages 18-35 having 99,319 (22.7%) cases, ages 36-53 having 194,831 (44.4%) cases, ages 54-71 having 121,121 (27.6%) cases, and ages 71+ having 7,093 (1.6%) cases. In regards to endodontists, ages 0-17 had 5,060 (3.6%) cases, ages 18-35 had 24,903 (18%) cases, ages 36-53 had 61,790 (44.6%) cases, ages 54-71 had 44,159 (31.8%) cases and ages 71+ had 2743 (2.0%) cases. In regards to non-endodontists, ages 0-17 had 11,063 (3.7%) cases, ages 18-35 had 74,416 (24.8%) cases, ages 36-53 had 133,041 (44.4%) cases, ages 54-71 had 76,962 (25.7%) cases and ages 71+ had 4,350 (1.5%) cases. Based on a Chi-squared analysis, there was a significant difference in the ages of the patients between the different provider types ($p<0.001$).

Of the 438,487 encounters, 276,611 (63.1%) had a core or a post and core placed within 90 days while 161,876 (36.9%) did not have a core or a post and core placed. Encounters with endodontists resulted in 79,949 (57.7%) cases having the core or post and core placed within 90 days while 58,706 (42.3%) did not have a core or post and core placed. Encounters with non-endodontists resulted in 196,662 (65.6%) cases having the core or post and core placed within 90 days while 103,170 (34.4%) did not have a core or post and core placed. Based on a Chi-squared analysis, there was a significant difference in the presence of a core or post and core at 90 days of the patients between the different provider types ($p<0.001$).

Of the 438,487 encounters, 121,549 (27.7%) had a crown placed within 90 days while 316,968 (72.3%) did not have crown placed. Encounters with endodontists resulted in 37343 (26.9%) cases having the crown placed within 90 days while 101,312 (73.1%) did not have a crown. Encounters with non-endodontists resulted in 84,206 (28.1%) cases having the crown placed within 90 days while 215,626 (71.9%) did not have a crown placed. Based on a Chi-squared analysis, there was a significant difference in the presence of a crown at 90 days of the patients between the different provider types ($p<0.001$) (Table 2).

	All (n = 438487)	Endodontist (n = 138655)	Other provider (n = 299832)	p-value	Test
Tooth location				<.001	Chi-squared
Anterior	75585 (17.2%)	14230 (10.3%)	61355 (20.5%)		
Pre-molar	121820 (27.8%)	25220 (18.2%)	96600 (32.2%)		
Molar	241082 (55.0%)	99205 (71.5%)	141877 (47.3%)		
Age at NSRCT				<.001	T-test
Mean (SD)	44.7 (14.1)	46.4 (14.0)	43.9 (14.0)		
Median [Min, Max]	46.0 [0.0, 99.0]	48.0 [0.0, 99.0]	45.0 [1.0, 96.0]		
Freq Missing	0	0	0		
Age at NSRCT				<.001	Chi-squared
0-17	16123 (3.7%)	5060 (3.6%)	11063 (3.7%)		
18-35	99319 (22.7%)	24903 (18.0%)	74416 (24.8%)		
36-53	194831 (44.4%)	61790 (44.6%)	133041 (44.4%)		
54-71	121121 (27.6%)	44159 (31.8%)	76962 (25.7%)		
71+	7093 (1.6%)	2743 (2.0%)	4350 (1.5%)		
Core/post within 90 days				<.001	Chi-squared
No core/post within 90 days	161876 (36.9%)	58706 (42.3%)	103170 (34.4%)		
Core/post within 90 days	276611 (63.1%)	79949 (57.7%)	196662 (65.6%)		
Crown within 90 days				<.001	Chi-squared
No crown within 90 days	316938 (72.3%)	101312 (73.1%)	215626 (71.9%)		
Crown within 90 days	121549 (27.7%)	37343 (26.9%)	84206 (28.1%)		

Table 2: Summary of variables based on number of cases

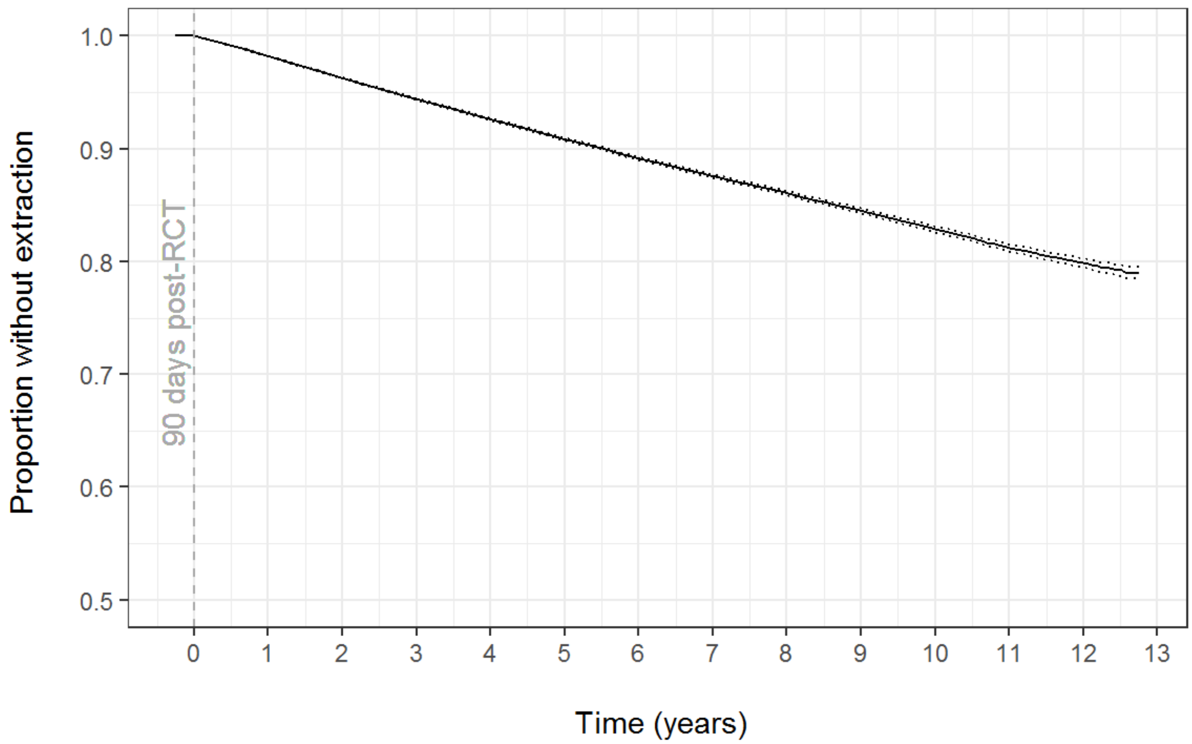

Figure 1: Survival estimates of endodontically treated teeth

	Survival	N events	N at risk
0 year	—	—	438487
1 year	98.19% [98.14%, 98.23%]	6889	326372
3 year	94.38% [94.29%, 94.46%]	9884	185966
5 year	90.83% [90.70%, 90.95%]	5454	105287
10 year	82.84% [82.57%, 83.11%]	4848	17762

