Survival Rates of Primary Endodontic Therapy Following Core/Post and Crown Placement

Kandace Yee
Marquette University

SURVIVAL RATES OF PRIMARY ENDODONTIC THERAPY FOLLOWING CORE/POST AND CROWN PLACEMENT

by

Kandace M. Yee, D.D.S.

A Thesis submitted to the Faculty of the Graduate School,
Marquette University,
in Partial Fulfillment of the Requirements for
the Degree of Master of Endodontics

Milwaukee, Wisconsin

May 2017

ABSTRACT
SURVIVAL RATES OF PRIMARY ENDODONTIC THERAPY FOLLOWING CORE/POST AND CROWN PLACEMENT

Kandace M. Yee, D.D.S.

Marquette University, 2017

Introduction: The objective of this study was to determine if a correlation exists between the time to core or post and core (core/post) placement following non-surgical root canal therapy (NS RCT), the time to crown placement following core/post placement, and the incidence of an untoward event.

Materials and Methods: Utilizing the Delta Dental of Wisconsin Insurance Database, information was analyzed from 476,479 initial NS RCT procedures. Of these teeth, 160,040 had a core/post and a crown placed before the end of the continuous coverage period or occurrence of an untoward event. Untoward events were defined as having a retreatment, apicoectomy, or extraction as defined by the Code on Dental Procedures and Nomenclature (1). Adjusted hazard ratios were calculated using a multivariable Cox proportional hazards model.

Results: The survival rate from the time of crown placement to an untoward event was 99.1% at 1 year, 96.0% at 3 years, 92.3% at 5 years, and 83.8% at 10 years. Failure rates were greater when the core/post was placed more than 60 days following the NS RCT, as illustrated by the adjusted hazard ratio of 1.08, and when the crown was placed more than 60 days following core/post placement, as illustrated by the adjusted hazard ratio of 1.14. Overall, the survival rates of NS RCT were greater when performed by an Endodontist versus other providers.

Conclusions: Along with other factors, such as provider type, this study shows that the long-term survival rates of initial endodontic therapy are significantly higher when the core/post is placed within 60 days following NS RCT and the crown is placed within 60 days following the core/post.

ACKNOWLEDGEMENTS

Kandace M. Yee, D.D.S.

I would like to personally thank the Endodontics faculty at Marquette University School of Dentistry, and specifically Dr. Sheila Stover and Dr. Lance Hashimoto. It is through their passion, generosity, and knowledge that the residents are able to thrive as Endodontic practitioners, allowing Marquette to become a highly sought after and renowned program. Not only have I learned the skills necessary to succeed in a professional career, but they have allowed me to develop an immense respect for Marquette School of Dentistry. Throughout the past two years, the guidance and genuine care of the faculty have provided the capacity for me to develop a practice philosophy that is emulated based on their experiences, understanding, and principles.

I would also like to thank Dr. Pradeep Bhagavatula, Dr. Frederick Eichmiller, and the biostatisticians at the Medical College of Wisconsin for their opinions, guidance, and role in developing this research opportunity and masters thesis. Without their widespread knowledge and background in epidemiology and correlational studies, the validity and information obtained from this study would not be possible.

My co-residents, Gordon Barkley and Scott MacDonald have also been instrumental to the practitioner that I have become and have pushed me educationally, personally, and professionally. Not only have we been able to bounce ideas and philosophies off of each other and provide support and guidance, but also have gained lifelong friendships and a mutual respect along the way. They have been invaluable assets to my experience in the Endodontics department and have made Milwaukee feel like home.

Last, but not least, I would like to thank my family for their support and love. They have provided an outlet for stress, and I would not be where I am today without the solid foundation they have built. They have supported me throughout this process and have provided positivity and encouragement throughout the countless all-nighters of dental school, the interview process for residencies, the move to Milwaukee, etc. I cannot begin to thank them enough for their constant advice and reassurance.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LITERATURE REVIEW

Non-surgical Root Canal Therapy

Non-surgical root canal therapy (NS RCT) is the removal of inflamed or infected pulpal tissue caused by caries, trauma, repeated dental procedures, or faulty restorations in order to save the patient's natural dentition in function and esthetics (2, 9). Microorganisms can invade the dental hard tissues causing subsequent pulpal damage that can elicit painful sensations via sensory pathways and periradicular pathoses (2). At this irreversible stage of pulpal involvement, endodontic therapy or extraction is necessary to alleviate the patient's symptoms.

Primary endodontic therapy is focused on the biologic capacity to resolve or prevent periradicular periodontitis via NS RCT (3). With more than 15 million teeth receiving root canal treatments each year, the need to determine an etiology and nature of the disease was significant. In the benchmark study by Kakehashi et al., it was illustrated that the presence or absence of microorganisms within the root canal system of rats was a significant determinant in the healing of apical lesions. Conventional and gnobiotic rats were subjected to mechanical pulp exposures and the teeth were left open for 42 days. The conventional rats exhibited pulpal necrosis in the coronal portion of the roots and abscesses at the apical and accessory foramens. The gnobiotic rats exhibited mild inflammation from the pulp exposure but did not show evidence of pulpal necrosis or abscess formation, thus demonstrating the important role of bacteria in the development and maintenance of apical periodontitis (4). This study was later corroborated in the monkey model (5) followed by the human model (6).

Microorganisms can infiltrate and colonize the root canal space and advance into the apical tissues causing inflammation and bone resorption. As time progresses, oxygen is metabolized by the early colonizers allowing a shift towards anaerobic bacteria. This subsequently inhibits the body's ability to control the pathogenic response (7). Over time, microorganisms become further organized structurally and better able to combat the oxygen tension and nutrient availability within the tooth (8). The endotoxins and byproducts produced by gram-negative bacteria initiate the host response and the inflammatory process. The release of inflammatory mediators activate osteoclastic cells to cause bone resorption and apical periodontitis (9). In order to control the bacterial colony forming units and prevent the extension of bacteria into the periapical tissues, NS RCT or extraction of the tooth is indicated.

The process of a NS RCT involves a dual chemomechanical procedure that requires both irrigation and mechanical cleaning and shaping of the root canals directed at controlling microbial challenges. This is a co-dependent process in that the mechanical efficacy is reliant on the capacity of the irrigating solution to penetrate the entire root canal system (10). In the classical study by Bystrom and Sundqvist, bacterial colony forming units were evaluated following instrumentation with stainless steel hand files and saline as the intracanal irrigant. The results of the study showed a decrease in bacterial units; however, the procedure was unable to produce root canals that were completely devoid of bacteria. Researchers, therefore, suggested that antimicrobial irrigants and agents should be used in conjunction with mechanical preparation for maximum disinfection potential of organic debris, necrotic tissue, and other substrates within the root canal system (11). In order for irrigants to be effective in the apical segments, Schilder suggested that the mechanical preparation of the root canal should create a uniform taper that allows irrigation needles to extend up to a few millimeters from the apical foramen (12). Along with the continuous taper of the root canal system, Ram demonstrated that larger apical preparation sizes, up to a size 40, resulted in the ability to eliminate more bacteria within the apical portion of the canal compared with smaller apical preparation sizes. This is necessary as irrigants can only progress 1 mm beyond the tip of the syringe needle (13, 14). Card et al. confirmed that large apical sizes were essential in dispensing irrigants to the apical segments and also found that irrigation with sodium hypochlorite versus other irrigants, were able to cause sterility within the majority of the root canals studied (15). This represents the current, widespread model of chemomechanical debridement that allows for the high success rates of NS RCT.

Following the complete debridement of the root canal system, obturation of the prepared, disinfected canal is necessary. Ingle et al. found that 58% of failures of the NS RCT was due to an incomplete obturation, however, it should also be noted that canals that are poorly obturated are often poorly disinfected and prepared (16). In a groundbreaking canine study, teeth with periapical lesions were instrumented via a chemomechanical procedure. In the control group, obturation was completed with gutta percha and a resin based sealer. In the experimental group, the canals were left unobturated. At 190 days, the dogs were sacrificed and the specimens were histologically evaluated to determine degrees of healing. The study concluded that there was no significant difference in the level of healing between the two groups (17). This emphasizes the importance of cleaning and shaping procedures as a means to reduce the bacterial count and decrease the likelihood of future development of resistant microorganisms. While obturation may not provide a significant role as illustrated in this short-term study, irrigants, disinfectants, and medicaments lose their substantivity over time. Therefore, an obturation material is useful in resisting coronal and apical leakage on a long-term basis (17). It has also been suggested that the obturation material should have the capacity to encase the bacteria within the canal so that the periapical tissues will not become exposed to the remaining microorganisms (18). It has been proven that all instrumentation techniques left at least 35% of the canal surface untouched indicating the need to seal remaining bacteria in the canal (19). Subsequent to obturation of the root canal system, a permanent restoration and a potential full coverage crown is necessary in order to reduce the risk of fracture and coronal microleakage.

Endodontically Treated Teeth

Endodontic practitioners' primary emphasis is on the predictability and success of the NS RCT treatment. However, successful treatment is also dependent on restorative parameters. It can be argued that a permanent restoration of an endodontically treated tooth is the final phase of NS RCT (20). The final restoration significantly affects the prognosis of treatment due to the macroscopic and microscopic disparities that exist between teeth that are endodontically treated versus non-treated teeth (21). Failure to adequately combat the coronal destruction that has occurred from the access preparation, caries, fractures, or previous restorative therapies reduces the capacity of a tooth to resist functional and parafunctional forces (22).

Following endodontic therapy, there are compositional and dentinal changes in the hard tissues that increase the brittleness and compromise the strength of the remaining tooth structure. Classical studies suggest a loss of 9% by weight moisture content of the dentinal tissues resulting in a 3.5% reduction in hardness of pulpless teeth versus their vital, contralateral counterparts (21, 23-25). While non-vital teeth endure mild compositional changes that can reduce the adhesion of the dentin to a substrate and also increase tooth fragility, other structural properties associated with endodontically treated teeth have been shown to play a greater role in the integrity of the tooth.

Throughout the chemomechanical procedure of an NS RCT, various irrigants, chelators, and intracanal medicaments are utilized as a means of canal irrigation, lubrication, tissue dissolution, and disinfection. These include sodium hypochlorite, ethylenediamine tetra-acetic acid (EDTA), and calcium hydroxide, which interact with root dentin. Sodium hypochlorite irrigation resulted in a significant decrease of Young's modulus of elasticity, microhardness, and flexural strength of the tooth and dentin (26). There was also a significant reduction in resin-dentin bond strengths (27). Currently, 5.25% concentration of sodium hypochlorite is the most widely used concentration due to its capacity to dissolve tissues and act as an antimicrobial agent. However, numerous studies have shown that the higher the concentration, the greater the negative effects on dentin (26, 28). This has been attributed to its ability to react with organic tissue and hydrolyze collagen via proteolysis (29, 30). EDTA is the most commonly used chelating agent in Endodontics and is used to remove the mineralized component of the smear layer that is formed during instrumentation and irrigation procedures. In the process, EDTA depletes the calcium within dentin, causing erosion and softening of the hard tissues. This can influence the ability of dentin to bond to other substrates and reduce its adhesive properties (31). Calcium hydroxide is frequently used as an intracanal medicament due to its high pH, which allows for a wide range of antimicrobial activity against endodontic pathogens. Its long-term use (32) and more recently, short-term use has been associated with a reduction in the flexural strength of dentin without having a significant effect on Young's modulus of elasticity (33). Due to the buffering capacity of hydroxyapatite, calcium hydroxide is unable to successfully penetrate into the core of the dentin (34). While the bulk of dentin may remain unaffected, crack initiation at the surface layer of dentin can propagate and increase the susceptibility of fracture (35). While these materials tend to reduce the strength and toughness of the dentinal tissues, eugenol based sealers and disinfectants have been shown to minimally reinforce the hard tissues and ultimately increase the tensile strength of dentin. The mechanism of action is via protein coagulation and chelation with hydroxyapatite (36). These chemicals are significant in their ability to perform a dual chemical and mechanical debridement of the root canal system, however, it is important to understand their potential adverse, long-term effects on the microhardness and flexural strength of dentin.