Table 3: Survival estimates of endodontically treated teeth

	Survival	N events	N at risk
Anterior			
0 year	—	—	75585
1 year	98.54% [98.45%, 98.63%]	945	56220
3 year	94.94% [94.74%, 95.14%]	1585	31702
5 year	91.50% [91.21%, 91.80%]	878	17730
10 year	83.28% [82.61%, 83.95%]	823	2792
Pre-molar			
0 year	—	—	121820
1 year	98.38% [98.31%, 98.46%]	1701	90825
3 year	94.83% [94.67%, 94.98%]	2576	52301
5 year	91.39% [91.16%, 91.62%]	1493	29985
10 year	83.74% [83.25%, 84.23%]	1330	5267
Molar			
0 year	—	—	241082
1 year	97.98% [97.92%, 98.04%]	4243	179327
3 year	93.98% [93.86%, 94.10%]	5723	101963
5 year	90.33% [90.16%, 90.50%]	3083	57572
10 year	82.23% [81.87%, 82.60%]	2695	9703

Table 4: Survival estimate of endodontically treated teeth based on tooth location

Using a Kaplan-Meier estimator, the survival rates were 98.19% at 1 year, 94.38% at 3 years, 90.83% at 5 years, and 82.84% at 10 years (Figure 1, Table 3). The survival rates were further divided by tooth location and anterior teeth had a survival rate of 98.54% at 1 year, 94.94% at 3 years, 91.21% at 5 years, and 83.28% at 10 years (Figure 2, Table 4). Premolar teeth had a survival rate of 98.39% at 1 year, 94.83% at 3 years, 91.39% at 5 years, and 83.74% at 10 years. Molars had a survival rate of 97.98% at 1 year, 93.98% at 3 years, 90.33% at 5 years, and 82.23% at 10 years.

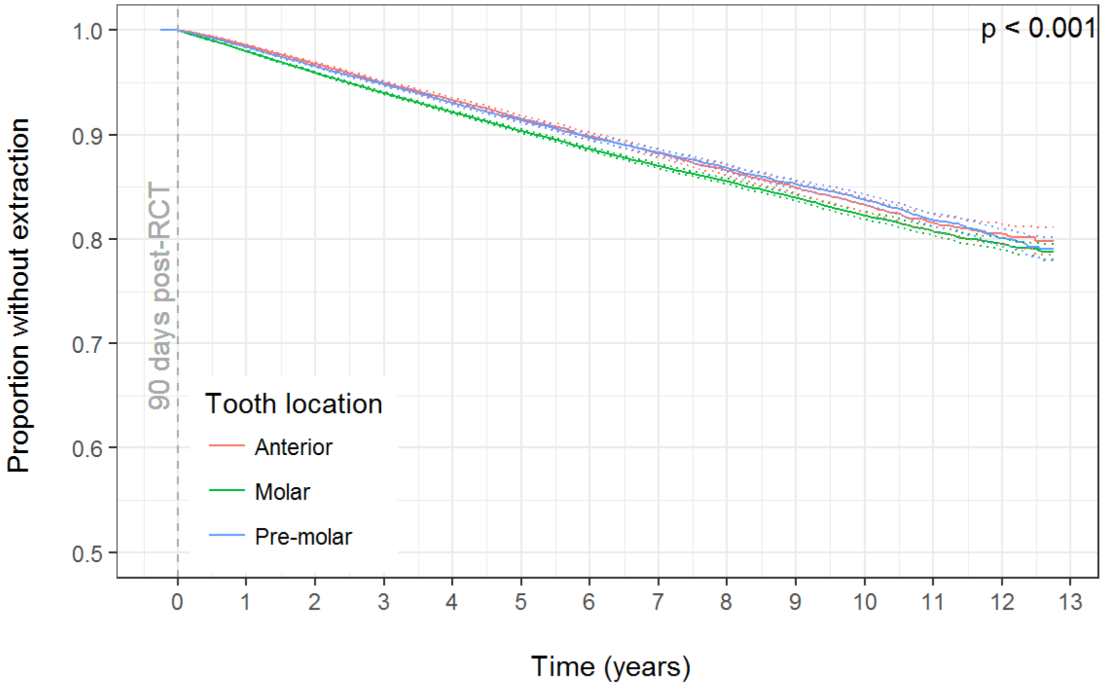

Figure 2: Survival estimate of endodontically treated teeth based on tooth location

When compared by the provider type, the survival rates for a tooth treated with NS-RCT by an endodontist were 98.25% at 1 year, 94.9% at 3 years, 91.84% at 5 years, and 84.94% at 10 years (Figure 3, Table 5). The survival rates for a tooth treated with NS-RCT by a non-endodontist were 98.16% at 1 year, 94.14% at 3 years, 90.38% at 5 years, and 81.93% at 10 years (Figure 3, Table 5).

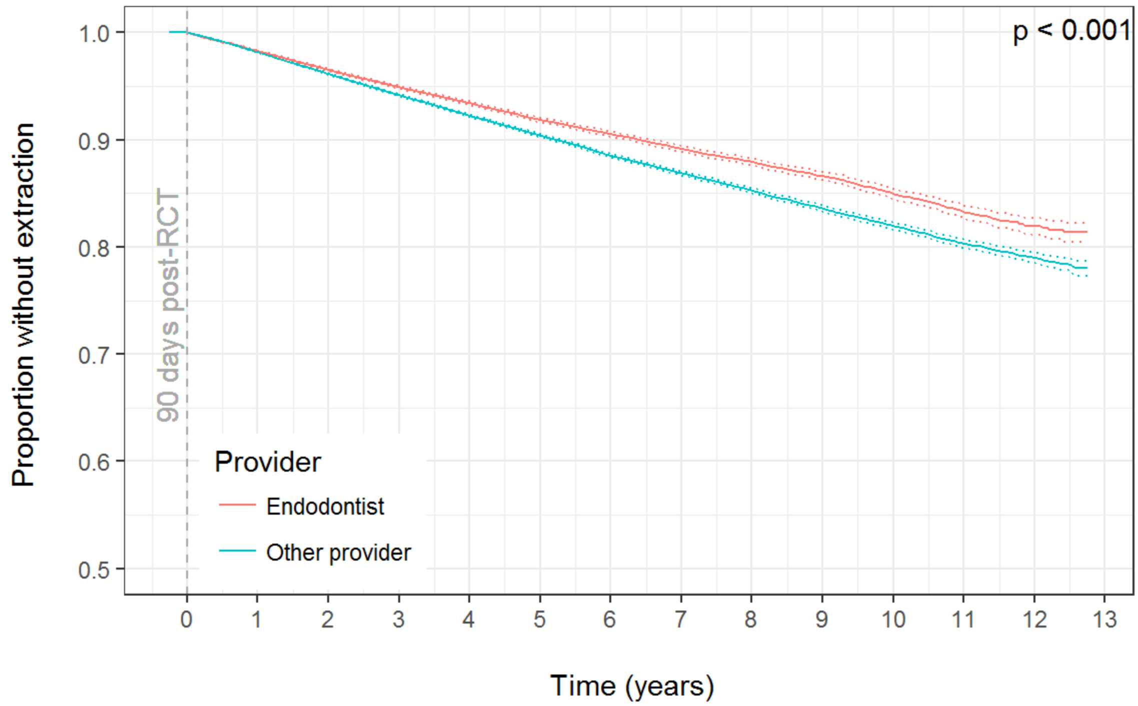

Figure 3: Survival estimate of endodontically treated teeth based on provider type

The survival rates for treated teeth in each of the age groups were evaluated at 1,3,5,10 years after the initial therapy. For the age group 0-17 years, the survival rates were 99.05% at 1 year, 96.36% at 3 years, 94.04% at 5 years, and 89.36% at 10 years (Figure 4, Table 6). For the age group 18-35, the survival rates were 98.54% at 1 year, 95.06% at 3 years, 91.94% at 5 years, and 85.13% at 10 years. For the age group 36-53, the survival rates were 98.17% at 1 year, 94.60% at 3 years, 91.24% at 5 years, and 83.38% at 10 years. For the age group 54-71, the survival rates were 97.89% at 1 year, 93.40% at 3 years, 89.13% at 5 years, and 79.7% at 10 years. For the age group 71 years and over, the survival rates were 97.03% at 1 year, 91.29% at 3 years, 86.32% at 5 years, and 75.82% at 10 years.