Endodontically treated teeth have also been associated with esthetic changes such as discoloration of the tooth. The darkening of the tooth may be attributed to root canal filling materials, inadequate cleaning and shaping, failing to remove pulp horns, endodontic cements and sealers, and gutta percha present in the coronal pulp chamber (37). This may necessitate the need for the restoration of a treated tooth, especially considering the esthetic zone.

Although the biomechanical properties of dentin may influence the brittleness of an endodontically treated tooth, macroscopic changes have a more significant effect in weakening of the remaining tooth structure. This can be due to the cumulative effects of caries, trauma, and previous restorative procedures (38). A loss of each surface of the tooth results in a 20% decrease in cuspal stiffness, while the largest loss of cuspal stiffness, 63%, was related to the loss of the marginal ridge. This is in contrast to a 5% loss of cuspal stiffness that was attributed to the access cavity alone. Instrumentation and obturation did not result in a further significant decrease of stiffness for an endodontically treated tooth (36). Therefore, the most detrimental combination associated with endodontic therapy was the preparation of the access cavity in conjunction with a mesial-occlusal-distal cavity preparation that can be required due to caries, trauma, or fractures (37). As with vital teeth, endodontically treated teeth are susceptible to the same masticatory and parafunctional forces. However, non-vital teeth reported a mean pain threshold level of twice as high as their vital counterparts (40). It was also suggested that the threshold for pressoreceptor sensitivity within the dentin was higher in non-vital teeth, as there is an elimination of the body's positive feedback and protective mechanisms (41). This can potentiate the risk of crown and root fractures and increase the susceptibility for the eventual loss of the tooth. Therefore, the proper restoration of an endodontically treated tooth is designed to protect and replace the remaining tooth structure and prevent reinfection of the root canal system, while also acknowledging potential esthetic demands.

Core and Post & Core

Following endodontic therapy, a permanent restoration or core material is necessary to reduce the risk of coronal leakage and replace missing coronal tooth structure with the purpose of retaining a full coverage restoration. In a study at Temple University, full mouth series of radiographs were evaluated to determine if there was a correlation between the quality of endodontic therapy and the quality of the coronal restoration. The results indicated that there was a stronger correlation between the presence of a periapical lesion and a poor coronal restoration versus a poor endodontic treatment (42).

The most common core materials used on endodontically treated teeth are amalgam and composite. Amalgam restorations have been the traditional core material characterized by a high compressive strength and stiffness that compensates for the low tensile strength of the material (43). While this restorative material provides stiffness and strength to the tooth, it does not possess the capacity to bond to the coronal structure, thus requiring adequate bulk of the material for the retention of the restoration. There is also the potential for corrosion and discoloration of the surrounding soft and hard tissue structures. In contrast, composite resin cores provide the advantage of adhesive bonding to the tooth structure, ease of manipulation, ideal setting properties, and optimal esthetics. Combe and colleagues assessed the characteristics of these two materials in regards with compressive and tensile strength, flexural strength, and elastic modulus. They concluded that no one material was considered an ideal restorative material based on its physical properties (44).

Many endodontic practitioners encounter teeth that have a significant amount of coronal tooth structure missing due to caries, trauma, or fractures. In these cases, restorative parameters are dependent on the amount of tooth structure remaining. In instances where there is a lack of tooth structure present, a post may be placed to perform a mechanical function in order to retain a core material in the tooth and protect the apical seal from bacterial contamination (45). While many studies indicate that there is no significant difference in outcome on whether the post space should be placed immediately or delayed (46), Portelli suggests that the post space should be placed immediately due to the familiarity with the canal anatomy and the setting of the sealer (47). In either case, the post space should be prepared and the post should be cemented under rubber dam isolation, as the success rates were 19.7% more successful with proper isolation techniques (48).

Within the prosthodontics literature, there have been many post designs that are classified based on composition, retention mechanism, and shape. The most common are: prefabricated metallic posts that can be further subdivided into gold, stainless steel, and titanium alloys; and active versus passive posts. Active posts are characterized by the inclusion of threaded flutes and accomplish their retentive task directly through the root dentin. These posts are actively screwed into the walls of the root canal. While these prefabricated posts provide a significant level of retention, there is a strong concern for potential vertical root fracture due to the wedging effect and stresses imposed on the tooth (49). Due to the idea that current cements and luting agents have been manufactured to provide greater retentive properties, active posts are no longer recommended in the restorative treatment process (50). Passive posts are placed in contact with the dentinal walls, but attain most of their retentive properties via cementation. The shape of the post can be classified as parallel or tapered. Parallel posts afford increased retention and decreased risk of root fracture, but also require more canal preparation. Tapered posts are less retentive and often require longer posts to combat this problem, which could potentially compromise the apical seal.

Within dentistry, esthetic options are becoming immensely more important in directing restorative treatment strategies. Fiber posts have been utilized as an esthetic means, primarily in the anterior region, as it consists of a resin-polymerized matrix of carbon, glass, silica, or quartz. In a retrospective study, 1,306 fiber posts were evaluated with a recall period of 1 to 6 years. Investigators found a 3.2% failure rate. This lower failure rate was attributed to the ability of the fiber post to improve the distribution of forces applied to the root and the retentive qualities of the post (51). Another study reported survival rates of 96-98% over a mean recall period of 5.3 years for fiber posts and full coverage restorations placed in the anterior region (52).

Traditionally, cast post and cores have been the conventional method of placing a foundation restoration. In these cases, the core is not dependent on the retention of the post, as the two parts are presented as one unit. However, there are various disadvantages to the cast post and core that include the removal of a significant amount of tooth structure for path of insertion and higher clinical failure rates due to root fracture (53, 54). These posts have also been shown to be the least retentive when there is an absence of an adequate ferrule (53).

There is a common perception that the insertion and presence of a post can ultimately cause root fractures or post-treatment complications that can lead to the failure of an endodontically treated tooth. Stress patterns found within the tooth have been associated with post insertion, which can eventually propagate and lead to root fractures (55). Goodacre et al. found that the loosening of the post and root fractures were the most common mechanisms of failure, which occurred in about 3-10% of cases. The study also determined that the optimal post length is ¾ the length of the root and not greater than ⅓ the root diameter, as increasing the length and decreasing the diameter of the post increases the resistance to root fracture (46).

According to Figueiredo et al., pre-fabricated posts have a 90% survival rate compared with an 83.9% survival rate for fiber-reinforced posts. While the incidence of root fractures was similar between pre-fabricated metal posts and fiber posts, they were associated with a 2-fold increase in the rate of root fractures compared with indirectly fabricated metal posts when a proper ferrule was achieved (56). A study by Makade et al. confirmed this, and concluded that custom cast post and cores exhibited a higher fracture resistance when a ferrule was present compared to prefabricated metal posts (57). In a retrospective study by Sorenson and Martinoff, 1,273 endodntically treated teeth were restored with custom, cast post and cores and evaluated over a 20-year recall period. Of these teeth, 12.7% were deemed failures, and of the 12.7%, 39% were deemed unrestorable due to root fractures and loss of retention (58). However, studies have referenced that cast post and cores placed in the presence of an adequate ferrule and ideal tooth preparation resulted in a greater than 90% success rate (59).

Crowns

The literature strongly suggests that permanent core buildups and full coverage crowns aid in the long-term survival of root canal treated teeth. Endodontically treated molars are more fracture prone due to the loss of bulk of the tooth structure and the need to endure the masticatory load. Linn and Messer evaluated the significance of retaining the marginal ridges of posterior teeth and selective cuspal coverage in order to preserve tooth stiffness. Teeth were loaded using a closed-loop servohydraulic system following restoration with an amalgam core, amalgam overlay, or gold overlay with partial or complete cuspal coverage. Researchers concluded that full cuspal coverage and reinforcement provides less tooth flexure than partial or no cuspal coverage on endodontically treated molars. Selective cuspal coverage was only found to reinforce the cusps that had been capped with a restoration rather than the entire tooth structure (60). According to Stavropoulou, the 10-year survival of a root canal treated tooth restored with a crown was 81% versus 63% for a root canal treated tooth with a direct restoration (61). While NS RCT typically has a high survival rate, there is an increased incidence of extraction in cases where the tooth is not adequately restored. In the epidemiological study performed by Lazarski et al, the failure rate of NS RCT was 5.56%. Of the teeth that had failed to heal, 0.48% was due to the NS RCT therapy while the remainder was attributed to prosthodontic factors. There was a 4 times greater incidence of extraction with teeth that did not have any permanent restoration placed (62). In a subsequent study, it was found that endodontically treated teeth that did not receive a full coverage crown were lost at a 6 times greater rate than teeth that had received a full coverage crown (63). In yet another study, researchers found that the survival rate of NS RCT was 97%. Of the remaining 3% that had failed, 85% did not have full cuspal coverage (64). Within the literature, the significance of protecting endodontically treated teeth with full cuspal coverage is evident, as these teeth are susceptible to greater cuspal deflection (65).

The most common types of full coverage restorations include full-metal, all-ceramic, and porcelain-fused-to-metal crowns. Full gold crowns are known for their great strength and durability and do not require as much tooth reduction due to the properties of the material. All-ceramic restorations have become more popular recently due to their superior esthetic qualities; however, these restorations require the most reduction of tooth structure due to the need for a bulk of material to prevent fracture.

Porcelain occlusal surfaces also can cause detrimental wear on the opposing, natural dentition. Porcelain-fused-to-metal restorations are essentially a hybrid of the all-ceramic and full-metal crowns. These restorations provide esthetics with durability, but, like all-ceramic restorations, can also cause significant wear on opposing teeth. The estimated 5-year survival rate of metal-ceramic full coverage restorations was 94.7-97.6% (66, 67). The estimated 5-year survival rate of all ceramic crowns was 94% (66).

Another subclass of full coverage restorations is stainless steel crowns. Stainless steel crowns are used extensively in the pediatric population as restorative means due to the limited chair side time requirement, ease of placement, and durability. However, in recent years, stainless steel crowns have become more popular in permanent teeth to serve as interim restorations in teens until the patient stops the growth process or in patients that cannot financially afford a definitive full coverage crown (68). Anecdotally, stainless steel crown margins tend to be inadequate and open, but there have been no studies that evaluate the long-term success and survival rates of teeth receiving stainless steel crowns as the definitive restoration.