	Survival	N events	N at risk
Endodontist			
0 year	—	—	138655
1 year	98.25% [98.18%, 98.33%]	2106	102940
3 year	94.90% [94.75%, 95.04%]	2727	57481
5 year	91.84% [91.63%, 92.05%]	1428	32193
10 year	84.94% [84.46%, 85.41%]	1197	5115
Other provider			
0 year	—	—	299832
1 year	98.16% [98.11%, 98.21%]	4783	223432
3 year	94.14% [94.04%, 94.25%]	7157	128485
5 year	90.38% [90.22%, 90.53%]	4026	73094
10 year	81.93% [81.61%, 82.26%]	3651	12647

Table 5: Survival estimate of endodontically treated teeth based on provider type

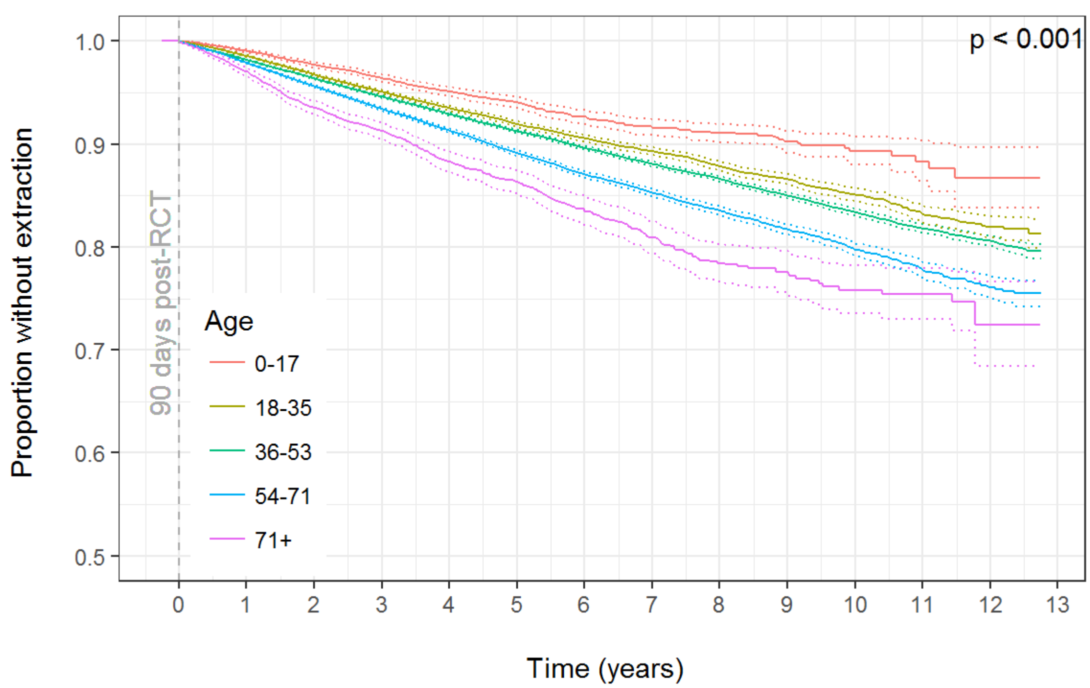

Figure 4: Survival estimate of endodontically treated teeth based on patient age

	Survival	N events	N at risk
0-17			
0 year	—	—	16123
1 year	99.05% [98.89%, 99.21%]	133	12423
3 year	96.36% [96.00%, 96.72%]	260	7009
5 year	94.04% [93.51%, 94.58%]	129	3604
10 year	89.36% [88.02%, 90.72%]	90	310
18-35			
0 year	—	—	99319
1 year	98.54% [98.46%, 98.63%]	1183	67316
3 year	95.06% [94.88%, 95.25%]	1730	33262
5 year	91.94% [91.66%, 92.22%]	814	17270
10 year	85.13% [84.50%, 85.77%]	633	2720
36-53			
0 year	—	—	194831
1 year	98.17% [98.11%, 98.23%]	3165	150587
3 year	94.60% [94.48%, 94.72%]	4420	92999
5 year	91.24% [91.06%, 91.41%]	2673	56814
10 year	83.38% [83.03%, 83.73%]	2728	11499
54-71			
0 year	—	—	121121
1 year	97.89% [97.80%, 97.98%]	2223	90643
3 year	93.40% [93.23%, 93.58%]	3213	49662
5 year	89.13% [88.87%, 89.39%]	1707	25964
10 year	79.70% [79.06%, 80.34%]	1285	3013
71+			
0 year	—	—	7093
1 year	97.03% [96.61%, 97.45%]	185	5403
3 year	91.29% [90.50%, 92.08%]	261	3034
5 year	86.32% [85.20%, 87.45%]	131	1635
10 year	75.82% [73.53%, 78.19%]	112	220

Table 6: Survival estimate of endodontically treated teeth based on patient age

The survival rates of the teeth without a core or a post and core placed within 90 days were 97.35% at 1 year, 92.57% at 3 years, 88.68% at 5 years, and 80.74% at 10 years (Figure 5, Table 7). The survival rates of teeth with a core or a post and core placed within 90 days was 98.68% at 1 year, 95.45% at 3 years, 92.11% at 5 years, and 84.11% at 10 years.