Time Interval from NS RCT to Core/Post to Crown

Typically, patients are referred to an endodontic specialist for NS RCT. Following treatment, the endodontic practitioner will generally place a temporary restoration and refer the patient back to the referring dentist for the restoration of the tooth. The provisional restorations that are commonly used in Endodontics include Cavit, Glass ionomer cement, and IRM. According to Balto, Cavit provided the best sealing ability for 3 weeks, while IRM showed maximum dye penetration via a dye leakage study (69). In contrast, Deveaux et al. suggested, via a bacterial leakage and turbidity study, that glass ionomer cement was the only material to prevent bacterial leakage at thirty days, which illustrated its superiority over IRM and Cavit (70). Although these materials have the capacity to adequately seal the tooth in a temporary manner from bacterial invasion following NS RCT, they should not be used for long-term restoration of the tooth. Failure to replace the provisional with a permanent restoration in a timely fashion results in leakage and reinfection, which therefore compromises the integrity of the coronal seal. This, in turn, decreases the prognosis of the treatment and potentially leads to loss of the tooth or the need for further endodontic therapy. There is evidence that root canals that have been adequately cleaned, shaped, and obturated can resist bacterial penetration for up to three months (71), however, a retreatment may be indicated if the provisional restoration has been leaking or the obturation material has been exposed for more than three weeks. This is due to the endotoxin invasion by gram-negative organisms that can result in apical periodontitis (72).

The frequent recommendation of dentists is to delay the restoration of endodontically treated teeth in order to evaluate the success of root canal therapy via the patient's relief of symptoms. However, this represents anecdotal evidence that is not recommended by the American Association of Endodontics due to the potential for leakage or structural compromise of the tooth. While it is evident that the quality of the coronal restoration significantly affects the prognosis of endodontic therapy (73), there have been no studies that focus on the ideal time period to place a core or post and core (core/post) following NS RCT or the ideal time period to place the crown following the core/post (74).

Success versus Survival

Throughout the endodontic and prosthodontic literature, there is a distinct discrepancy on the criteria that define success versus survival. Strindberg proposes that success should be based on stringent radiographic criteria in that complete radiographic resolution should be required within a one-year time frame (75). However, several authors have suggested that the primary use of radiographic criteria as a determinant of success is ill advised due to the potential for delayed radiographic healing (76-79). It has been proven that radiographic healing can occur at 4-6 years following endodontic therapy (80) and even 20-27 years following NS RCT (78). Another study suggests that success is determined if the pre-existing lesion has decreased in size and was asymptomatic in nature (81). Unlike the evaluation of many prosthodontic treatment outcomes, endodontic therapy aims to cure existing disease. Therefore, many NS RCT studies seek to measure both healing of the existing disease and also the occurrence of new disease (82-84). The inconsistencies associated with the standards for success rates may lead to significant differences in the prognostic outcomes of treatment. Therefore, it may be more probable to note survival rates in order to eliminate subjectivity and introduce less bias (85).

Failure of NS RCT

According to the American Association of Endodontics, 15 million root canal treatments are performed in the United States each year with 89% of patients indicating a satisfactory experience following NS RCT. The success and survival rates of NS RCT have been proven to be very high. This, in conjunction with the strong, negative feelings towards tooth extractions that patient's experience, further promote the rationale of performing the procedure for retaining diseased teeth. While various studies have shown a 75-96% success rate, there are several patient and prognostic factors that have been associated with a decrease in success and ultimately failure of the initial endodontic therapy (64, 86-87). Patient factors have included systemic diseases and conditions affecting the immune response, for instance, diabetes mellitus, renal insufficiency, hypertension, coronary artery disease, and breast cancer (88). Marx also states that patients with a prior history of radiation therapy over 5,000 centigray had a decreased success of NS RCT that was attributed to both the dose of radiation and also the underlying condition involved (89). Patients with genetic defects in the interleukin-B gene were also associated with an increased risk of abscess formation (90).

There are four etiologic categories that can result in post-treatment disease following endodontic therapy. These include persistent intradadicular infections, extraradicular infections, foreign body reactions, and true cysts (91). Persistent or reintroduced, intraradicular infections occur when microorganisms contaminate the root canal space and contact the periradicular tissues. Post-treatment disease can result from untreated or missed canals, iatrogenic procedural errors, and complex canal anatomy that does not allow the initial endodontic therapy to thoroughly debride the canal of bacteria (92). These types of infections can also occur if the obturation material does not adequately seal the microorganisms within the canal or if new microorganisms are allowed to enter via coronal leakage. In these instances, *Enterococcus Faecalis* is the primary pathogen, which has been proven to be resistant to disinfection and irrigation procedures (93). Extraradicular infections are caused by microorganisms that persist within the periapical tissues. Typically, the immune system is able to resist and destroy the causative agents, however, *Actinomyces israelii* and *Propionibacterium propionicum* can prevent healing within the periradicular tissues (91). Iatrogenic errors, such as extrusion of materials or overextension of gutta percha can result in a foreign body reaction (91). This can also result from cellulose fibers on paper points (94). These reactions are essentially non-microbial in nature; however, they produce a low-grade chronic inflammation surrounding the extruded material (91). Extruded materials, like gutta percha, can also activate the C3 complement and induce bone resorption in the apical tissues (95). This localized tissue response is characterized by macrophages and giant cells that delay the body's capacity to heal (91). True cysts form when the body attempts to isolate the source of inflammation from the bone. These are epithelial lined cavities with a fibrous connective tissue wall that typically requires surgical intervention in order for healing to occur as the cyst contents are independent of the root canal space (91).

According to Vire, endodontic failures account for only 8.6% of post-treatment disease, which can be attributed to iatrogenic errors such as perforations, ledges, transporations, separated instruments, or blockage of the canal (6, 96). This is compared with 59.4% of failures due to prosthetics (inadequate coronal restorations) and 32% of failures due to periodontal factors (significant loss of attachment). While endodontic failures were less frequent, they appeared, on average, 2 years earlier than failures attributed to other treatment modalities (96). Without an adequate coronal seal and the placement of a temporary restoration, no obturation technique was able to prevent bacterial leakage after 60 days (72). While the quality of the endodontic therapy is significant, it can be argued that the quality of the coronal seal is more important in the prevention of apical periodontitis (21, 97). This illustrates the immense need for practitioners to evaluate a diseased tooth from every restorative angle.

Several studies have evaluated different prognostic factors in order to determine whether instrumentation and obturation procedures would affect the success of NS RCT. One study found that obturation within 2 mm of the radiographic apex, an obturation without voids, and the presence and quality of a coronal restoration improved the outcome of treatment (67, 73, 83). In the Toronto studies, teeth with apical periodontitis that had intraoperative complications and inadequate root filling were associated with inferior success rates (98). Other factors that have been proven detrimental to a successful outcome include perforations, poor obturation, missed root canals, periodontal disease, other teeth, fractures, complex root anatomy, trauma, and microleakage (99).

Failure of the initial NS RCT requires further intervention in terms of endodontic therapy (retreament or apicoectomy) or extraction of the tooth. If an extraction is indicated, a treatment plan should potentially include the replacement of the edentulous space. This replacement can be accomplished with the placement of a bridge or implant. While single tooth implants and NS RCT outcome studies reveal no significant statistical difference in survival rates, there are widely differing criteria used to measure successful outcomes (75-79). Success rates for a single tooth implant versus NS RCT and restoration were 73.5% and 82.1%, respectively. However, it was also noted that there was a 4 times greater incidence of post-operative complications requiring subsequent treatment intervention with the single tooth implants (85). In a study comparing the maximum bite force and chewing efficiency of a mandibular molar treated with NS RCT and crown versus the contralateral natural tooth versus a single tooth implant and crown, there was a reduction in the masticatory function associated with the implant and crown. The tooth treated with NS RCT and the contralateral, natural tooth showed no statistically significant difference in regards to effective occlusal contact during function (100). It should be strongly noted that the placement of an implant is a probable treatment plan in the case of a missing tooth rather than a diseased, natural tooth. Due to the evidence to support the high success rates and cost effectiveness of NS RCT compared to that of an extraction and fixed partial denture or implant, NS RCT should be considered a valuable treatment option for diseased teeth (101).

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 13,329,249 patient encounters that occurred between January 1, 2000 and December 31, 2013. Of the total patient encounters, 476,479 initial NS RCT procedures were completed. The triggering event was assessed and defined based on the Code on Dental Procedures and Nomenclature (CDT) D3310, D3320, and D3330, which indicated an NS RCT for anterior, premolar, and molar teeth respectively. The data was further restricted to 160,040 patients who had received an NS RCT, core/post, and crown by the end of the continuous coverage period or the occurrence of an untoward event. Untoward events were defined as having a retreatment, apicoectomy, or extraction as defined by CDT codes, indicating failure of the initial NS RCT (1). NS RCT was considered successful until the presence of the untoward event or a lapse in the patient's enrollment status.

For each of these encounters, information was obtained regarding the provider type, core material, type of post, and crown material. Provider types were subdivided into Endodontists, whom graduated from an American Dental Association accredited United States endodontic residency program, and non-endodontic specialists (or other providers). Permanent restorations were classified according to the type of restorative material used: metallic, composite, ceramic, and a uniform core buildup group in which a material could not be determined via CDT codes. For the endodontically treated teeth that required a post and core, these teeth were subdivided into prefabricated and indirectly fabricated post and cores. Full coverage restorations were also grouped according to the type of material involved. These included non-metallic crowns, metallic crowns, and prefabricated stainless steel crowns. Porcelain-fused-to-metal crowns were classified in the metallic category, as the margins of the crown are present in metal as they abut the tooth. Data was also obtained on the tooth location and the age of the patient at the time of NS RCT.

Once the variables were defined, the Biostatistics department at the Medical College of Wisconsin completed the insurance claims analysis using SAS 9.4 software. Hazard ratios were calculated using a univariate Cox proportional hazards model. From this data, adjusted hazard ratios were calculated using a multivariable Cox proportional hazards model to account for numerous variables and predictors. Biostatisticians utilized a p-value of <0.05 as the level of significance due to the high survival rates of the large statistical population. Survival estimates were calculated at 1, 3, 5, and 10 years following the crown placement to the presence of an untoward event or the end of the continuous enrollment period.

An IRB was submitted, however, according to 45CFR46.102(f), the IRB was not required, as the study did not meet the criteria for “human subjects.” Although the secondary analysis of Delta Dental subscribers contains dates of birth and zip code, the combination of the two in relation to the total number of records would not be readily ascertainable.

RESULTS

Within the 160,040 encounters where an initial NS RCT was performed, followed by a core/post and crown, 88,666 (55.4%) were molars, 50,246 (31.4%) were premolars, and 21,128 (13.2%) were anteriors (Table 1). Anterior teeth were associated with a greater risk of an untoward event than molars as illustrated by the univariate Cox proportional hazards ratio of 1.08 (Table 2), and an adjusted hazard ratio of 0.90 (Table 3). There was no significant difference between the failure rate of premolars and molars. The number of NS RCTs that were completed by an Endodontist was 46,984 (29.4%), and the number of NS RCTs completed by other providers was 113,056 (70.6%) (Table 1, Figure 2). There was a greater risk of failure associated with the NS RCT that was completed by other providers compared to Endodontists, as shown by the univariate cox proportional hazard ratio of 1.33 and the adjusted hazard ratio of 1.43 (Table 2, Table 3). The mean age at the time of NS RCT was 44.6 with a standard deviation of 13.4. Age was further categorized into age group with ages 0-17 having 4,087 (2.6%) cases, ages 18-35 with 37,531 (23.5%) cases, ages 36-53 with 73,975 (46.2%) cases, ages 54-71 with 42,231 (26.4%) cases, and over 71 years of age with 2,216 (1.4%) cases (Table 1, Figure 3). There was a greater increase in the risk of failure in teeth with NS RCT, core/post, and crowns as age increases (Table 2, Table 3).