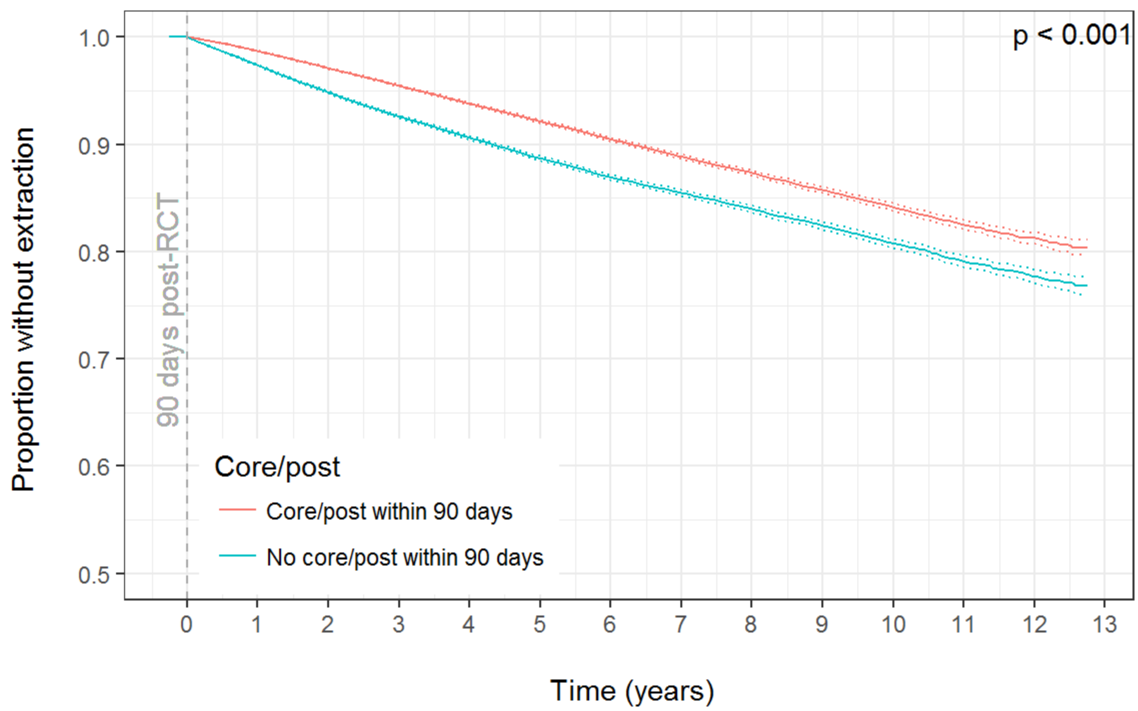

Figure 5: Survival estimates of endodontically treated teeth with core/post material

	Survival	N events	N at risk
No core/post within 90 days			
0 year	—	—	161876
1 year	97.35% [97.27%, 97.43%]	3749	120517
3 year	92.57% [92.42%, 92.73%]	4684	69244
5 year	88.68% [88.47%, 88.90%]	2293	40054
10 year	80.74% [80.32%, 81.17%]	1945	7565
Core/post within 90 days			
0 year	—	—	276611
1 year	98.68% [98.63%, 98.73%]	3140	205855
3 year	95.45% [95.36%, 95.55%]	5200	116722
5 year	92.11% [91.96%, 92.26%]	3161	65233
10 year	84.11% [83.76%, 84.45%]	2903	10197

Table 7: Survival estimates of endodontically treated teeth with core/post material

The survival rates of the teeth without crown placed within 90 days were 97.76% at 1 year, 93.33% at 3 years, 89.47% at 5 years, and 81.01% at 10 years (Figure 6, Table 8). The survival rates of the teeth with a crown placed within 90 days was 99.31% at 1 year, 97.16% at 3 years, 94.44% at 5 years, and 87.71% at 10 years.

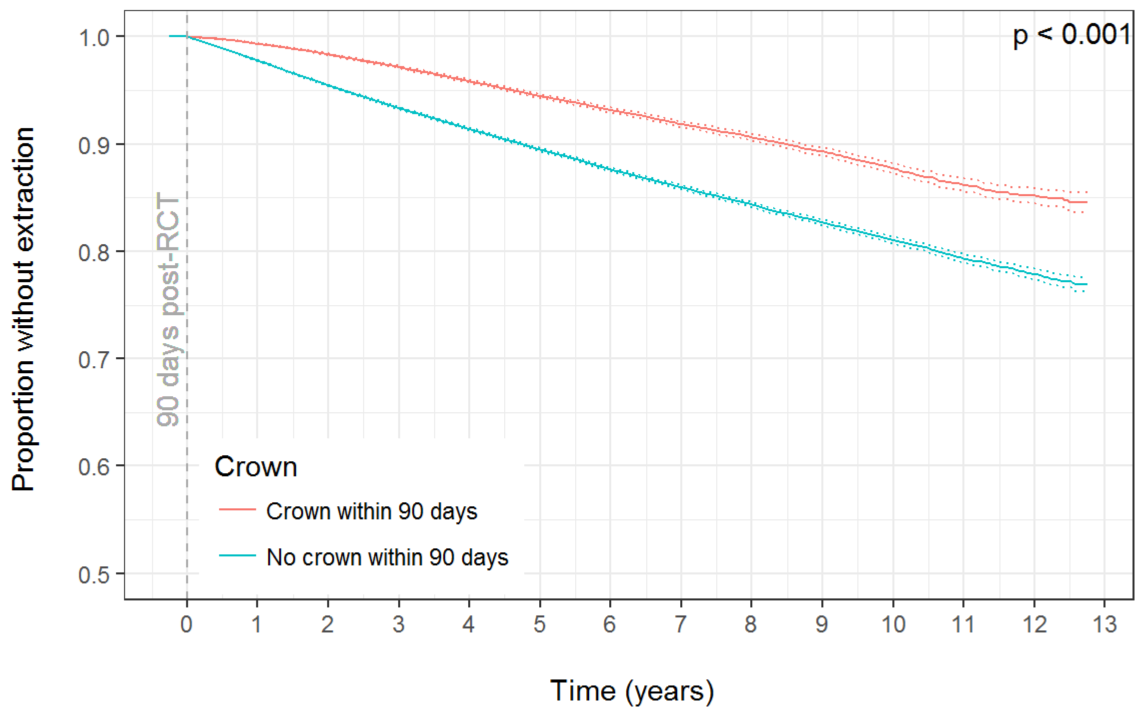

Figure 6: Survival estimates of endodontically treated teeth based on presence of a crown

	Survival	N events	N at risk
No crown within 90 days			
0 year	—	—	316938
1 year	97.76% [97.70%, 97.81%]	6182	235694
3 year	93.33% [93.22%, 93.44%]	8387	134185
5 year	89.47% [89.31%, 89.62%]	4325	75602
10 year	81.01% [80.68%, 81.33%]	3771	12654
Crown within 90 days			
0 year	—	—	121549
1 year	99.31% [99.26%, 99.36%]	707	90678
3 year	97.16% [97.04%, 97.28%]	1497	51781
5 year	94.44% [94.24%, 94.64%]	1129	29685
10 year	87.71% [87.23%, 88.18%]	1077	5108

Table 8: Survival estimates of endodontically treated teeth based on presence of a crown

The Multiple Cox proportional hazards regression results compared survival times of teeth based on different variables. The larger the adjusted hazard ratio (aHR), the greater likelihood of extraction compared to the reference category. In comparing provider type of a non-endodontist to an endodontist, the aHR was 1.308 ($p < 0.001$) (Table 9). This means that a tooth is more likely to be extracted if the initial provider type is not an endodontist. When comparing tooth location, the aHr comparing a premolar to an anterior the aHR was 1.044 ($p < .043$), which is statistically significant but not to the same extent as the other variables. However, when comparing a molar to an anterior the aHR was 1.255 ($p < 0.001$) meaning a molar is more likely to be extracted than an anterior tooth.

The age groups were each compared to the reference age group of 0-17 because that age group had the least likelihood of extraction. When comparing the age group of 18-35 to 0-17 the aHR was 1.385 ($p < 0.001$) (Table 9). When comparing the age group of 36-53 to 0-17 the aHR was 1.602 ($p<0.001$). When comparing the age group of 54-71 to 0-17 the aHR was 2.055 ($p<0.001$). When comparing the age group of 71 and older to 0-17 the aHR was 2.861 ($p<0.001$). As the patient age increased, the likelihood of extraction increased with the largest aHR being the 71 and older age group. Every age group had a statistically significant aHR when being compared to the 0-17 age group.