Survival estimates were based on the presence of the tooth with the NS RCT, core/post, and crown without any incidence of an untoward event or break in the continuous enrollment period. The survival rate was 99.1% at 1 year, 96.0% at 3 years, 92.3% at 5 years, and 83.8% at 10 years (Table 4, Figure 4).

	All (n=160,040)
Tooth Location	
Molar	88,666 (55.4%)
Pre-Molar	50,246 (31.4%)
Anterior	21,128 (13.2%)
Age at NS RCT	
Mean (SD)	44.6 (13.4)
Median [Min, Max]	46.0 [0.0, 98.0]
Age at NS RCT	
0-17	4,087 (2.6%)
18-35	37,531 (23.5%)
36-53	73,975 (46.2%)
54-71	42,231 (26.4%)
71+	2,216 (1.4%)
NS RCT Provider	
Endodontist	46,984 (29.4%)
Other Provider	113,056 (70.6%)
Core/Post Type	
Core	99,005 (61.9%)
Post & Core	61,035 (38.1%)
Core/Post Provider	
Endodontist	2,435 (1.5%)
Other Provider	157,587 (98.5%)
Core/Post Material	
Core: Amalgam/Metallic Inlay	8,801 (5.5%)
Core: Core Build-Up	76,323 (47.7%)
Core: Direct Resin-Based	13,879 (8.7%)
Core: Porcelain/Ceramic/Resin Inlay	2 (0.0%)
Post & Core: Indirectly Fabricated	9,391 (5.9%)
Post & Core: Prefabricated	51,644 (32.3%)
Crown Provider	
Endodontist	61 (0.0%)
Other Provider	159,979 (100.0%)
Crown Material	
Metallic	127,929 (79.9%)
Non-Metallic	31,477 (19.7%)
Stainless Steel	634 (0.4%)
Time from NS RCT to Core/Post	
Mean (SD)	66.6 (219.7)
Median [Min, Max]	14.0 [0.0, 4675.0]
Time from NS RCT to Core/Post	
0-14 days	82,780 (51.7%)
15-59 days	48,387 (30.2%)
60+ days	28,873 (18.0%)
Time from Core/Post to Crown	
Mean (SD)	160.5 (412.1)
Median [Min, Max]	14.0 [0.0, 4447.0]
Time from Core/Post to Crown	
0-14 days	81,474 (50.9%)
15-59 days	34,658 (21.7%)
60+ days	43,908 (27.4%)
Time from NS RCT to Crown	
Mean (SD)	227.1 (465.1)
Median [Min, Max]	49.0 [0.0, 4676.0]
Time from NS RCT to Crown	
0-30 days	103,790 (64.9%)
31-89 days	18,122 (11.3%)
90+ days	38,128 (23.8%)

Table 1: Descriptive summary of variables based on number of cases

Univariate Cox Proportional Hazards Results	HR	95% CI	p-value
Tooth Location			
Premolar vs Molar	0.78	[0.74, 0.82]	<0.001
Anterior vs Molar	1.08	[1.01, 1.15]	0.017
Core/Post Type			
Post&Core vs Core	1.01	[0.97, 1.06]	0.684
Core/Post Material			
Core: Build-up vs Amagalm/Metallic Inlay	0.91	[0.83, 1.00]	0.040
Core: Resin-Based vs Amalgam/Metallic Inlay	1.16	[1.03, 1.29]	0.011
Post&Core: Indirectly Fabricated vs Core: Amalgam/Metallic Inlay	1.04	[0.93, 1.18]	0.483
Post&Core: Prefabricated vs Core: Amalgam/Metallic Inlay	0.94	[0.86, 1.04]	0.220
Crown Type			
Stainless Steel Crown vs Other Crowns	2.45	[1.92, 3.12]	<0.001
Crown Material			
Non-Metallic vs Metallic	1.15	[1.08, 1.23]	<0.001
Stainless Steel vs Metallic	2.49	[1.95, 3.19]	<0.001
NS RCT Provider			
Other Provider vs Endodontist	1.33	[1.26, 1.40]	<0.001
Core/Post Provider			
Other Provider vs Endodontist	1.13	[0.92, 1.39]	0.245
Age of NS RCT			
18-35 vs 0-17	0.94	[0.79, 1.11]	0.466
36-53 vs 0-17	1.18	[1.00, 1.40]	0.046
54-71 vs 0-17	1.46	[1.24, 1.73]	<0.001
71+ vs 0-17	1.68	[1.35, 2.11]	<0.001
Time from NS RCT to Core/Post			
15-59 days vs 0-14 days	0.89	[0.85, 0.94]	<0.001
60+ days vs 0-14 days	0.97	[0.91, 1.03]	0.308
Time from Core/Post to Crown			
15-59 days vs 0-14 days	0.98	[0.93, 1.04]	0.565
60+ days vs 0-14 days	1.17	[1.11, 1.23]	<0.001
Time from NS RCT to Crown			
31-89 days vs 0-30 days	0.99	[0.93, 1.07]	0.866
90+ days vs 0-30 days	1.21	[1.15, 1.28]	<0.001
Post hoc test (un-adjusted): Indirectly Fabricated vs Prefabricated Post&Core			
Core/Post Material			
Post&Core: Indirectly Fabricated vs Prefabricated	1.11	[1.01, 1.21]	0.032

Table 2: Univariate cox proportional hazards results

Multivariable Cox Proportional Hazards Results	HR	95% CI	p-value
Tooth Location			
Premolar vs Molar	0.70	[0.66, 0.74]	<0.001
Anterior vs Molar	0.90	[0.84, 0.96]	0.002
Core/Post Material			
Core: Build-up vs Amagalm/Metallic Inlay	0.99	[0.90, 1.09]	0.838
Core: Resin-Based vs Amalgam/Metallic Inlay	1.16	[1.03, 1.29]]	0.012
Post&Core: Indirectly Fabricated vs Core: Amalgam/Metallic Inlay	1.14	[1.00, 1.29]	0.045
Post&Core: Prefabricated vs Core: Amalgam/Metallic Inlay	1.02	[0.92, 1.13]	0.681
Crown Material			
Non-Metallic vs Metallic	1.16	[1.09, 1.24]	<0.001
Stainless Steel vs Metallic	2.44	[1.90, 3.14]	<0.001
NS RCT Provider			
Other Provider vs Endodontist	1.43	[1.35, 1.51]	<0.001
Core/Post Provider			
Other Provider vs Endodontist	1.00	[0.81, 1.24]	0.975
Age of NS RCT			
18-35 vs 0-17	1.08	[0.91, 1.29]	0.377
36-53 vs 0-17	1.41	[1.20, 1.67]	<0.001
54-71 vs 0-17	1.81	[1.52, 2.14]	<0.001
71+ vs 0-17	2.14	[1.70, 2.68]	<0.001
Time from NS RCT to Core/Post			
15-59 days vs 0-14 days	0.96	[0.91, 1.01]	<0.001
60+ days vs 0-14 days	1.08	[1.02, 1.15]	0.010
Time from Core/Post to Crown			
15-59 days vs 0-14 days	0.98	[0.92, 1.04]	0.463
60+ days vs 0-14 days	1.14	[1.08, 1.21]	<0.001
Post hoc test (un-adjusted): Indirectly Fabricated vs Prefabricated Post&Core			
Core/Post Material			
Post&Core: Indirectly Fabricated vs Prefabricated	1.11	[1.02, 1.22]	0.022

Table 3: Multivariable cox proportional hazards ratio

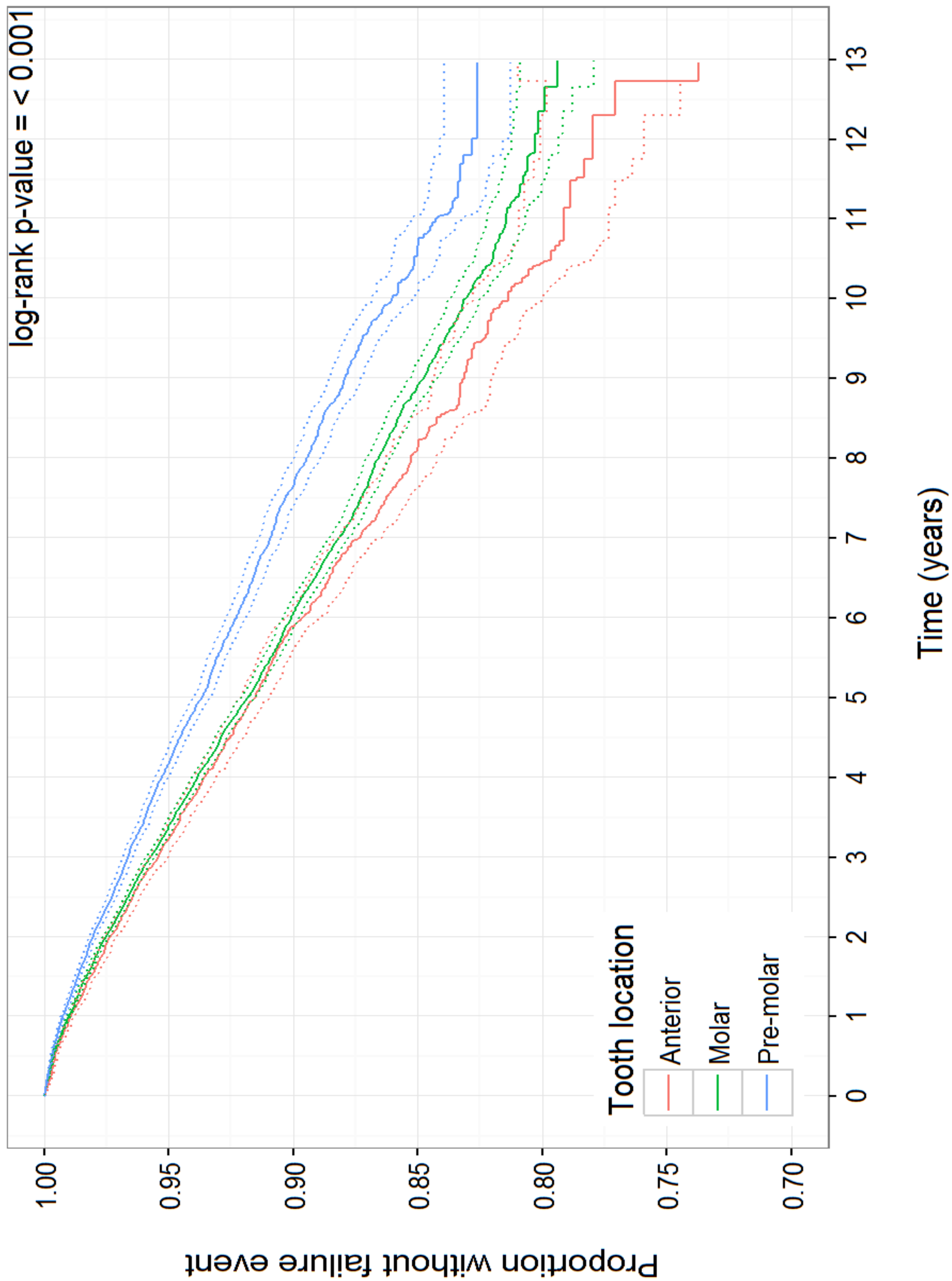

Figure 1: Survival estimates of endodontically treated teeth based on tooth location

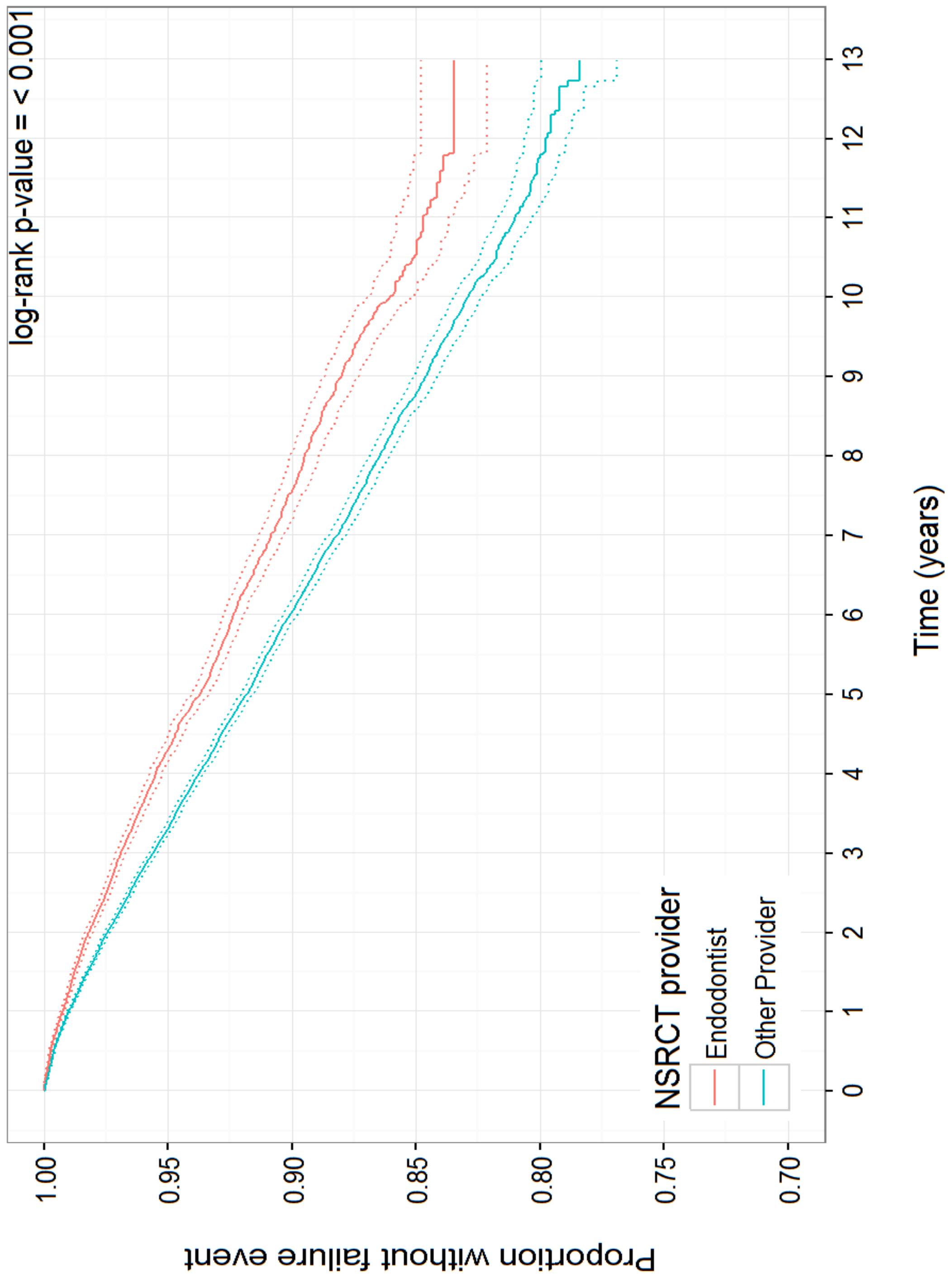

Figure 2: Survival estimates of endodontically treated teeth based on provider type

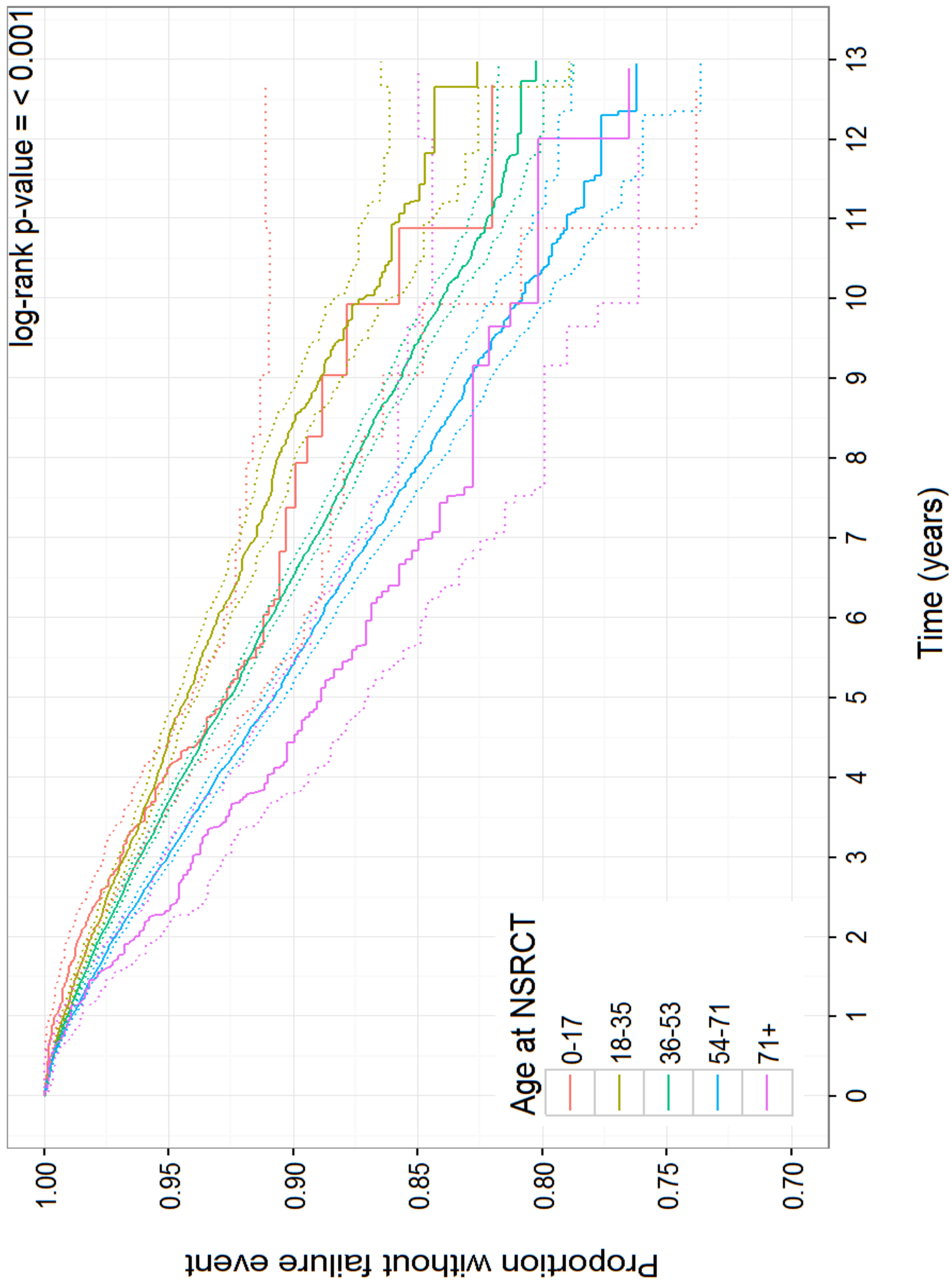

Figure 3: Survival estimates of endodontically treated teeth based on age of the patient

Follow-up Time Frame	Survival
1 year	0.991 [0.990, 0.991]
3 year	0.960 [0.958, 0.961]
5 year	0.923 [0.921, 0.925]
10 year	0.838 [0.833, 0.843]

Table 4: Survival estimates from the time of crown placement to incidence of an untoward event

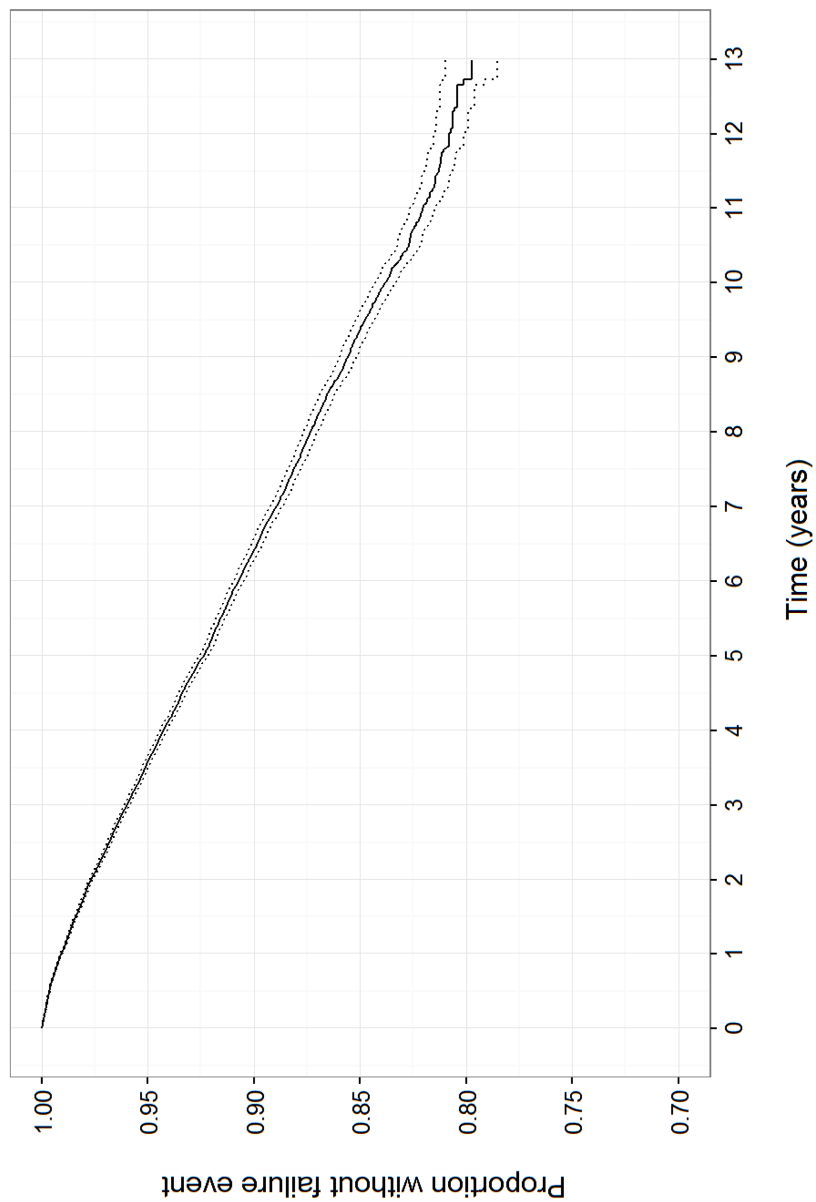

Figure 4: Survival estimates from the time of crown placement to incidence of an untoward event