The aHR of a tooth with a core or a post and core compared to lacking a core or a post and core was 0.741 ($p<0.001$). The tooth was more likely to be extracted if there was not a core or a post and core present at 90 days after the NS-RCT. The aHR of a tooth with a crown compared to lacking a crown was 0.525 ($p<0.001$). The tooth was more likely to be extracted if there was not a crown present at 90 days after the NS-RCT.

N = 438487	aHR	95% CI	p-value
RC provider			
Other provider vs. Endodontist	1.308	[1.271, 1.347]	< 0.001
Tooth location			
Pre-molar vs. Anterior	1.044	[1.001, 1.089]	0.043
Molar vs. Anterior	1.255	[1.207, 1.305]	< 0.001
Age			
18-35 vs. 0-17	1.385	[1.267, 1.514]	< 0.001
36-53 vs. 0-17	1.602	[1.471, 1.746]	< 0.001
54-71 vs. 0-17	2.055	[1.885, 2.240]	< 0.001
71+ vs. 0-17	2.861	[2.547, 3.215]	< 0.001
Core/post			
Core/post within 90 days vs. No core/post within 90 days	0.741	[0.723, 0.760]	< 0.001
Crown			
Crown within 90 days vs. No crown within 90 days	0.525	[0.507, 0.542]	< 0.001

Table 9: Multiple Cox proportional hazards regression results. Adjusted hazard ratios for variables affecting tooth survival

The following plots demonstrate the cumulative incidence of the first failure to occur following the initial root canal therapy (Figures 7,8). It also compares the incidence based on the initial provider type. There is a very high probability that the tooth will not undergo a failure event, but if it does, then most likely it will be extracted. If it is going to be retreated, it is more likely to be retreated non-surgically than surgically. When comparing endodontists to other providers, a tooth initially treated by an endodontist is less likely to be retreated or extracted (Figure 8).

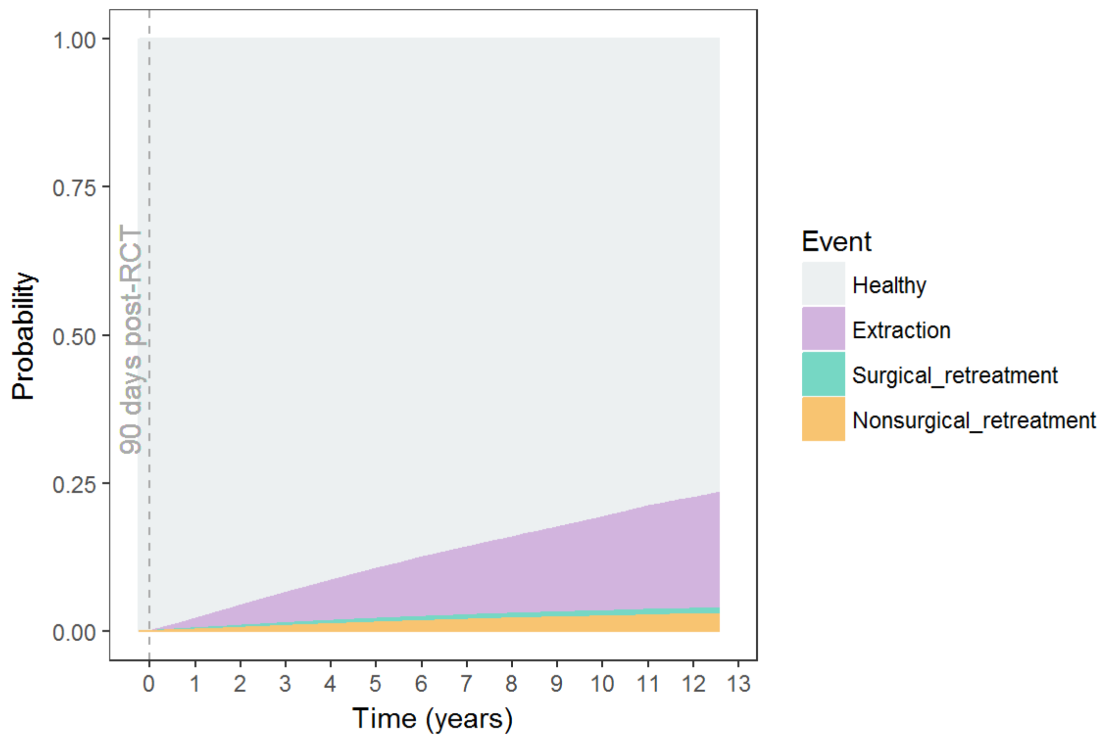

Figure 7: Cumulative incidence of the first failure event to occur following the initial root canal (nonsurgical retreatment, surgical retreatment, or extraction).

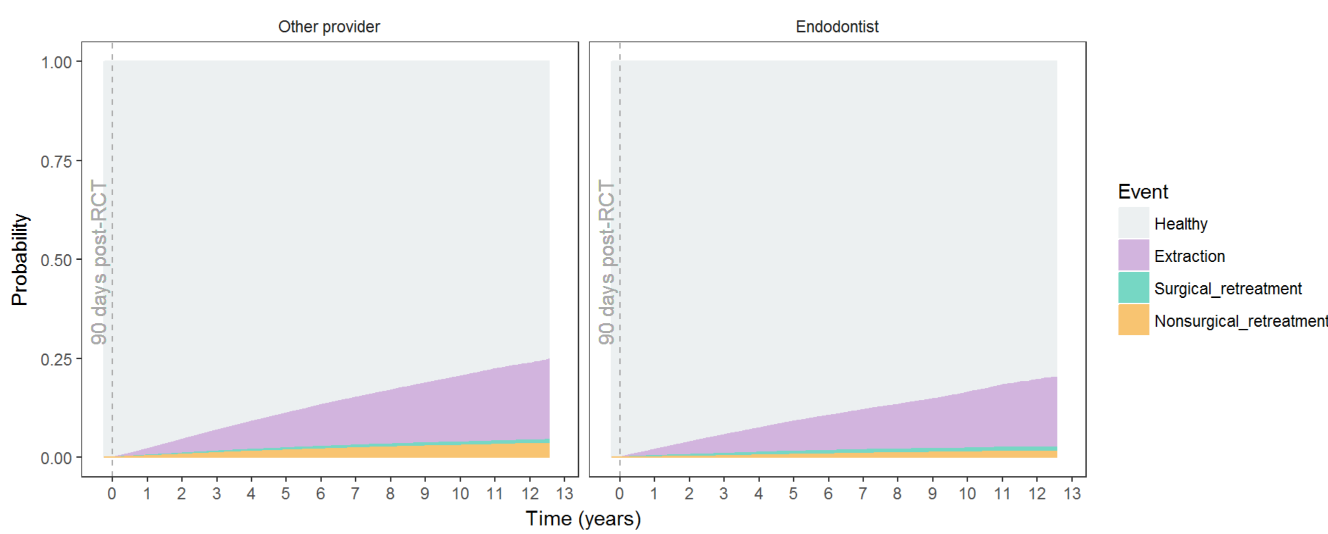

Figure 8: Cumulative incidence of the first failure event to occur following the initial root canal (nonsurgical retreatment, surgical retreatment, or extraction) based on provider type