Of the foundation restorations, 99,005 (61.9%) were cores and 61,035 (38.1%) were post and cores. Core materials consisted of 8,801 (5.5%) amalgam restorations or metallic inlays, 13,879 (8.7%) direct composite resins, and 76,323 (47.7%) core buildups (Table 1). Porcelain, ceramic, and resin inlays were excluded from the analysis due to the small group size. Direct resin-based cores illustrated a greater risk of failure after controlling for other variables compared to amalgam restorations as indicated by the hazard ratio and adjusted hazard ratio of 1.16. Core buildups and amalgam restorations did not show any difference in failure rates (See Figure 5). Types of post and cores consisted of 9,391 (5.9%) indirectly fabricated and 51,644 (32.3%) prefabricated (Table 1). Of those teeth that were treated with post and cores, indirectly fabricated posts demonstrated a greater risk of failure than prefabricated posts, as seen by the hazard ratio and adjusted hazard ratio of 1.11 (Table 2, Table 3, Figure 5). Teeth with a post and core versus a core showed higher failure rates as illustrated by the hazard ratio of 1.01 (Table 2).

Full coverage crowns were placed on all 160,040 teeth following the core/post placement. Metallic crowns were placed on 127,929 (79.9%) teeth and consisted of porcelain fused to metal, ¾ cast metal, full cast metal, titanium crowns and their counterparts in retainer crowns for fixed partial dentures. Non-metallic crowns were placed on 31,477 (19.7%) teeth and consisted of porcelain and ceramic crowns and their counterparts in retainer crowns for fixed partial dentures. Stainless steel crowns were placed as a final restoration on 634 (0.4%) teeth (Table 1). Non-metallic crowns demonstrated a higher risk of failure than metallic crowns with a hazard ratio of 1.15 and placed as a final restoration on 634 (0.4%) teeth (Table 1). Non-metallic crowns

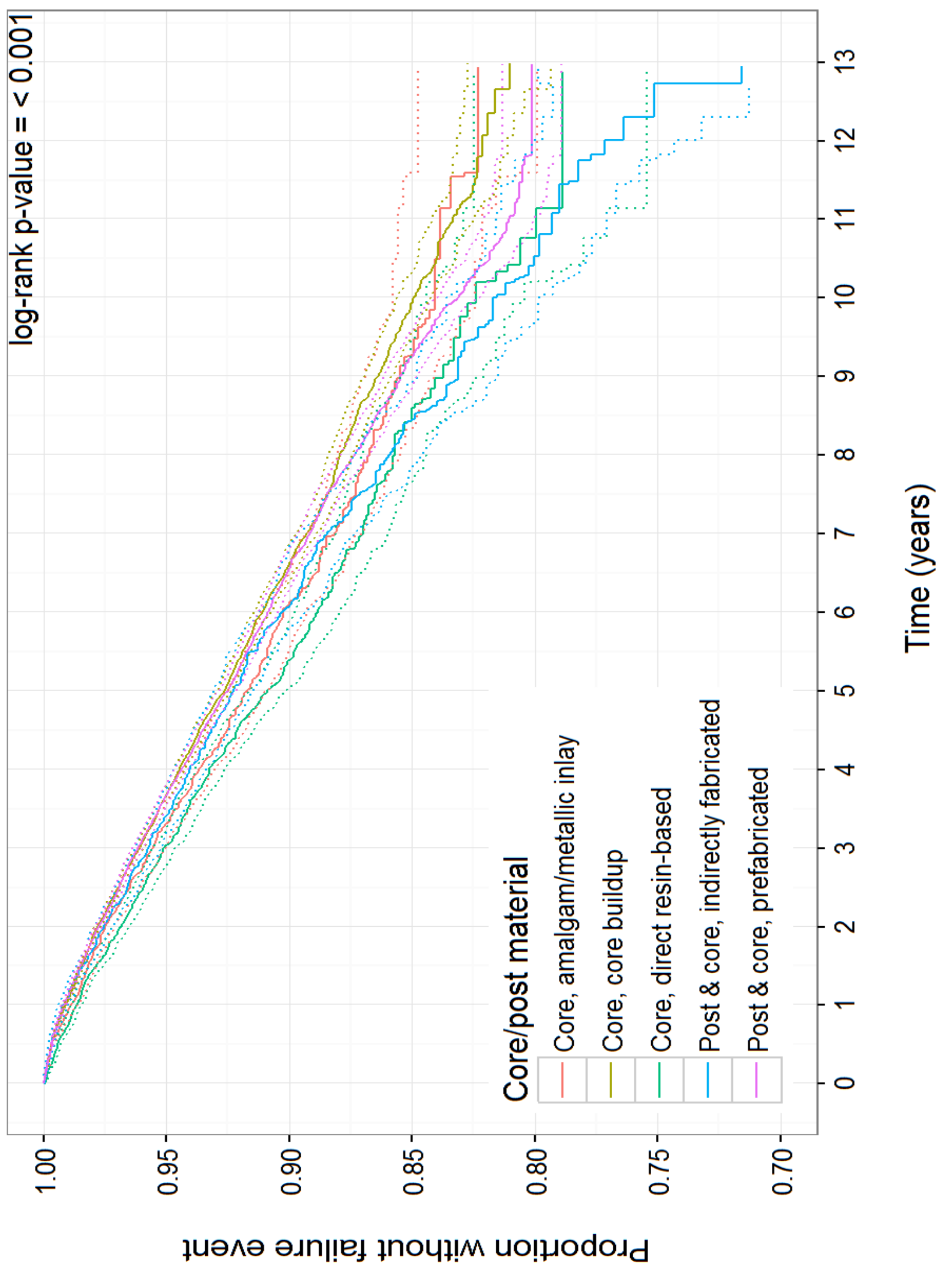

Figure 5: Survival estimates of endodontically treated teeth based on core/post material

placed as a final restoration on 634 (0.4%) teeth (Table 1). Non-metallic crowns demonstrated a higher risk of failure than metallic crowns with a hazard ratio of 1.15 and an adjusted hazard ratio of 1.16 (Table 2, Table 3, Figure 6). Stainless steel crowns illustrated a significant increase in failure rate versus metallic crowns with a hazard ratio of 2.45 and an adjusted hazard ratio of 2.44 (Table 2, Table 3, Figure 6).

The time from the NS RCT to the core/post averaged at 66.6 days with a median of 14.0 days. This was subsequently categorized into time frames. At 0-14 days, 82,780 (51.7%) teeth with an NS RCT had a core/post placed. At 15-59 days, 48,387 (30.2%) teeth with an NS RCT had a core/post placed. At greater than 60 days, 28,873 (18.0%) teeth with an NS RCT had a core/post placed (Table 1). There was no statistically significant difference when the core/post was placed within 0-14 days versus 15-59 days following NS RCT, however, there was a greater risk of failure in endodontically treated teeth with the core/post placed at greater than 60 days after NS RCT. This was shown by the adjusted hazard ratio of 1.08 (Table 2, Table 3, Figure 7).

The time from the core/post to the crown averaged at 160.5 days with a median of 14.0 days. The procedure from the core/post to the crown was completed within 0-14 days in 81,474 (50.9%) cases. The procedure from the core/post to the crown was completed within 15-59 days in 34,658 (21.7%) cases. The procedure from the core/post to the crown was completed in greater than 60 days in 43,908 (27.4%) cases (Table 1). There was no statistically significant difference when the crown was placed within 0-14 days versus within 15-59 days in 34,658 (21.7%) cases. The procedure from the core/post to the crown was completed in greater than 60 days in 43,908 (27.4%) cases (Table 1). There was no statistically significant difference when the crown was placed within 0-14

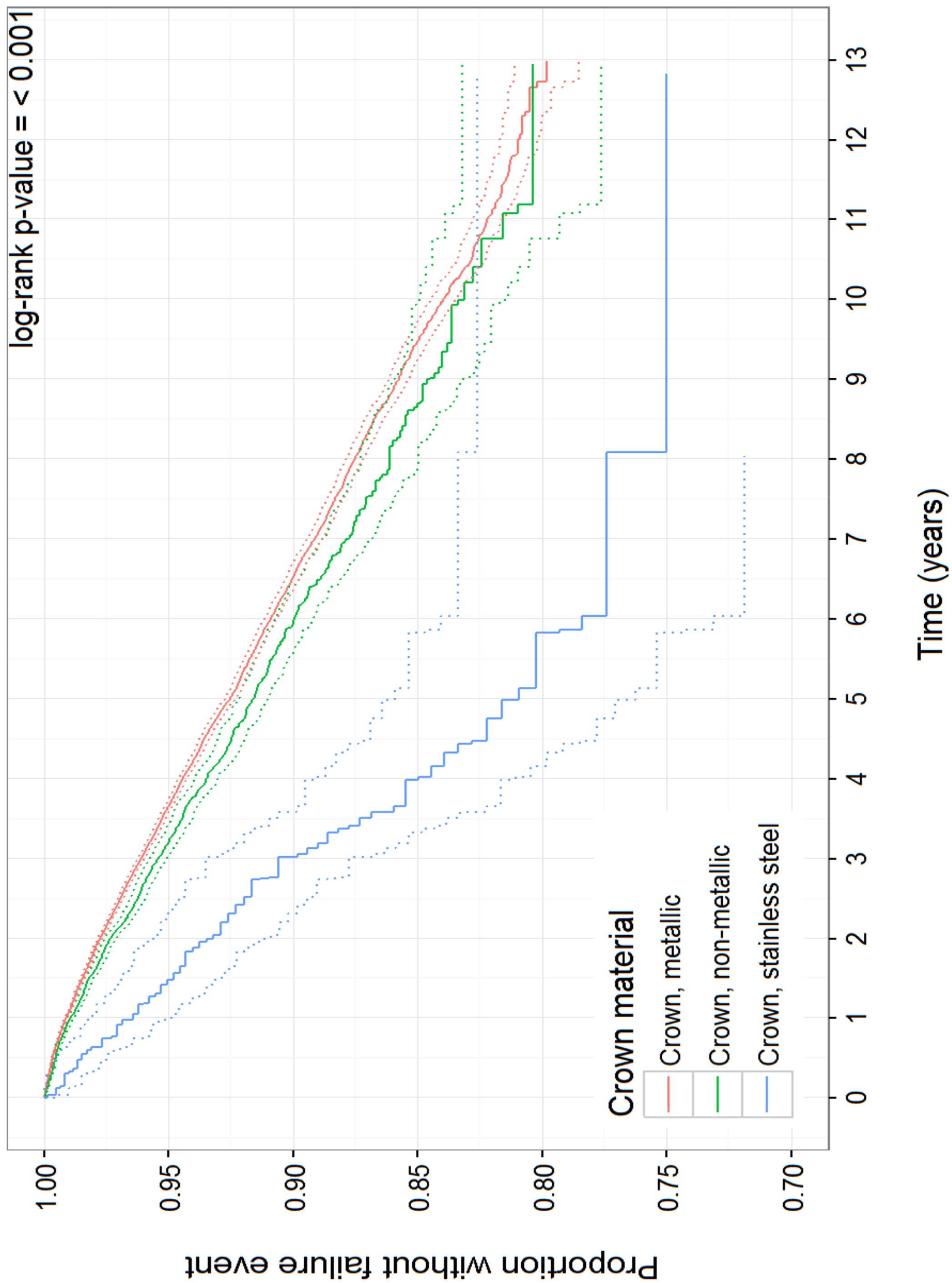

Figure 6: Survival estimates of endodontically treated teeth based on crown material

days versus 15-59 days following core/post, however, there was a greater risk of failure in endodontically treated teeth with the crown placed at greater than 60 days following the core/post. This was shown by the hazard ratio of 1.17 and the adjusted hazard ratio of 1.14 (See Figure 7). Overall, there was a greater incidence in an untoward event in endodontically treated teeth with the crown placed at greater than 90 days following the NS RCT as illustrated by the adjusted hazard ratio of 1.21 (Table 2).

Overall, average time from the NS RCT to crown was 227.1 days with a median of 49.0 days. Within 0-30 days, 103,790 (64.9%), within 31-89 days, 18,122 (11.3%), and greater than 90 days, 38,128 (23.8%) of the procedures were completed from NS RCT to crown (Table 1).

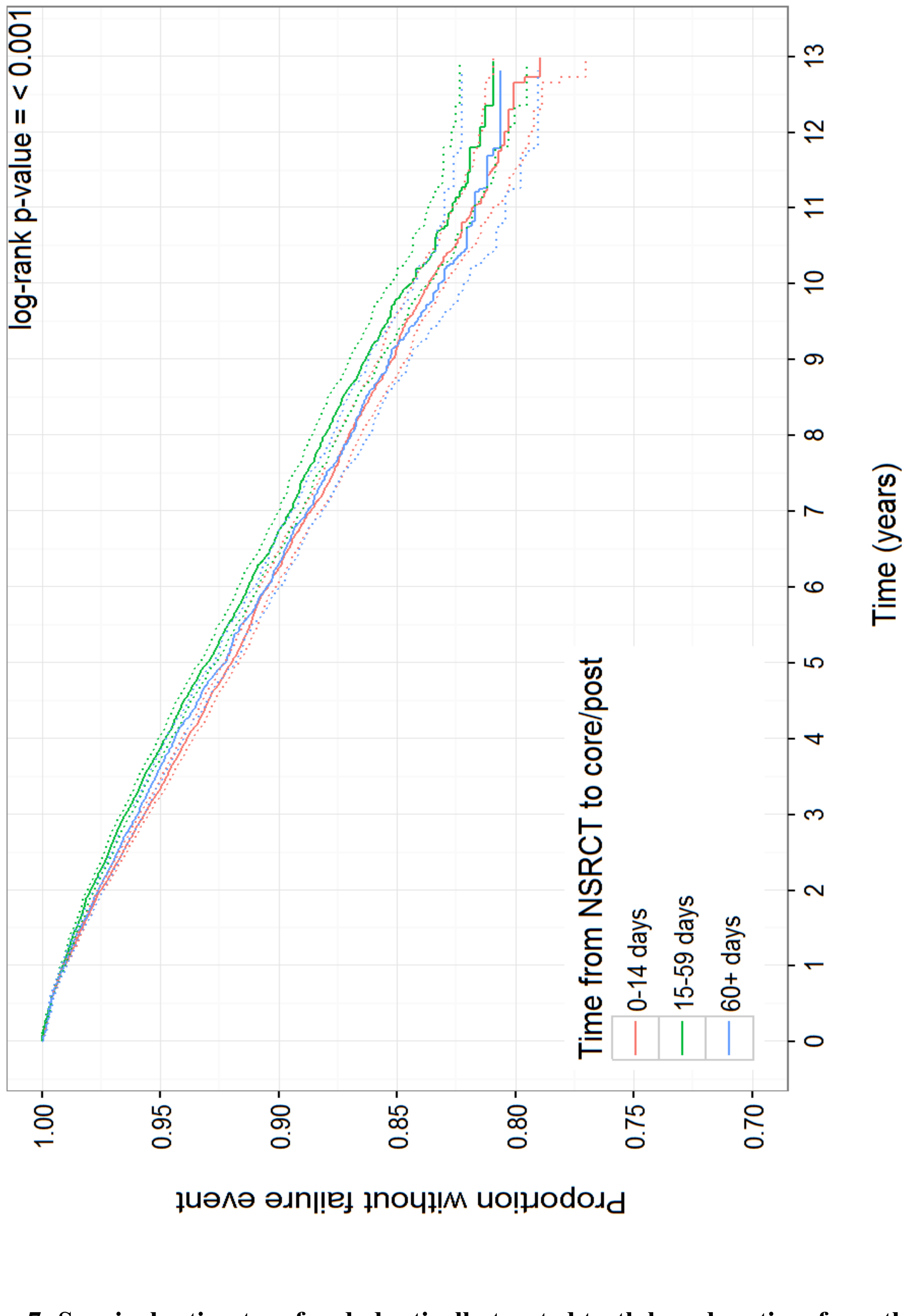

Figure 7: Survival estimates of endodontically treated teeth based on time from the NS RCT to core/post placement

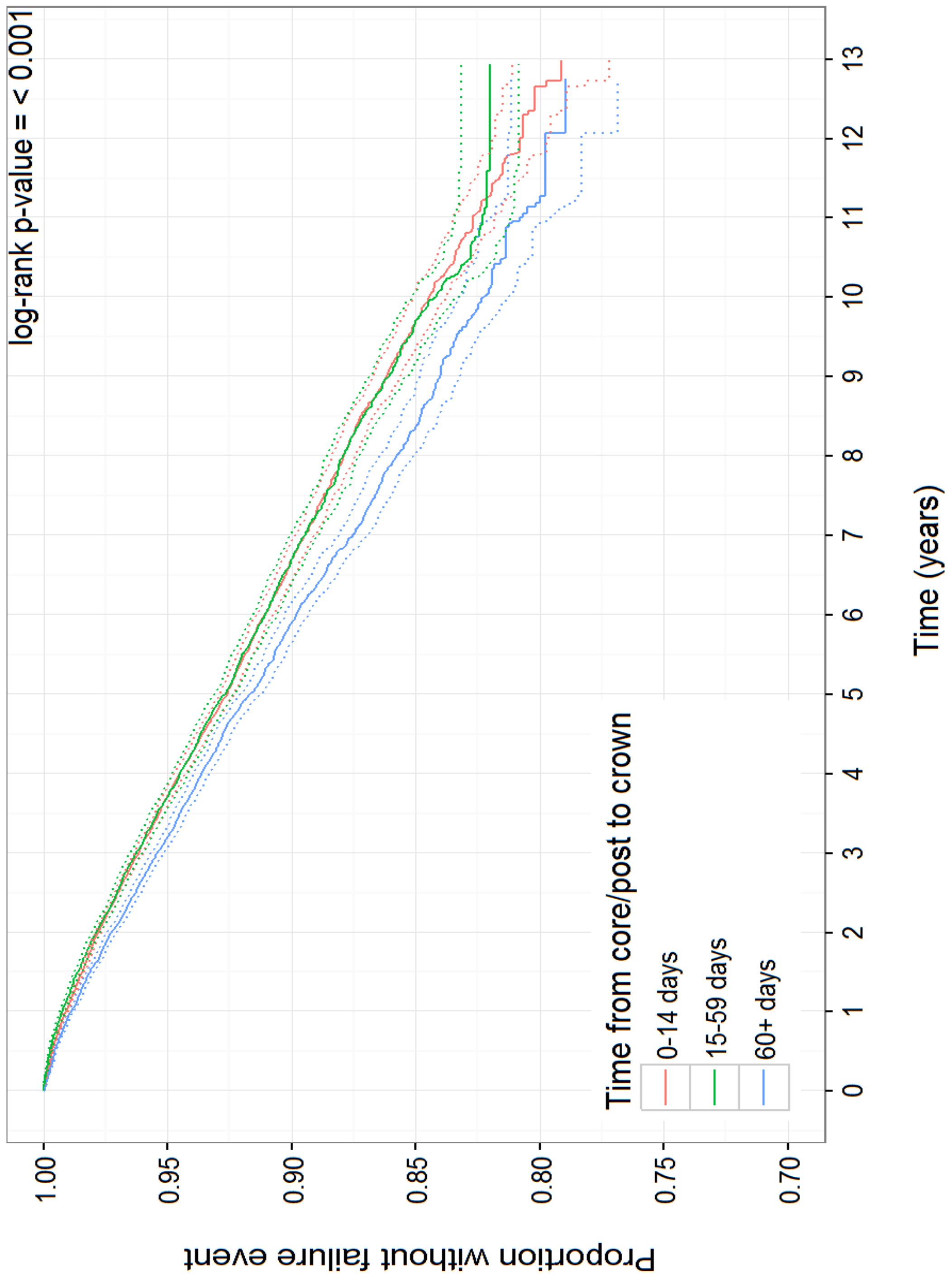

Figure 8: Survival estimates of endodontically treated by time from core/post placement to crown placement

DISCUSSION

The primary objective of this study was to determine if there is a correlation between the time from NS RCT to core/post placement, the time from the core/post to crown placement, and the presence of an untoward event. This is of considerable interest as there has not been a long-term, large-scale study that seeks to provide insight on the ideal restorative parameters following endodontic therapy. While many general dentists advocate for postponing the restoration of an endodontically treated tooth until it can be verified that healing is occurring and symptoms are resolving, this is fully reliant on anecdotal evidence.

By utilizing the Delta Dental of Wisconsin insurance database, the study was able to gain access to a substantial dataset from which information could be assessed. However, the limitations of such a large-scale population is that it is impossible to determine various prognostic or diagnostic predictors, for instance the initial pulpal and periradicular status of the tooth, systemic diseases of the patient, or the amount of tooth loss that would contribute to a decreases in the prognosis of treatment outcomes (73, 89). Within this study, the ability to differentiate between success and survival also cannot be determined, as radiographic and clinical evaluations are not available. It can only validate if a tooth is present by the end of the continuous enrollment period. While it is the hope that the large-scale nature of this study can eliminate sources of potential biases, it cannot provide insight on the standard of treatment of the practitioners- i.e. dental dam isolation, irrigation protocol, or experience of the practitioners. Although this study cannot control for these variables, it provides significant information to aid in the treatment planning process with regards to the long-term success of endodontic therapy.