6 possible transitions				
	to			
from	root_canal	non_surgical_rt	surgical_rt	extraction
root_canal	NA	1	2	3
non_surgical_rt	NA	NA	4	5
surgical_rt	NA	NA	NA	6
extraction	NA	NA	NA	NA

Observed transition frequencies:						
	to					
from	root_canal	non_surgical_rt	surgical_rt	extraction	no event	total entering
root_canal	0	4030	1935	25186	407336	438487
non_surgical_rt	0	0	117	422	3491	4030
surgical_rt	0	0	0	279	1773	2052
extraction	0	0	0	0	25887	25887

Observed transition Proportions					
	to				
from	root_canal	non_surgical_rt	surgical_rt	extraction	no event
root_canal	0.000000000	0.009190694	0.004412902	0.057438419	0.928957985
non_surgical_rt	0.000000000	0.000000000	0.029032258	0.104714640	0.866253102
surgical_rt	0.000000000	0.000000000	0.000000000	0.135964912	0.864035088
extraction	0.000000000	0.000000000	0.000000000	0.000000000	1.000000000

Figure 9: Multi-state model created using the 'm-state' R package with 6 transitions between failure states (no failure, nonsurgical retreatment, surgical retreatment, extraction)

Of the 438,487 teeth that had initial NS-RCT, 407,336 had no subsequent event, 25,186 were extracted, 4,030 were retreated non-surgically and 1,935 were retreated surgically (Figure 9). Of the 4,030 teeth that were retreated non-surgically, 3,491 had no subsequent event, 422 were extracted, and 117 were surgically retreated. Of the 2,052 teeth that were treated surgically, 1,773 had no subsequent event while 279 were extracted.

The cumulative hazard plot showed these transitions over a 12-year period (Figure 9,10). Teeth that were retreated surgically or non-surgically were more likely to be extracted than teeth that did not have such an intervention. Teeth were more likely to be extracted than retreated. Teeth were more likely to be retreated non-surgically than surgically. If a tooth had a nonsurgical retreatment and then subsequently had a surgical retreatment, then it was more likely that the surgical intervention occurred during the first year of treatment.

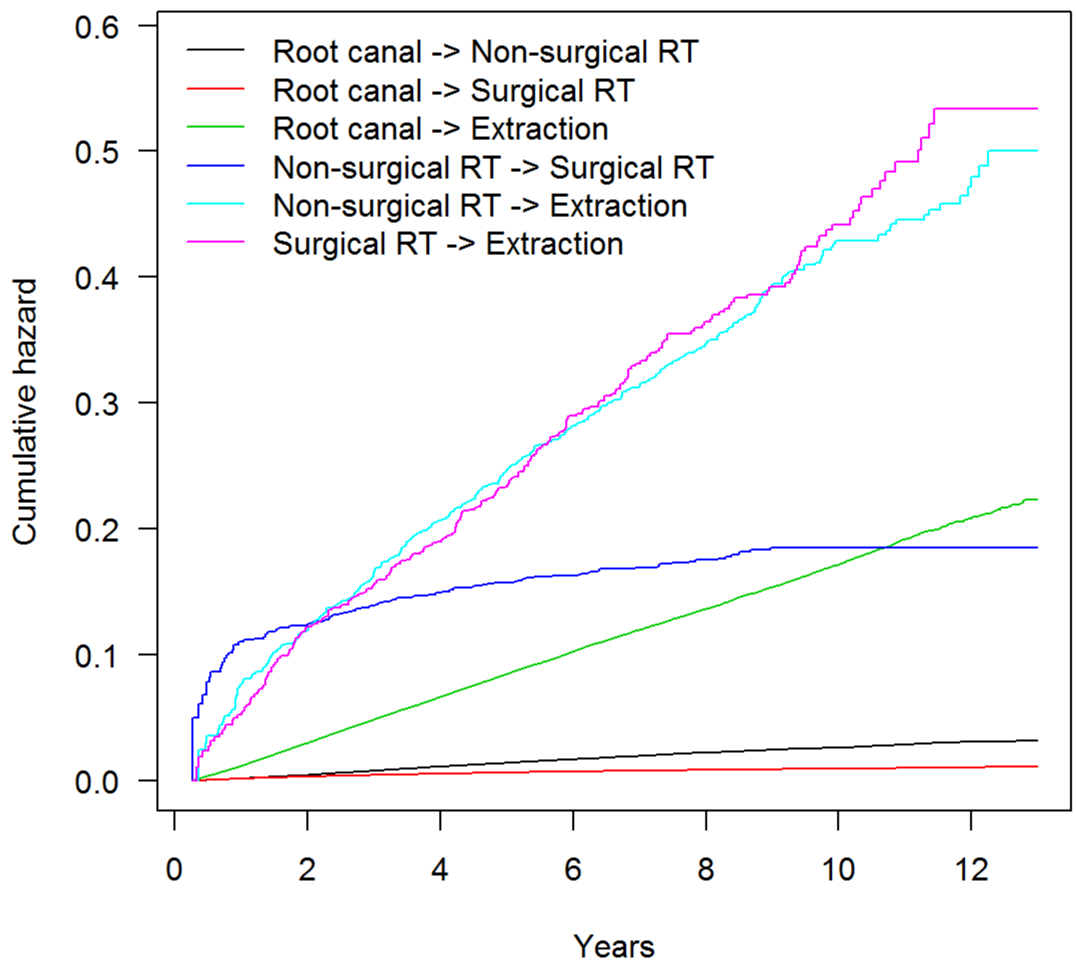

Figure 10: Transitions between failure states in the multi-state model (no failure, nonsurgical retreatment, surgical retreatment, extraction) based on time

The cumulative hazard plots demonstrate the time to the transition state based on initial provider type with endodontists represented in black and non-endodontists in red, respectively (Figure 11). A tooth that was treated by a non-endodontist was more likely to undergo nonsurgical retreatment or extraction than if the initial therapy was provided by an endodontist. The transitions of nonsurgical retreatment to surgical retreatment, nonsurgical retreatment to extraction, and surgical retreatment to extraction based on the different provider types yielded confidence intervals with too much overlap to make any conclusions (Figure 11).

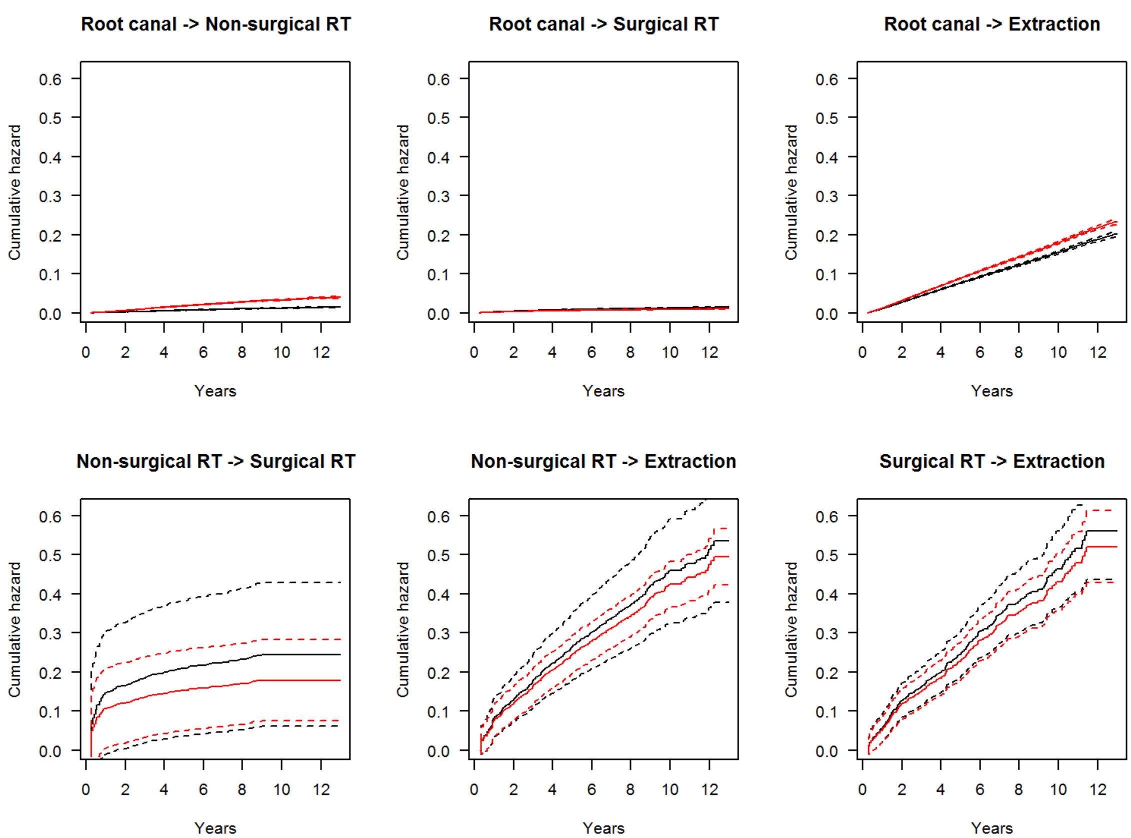

Figure 11: Cumulative hazard plot demonstrating time to the transition state based on initial provider type (endodontist black, other red)

The plot of transition probabilities demonstrates that most teeth that were treated by NS-RCT had no subsequent treatment interventions at the end of the 10-year follow-up period (Figure 12). However, if an intervention is going to occur, the probability is higher that it will be an extraction compared to a retreatment. When comparing a non-endodontist to an endodontist the probability of a tooth being retreated or extracted is higher if the initial provider was not an endodontist (Figure 13).

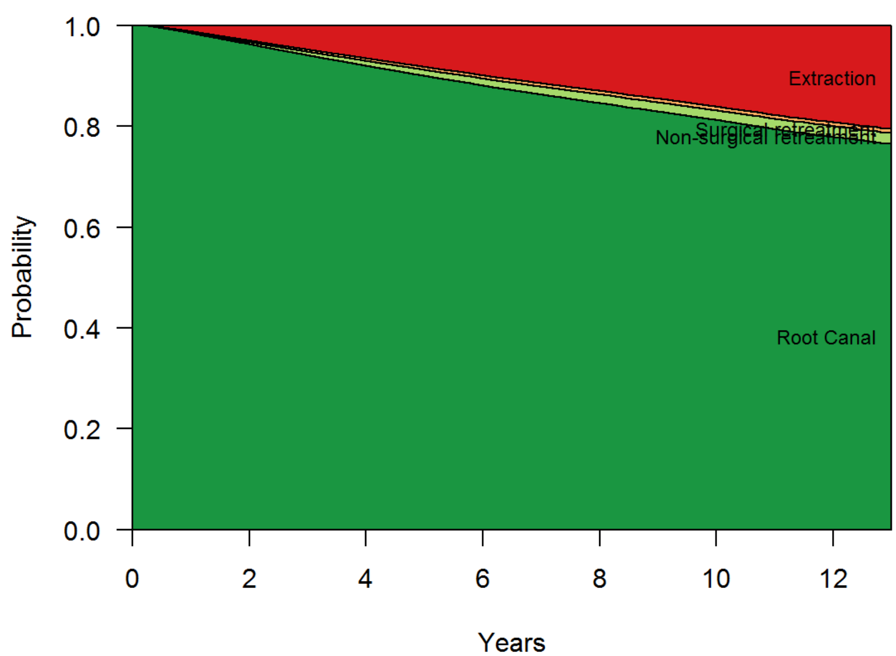

Figure 12: Plot of transition probabilities of endodontically treated teeth

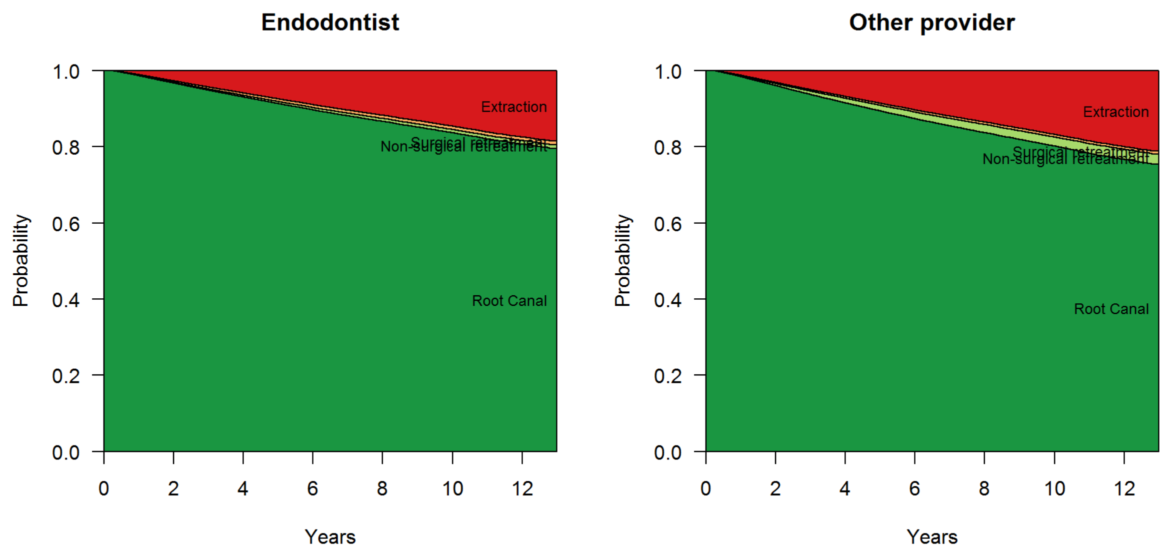

Figure 13: Plot of transition probabilities of endodontically treated teeth based on provider type

DISCUSSION

The primary objectives of this study were to evaluate the factors that affect endodontic success and to further understand the impact the type of clinician has on the final outcome of a tooth treated with NS-RCT. It is important to understand what impacts endodontic success and tooth survival so that the clinician can best practice evidence-based dentistry. Understanding true outcomes is also important so that the patients can have proper expectations and an informed consent of the expected results of their treatment.

In utilizing the Delta Dental of Wisconsin insurance database, this study had access to a very large patient base, but there are obvious limitations in such insurance studies. This study lacks patient diversity as it only evaluates patients with Delta Dental insurance and patients without it may be in a different demographic group. Also, this study can only evaluate the data submitted to Delta Dental and if information is not submitted or improperly coded, then that will not be represented in the data. As patients lose their Delta Dental insurance coverage, they are no longer followed in this study and any subsequent interventions to the teeth cannot be recorded. There were a rather large percentage of patients that were lost during the follow-up period because their dental insurance coverage changed, which impacts the validity of the data.

In retrospective insurance studies, there is not a way to have standardization of the providers or attempt to understand the rationale for a treatment decision. They cannot provide insight into the quality of treatment provided or if proper techniques were followed. The inability to understand the rationale for treatment can underestimate survival as providers may be extracting teeth that are otherwise restorable or choosing not to retreat a tooth that may have a good chance of success in favor of an implant. It is also impossible to consider additional factors that may affect the survival such as the periodontal health of the patient, pulpal and periradicular diagnosis of the tooth prior to treatment, or remaining tooth structure prior to treatment. Additionally, because this study is evaluating survival, the teeth in this study that have survived may not actually be a true successful treatment. This would be the case in instances that the teeth could have lesions associated with them, causing the patients pain, or be non-restorable. Also, tooth loss can occur unrelated to endodontic reasons.

However, even though there are limitations regarding this study, there are multiple benefits that allow the study to yield meaningful information. By having access to the Delta Dental of Wisconsin's entire database, this study has a very large study population. This large study population allows the statistical analysis to detect minor departures from the null. The immense dataset can minimize the effects of variations in treatment or providers. It also provides a way to study tooth survival and true outcomes of teeth treated by NS-RCT in the real world. Many studies are performed in residency programs or evaluating a handful of private practices, where there is a limitation as it is only representative of their office and the treatment and decisions by their referring dentists (4,45). With this study, we have access to the true outcome of teeth treated across the entire state of Wisconsin with a broad variety of patients and providers. Because it is a retrospective study, the providers are unaware that they are taking part of the study so it eliminates that form of treatment bias. This allows for this study to yield real-world outcomes and provide information as to the treatment being provided to the population at large.

The first criteria to evaluate in this study are the case selection based on the provider type. It was found that endodontists are performing NS-RCT on more premolars/molars, on older patients, and having significantly fewer cores and crowns placed in a timely fashion. Each of these criteria have been previously established as being significant factors in the survival of endodontically treated teeth (5,29,77). Based on the case selection represented in this study, which is representative of a typical private practice, the teeth endodontists are treating have a higher predisposition to failure just based on tooth type and patient age (78). In addition, according to Yee, the failure rates of endodontically treated teeth were greater when the core is not placed within 60 days (29). This could be from bacterial contamination of the temporary filling or of a catastrophic fracture of the tooth while in a weakened state (67,69). When an endodontist performed the root canal therapy, the patients had cores placed within 90 days 8% less than if a general dentist performed the initial NS-RCT. This is a significant difference and can impact the success of the endodontic therapy. It is important for endodontists to emphasize the need for a prompt final restoration by the referring dentist, or to consider placing the core at the time of the completion of the endodontic therapy. It is interesting to note that only 26-28% of patients had a crown placed 90 days after root canal therapy. This can be due to lack of finances, inability to get prompt care by the referring dentist, persisting symptoms, or other factors. However this study found that the presence of a crown within 90 days of NS-RCT had the greatest impact on decreasing tooth extraction. This is in agreement with Aquilino who found that teeth that were not crowned were lost at a rate six times teeth with a fixed restoration (75).

However, this study did demonstrate success rates of nonsurgical root canal therapy consistent with previous studies (14,15,16,17). Even though endodontists are treating the more challenging and compromised cases, at ten years, the teeth treated by endodontists had a 85% survival while the teeth treated by non-endodontists had a survival rate of 82%. The success for all providers in this study decreased with multi-rooted teeth, as patient age increased, and with the lack of a core and crown placed within 90 days.

In corroboration with previous studies, premolars and molars were shown to have a decreased survival compared to anterior teeth (5). It is more common for multi-rooted teeth to have isthmuses, lateral canals, accessory canals and other areas that providers will not be able to fully chemo-mechanically debride (13,79). Posterior teeth are also subject to more occlusal forces and are more likely to have fractures, which increase the likelihood of tooth extraction (80). Along with tooth type decreasing tooth survival, patient age had a similar effect. As patients age, teeth become more calcified, which can increase the difficulty of the treatment. There is also an increase in prior caries and restorations that can weaken the teeth over time. With older patients, their teeth have had to withstand more forces and thus would have a higher predisposition to cracks and fractures (80). The risk of periodontal disease increases with age, which also will impact the survival of teeth treated in the older age groups. Tooth loss may not be of endodontic origin in these situations, but it is still useful for being able to give a more informed prognosis for these patients (81).

The multi-state analysis investigated each of the different transition states that can occur subsequent to endodontic therapy. When there was an intervention after NS-RCT, most often the tooth was extracted but if it was retreated, there was a greater likelihood of a nonsurgical retreatment than a surgical retreatment. Extracting endodontically treated teeth may be due to non-restorability, patient finances, crown or root fractures, or provider philosophy. Clinicians may lack confidence in the success of retreatment therapy leading to increased pressure to replace 'failed' endodontically treated teeth with implants (82). However, Kim found that after primary endodontic failure, the most cost-effective treatment was microsurgery. This was followed by nonsurgical retreatment, then extraction and fixed partial denture, and the least cost effective treatment was a single unit implant (83). Nonsurgical retreatment should be considered as the first line treatment for an endodontic failure if the tooth is restorable (4,43,45). The multi-state analysis found that teeth non-surgically retreated or surgically retreated had similar probabilities of being extracted, which was much higher than teeth that did not have secondary treatment after the NS-RCT.

In a recent survey, nearly 50% of active endodontists in the United States felt that they did not receive adequate instruction on microsurgical technique during their residency (84). This can result in providers more often electing to either non-surgically retreat an endodontic failure or to recommend extraction based on their comfort level. In situations where the canal morphology was altered during the endodontic therapy, the success of the retreatment dropped to 47% (43). In these situations, endodontic microsurgery is a more predictable and successful option for treatment (83). With the cost-effectiveness in mind, it is imperative that endodontists become adequately trained in endodontic microsurgery in order to feel comfortable and confident providing such treatment options with the best prognosis for their patients.

When a tooth was retreated non-surgically followed up by surgically, this intervention occurred much more likely in the first year after the nonsurgical retreatment. This corroborates the findings of Salehrabi and Rotstein who found that such intervention usually occurred soon after the retreatment (6). Such therapy could be explained by an iatrogenic event during treatment or poor treatment planning by opting for a nonsurgical retreatment when the clinician would not be able to address the etiology of the problem (43). This would force the clinician to provide a surgical intervention in situations of persisting signs/symptoms, suspected presence of a cyst, root fracture or other unspecified reasons. However, due to the limitations of the study, the rationale for such treatment is unknown.

CONCLUSION

Within the constraints and limitations of this study, it was concluded that endodontists are more often treating the types of teeth that have been shown to have decreased long-term survival. Patients having NS-RCT performed by endodontists are also not having their final restorations placed in a prudent time frame as often compared to if a different provider completed the NS-RCT. Provider type, patient age, tooth type, and restoration after root canal therapy were all significantly associated with tooth survival. The multi-state analysis provides a useful way to evaluate the trends of the different transitions that can occur to a tooth in its lifetime and give insight into true outcomes.

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