Another limitation of the study included the stratification of patients and the inability for the population of the study to be representative of the whole. By utilizing an insurance database, statistical analysis could only include patients that had private dental insurance. This population may potentially present with different outcomes as access to care and expectations are distinct compared to the uninsured dental population. It should also be noted that information from this study could only be deduced for this respective population.

With a large-scale population and insurance database, there is a distinct difference between statistical significance and clinical or outcome significance. Large population sets can provide statistical significance to relatively minor differences. Therefore, in this study, the actual change in outcomes may not be clinically meaningful. The actual lifetime differences in time intervals from NS RCT to core/post and from core/post to crown are so small that while they are statistically significant, they could potentially have little impact on survival outcomes.

The study design first isolated the type of provider that completed the initial root canal therapy, Endodontist versus other providers. The NS RCT was completed by an Endodontist in 46,984 cases, which equated to 29.4% of the treatments and a non-endodontist in 113,056 cases, which equated to 70.6% of the treatments. These values were comparable to previous studies, which illustrated observations of 31.5% completed by an endodontist versus 68.6% completed by a non-endodontist and 28% versus 72%, respectively (1,62). Overall, there was a higher survival rate associated with Endodontists performing the NS RCT compared to other providers. This is likely due to additional training, the ability to treat cases of higher complexity, and a thorough understanding of the intricate root canal system and the biologic aspects behind the chemomechanical procedure that is afforded to Endodontists.

With regards to tooth location, anterior teeth illustrated the greatest failure rate followed by molar teeth and premolar teeth, respectively; this discrepancy was not statistically significant as seen with the adjusted hazard ratio of 0.90. Within the confines of this study, all teeth that had an NS RCT performed were only included in the data set if there was a subsequent core/post and crown placed. Tooth location has been proven to be a predictive factor in the success of NS RCT, with most studies indicating that anterior teeth typically have higher success rate than molar teeth (1, 73, 86, 98). In the present study, it is probable that anterior teeth would have a higher failure rate due to the amount of tooth structure loss that would need to occur for the anterior tooth to require a full coverage crown. It is also more likely that an anterior tooth would require a post and core for restorability and the ability to maintain the crown, which would increase its susceptibility to fracture (45, 102).

This study also sought to evaluate core/post and crown materials and determine if there was a significant effect of the type of material on the survivability of endodontically treated teeth. With regards to core materials, composite and amalgam were assessed. Composite resin failed at a higher rate than amalgam restorations. This is in accordance with a previous study that stated the success rate was 85.5% for composite restorations and 94.4% for amalgam restorations over a 7-year recall period. In this instance, the rate of recurrent decay was higher in the composite groups than amalgam groups, which was the predominent source of failure (103, 104). Along with recurrent decay, composite restorations were subjected to higher incidences of microleakage and polymerization shrinkage (105). The bulk of the core material group was placed into the core build-up category. Within this subset, the material used could not be determined as this is dependent on the provider's tendencies to code as a core build-up or as a resin or amalgam restoration. A limitation of this study was that the number of restorative surfaces was not taken into account. Therefore, it was impractical to determine whether the overall failure rate was associated with the type of restoration versus the size of the restoration.

Evaluation of core versus post and core was performed over the 13-year follow-up period. This study corroborated the evidence found in a previous study in which teeth with cores were more successful than teeth with post and cores (45). This is due to the loss of tooth structure afforded to teeth that require post and cores. In these circumstances, the tooth is structurally compromised due to caries, fracture, or resorption where a post is essential for retaining the crown. This causes potential transference of stresses to the root and subsequently weakens the root structure. It was also found within this study that indirectly fabricated posts were associated with a higher failure rate than prefabricated posts. With an indirectly fabricated post and core, significant tooth structure must be removed in order to create a path of insertion and withdrawal (55). Another disadvantage is that there is a higher clinical rate of root fracture with indirectly fabricated post and cores, which predominately occurs at the post and core interface. However, this study does not consider shape, retentive pattern, or material of the posts used, which could contribute to a decreased survivability.

Crown materials were categorized into non-metallic, metallic, and stainless steel crowns. Non-metallic crowns had a greater risk of failure than metallic crowns. This could be attributed to increased tooth structure that must be prepared during crown preparation, the inability to form as ideal of a seal as metallic crowns, and complications associated with porcelain cracks and fractures (106). This was also the first study in the literature that illustrates the detrimental effect of placing stainless steel crowns as a permanent, full coverage restoration. This has been primarily seen in patients with the inability to obtain a permanent crown due to financial concerns or in young individuals in which their jaws are still undergoing the growth process. Within this study, stainless steel crowns were utilized on 634 teeth, which only comprised 0.4% of the crown population. Previous studies have shown that stainless steel crowns done properly are effective in creating an adequate seal as a provisional crown or within the pediatric population on deciduous teeth (68). However, anecdotally, many of these crowns are ill-fitting and improperly sized allowing for microleakage, recurrent decay, and fracture. This study illustrates the importance of permanent, full coverage crowns in the restoration of endodontically treated teeth.

The primary focus of this study was to determine if there was a correlation between the time of core/post placement and the time of crown placement following NS RCT and the incidence of an untoward event. Within the study, time frames were divided into 0-14 days, 15-59 days, and 60+ days from the time from the NS RCT to core/post placement and from the time of core/post placement to the time of crown placement. With patients that did not have the core/post placed within 60 days, there was a significantly greater failure rate as microbial leakage could occur via the temporary restoration. Williamson found that lipopolysaccharide can penetrate the temporary restoration within 3 weeks (72) and Balto found that IRM leaked within 10 days and

Cavit leaked within 2 weeks (69). Other studies indicate that well-prepared and obturated canals are able to resist bacterial penetration up to 3 months (71). The results of the study failed to show an increase in risk of failure between placing the core/post after 0-14 days or 15-59 days from the NS RCT. However, due to the increased incidence of an untoward event, this study illustrates a correlation between placing the core/post within 60 days following NS RCT and an increased survival rate of endodontically treated teeth.

As with the time frame from NS RCT to core/post, the time frame from core/post to crown was also evaluated. Within the literature, there is a significant amount of research on the necessity for a full coverage restoration of endodontically treated teeth. According to Aquilino, endodontically treated teeth that were not crowned following obturation were lost at a 6 times greater rate than teeth that were crowned after obturation (63). Linn reported that endontically treated molar teeth are considered more susceptible to fracture due to loss of tooth structure (60). While it is heavily illustrated that full coverage restorations are significant in the survival of root canal therapy, there have been no studies that address how soon the crown should be placed following endodontic therapy. Within this study, there was no significant difference between crowns placed 0-14 days and 15-59 days following core/post, however, there was a significant difference when crowns were placed more than 60 days following core/post. This could be due to the increased likelihood of fracture without cuspal coverage with a greater increase in time period after NS RCT. The stresses from masticatory forces, parafunctional habits, and trauma have an increased susceptibility of detrimentally harming the tooth in an unrestorable manner. Therefore, the longer the tooth is predisposed to these stresses, the greater the chance of failure. This illustrates the long-term necessity for crowns to be placed within 60 days of core/post as full coverage restorations are necessary to protect against cuspal fracture.

CONCLUSION

This was the first study that detailed the immensely elevated long-term failure rate associated with stainless steel crowns as a permanent, full coverage restoration, which emphasizes the detrimental effect of these restorations on endodontic survival. Overall, the survival rates of NS RCT were greater when performed by an Endodontist versus other providers. This study illustrates that the long-term survival rate of teeth with initial endodontic therapy are significantly higher when the core/post is placed within 60 days following NS RCT and the crown is placed within 60 days following the core/post.

The objective of this study seeks to influence treatment-planning methodology to include a core and full coverage restoration within a given time period in order to increase the long-term survival rate of primary endodontic therapy.

Future areas of research using the Delta Dental of Wisconsin insurance database could include a long-term evaluation of retreatment and apicoetomy by provider type. Researchers could also evaluate the co-relationship between implants and endodontic therapy and a neighboring implants effect on adjacent endodontically treated teeth.

Bibliography

1. Burry J, Stover S, Eichmiller F, Bhagavatula P. Outcomes of Primary Endodontic Therapy Provided by Endodontic Specialists Compared with Other Providers. J Endod 2016;42:702-705.

2. Trope M. The Vital Tooth: It's Importance in the Study and Practice of Endodontics. Endod topics 2003; 5(1).

3. Ørstavik D, Pitt Ford TR. Prevention and Treatment of Apical Periodontitis. Essential Endodontology, 2nd ed. Oxford, UK: Blackwell Munksgaard Ltd; 2008.

4. Kakehashi S, Stanley H, Fitzgerald R. The Effects of Surgical Exposure of Dental Pulps in Germ-Free and Conventional Laboratory Rats. Oral Surg Oral Med Oral Pathol Oral Radiol Endod 1965;20:340-349.

5. Möller A, Fabricius L, Dahlén G, Heyden G. Influence on Periapical Tissues of Indigenous Oral Bacteria and Necrotic Pulp Tissue in Monkeys. Scand J Dent Res 1981;89(6):475-484.

6. Sundqvist G. Bacteriological studies of necrotic dental pulps. (Odontological Dissertation no.7). Umea, Sweden: University of Umea 1976.

7. Siquiera J, Rocas I. Distinctive Features of the Microbiota Associated with Different Forms of Apical Periodontitis. J Oral Microbiol 2009.

8. Duggan J, Sedgley C. Biofilm Formation of Oral and Endodontic Enterococcus Faecalis. J Endod 2007;33(7): 815-818.

9. Bergenholtz G. Pathogenic Mechanisms in Pulpal Disease. J Endod 1990;16(2): 96-101.

10. Trope M. The Vital Tooth: It's Importance in the Study and Practice of Endodontics. Endod topics 2003; 5(1).

11. Boutsioukis C, Lambrianidis T, Vergaagen B, et al. The Effect of Needle Insertion Depth on the Irrigant Flow in the Root Canal: Evaluation using an Unsteady Computational Fluid Dynamics Model. J Endod 2010; 36: 1664.

12. Bystrom A, Sundqvist G. Bacterial Evaluation of the Effect of 0.5 Percent Sodium Hypochlorite in endodontic Therapy. Oral Surg Oral Med Oral Pathol 1983; 55: 307.

13. Schilder H. Cleaning and Shaping the Root Canal. Dent Clin North Am 1974;18:269.

14. Ram Z. Effectiveness of Root Canal Irrigation. Oral Surg Oral Med Oral Pathol 1977;44:306.

15. Card SJ, Sigurdsson A, Orstavik D, Trope M. The Effectiveness of Increased Apical Enlargement in Reducing Intracanal Bacteria. J Endod 2002; 28: 779.

16. Ingle JI, Beveridge E, Glick D, et al. The Washington Study. Endodontics 1994: 1-59.

17. Sabeti MA, Nekofar M, Motahhary P, et al. Healing of Apical Periodontitis after Endodontic Treatment With and Without Obturation in Dogs. J Endod 2006;32:628.

18. Whitworth J. Methods of Filling Root Canals: Principles and Practices. Endod Topics 2003; 12:2.

19. Sjogren U, Hagglund B, Sudqvist G, et al. Factors Affecting the Long-Term Results of Endodontic Treatment. J Endod 1990; 16:498.

20. Peters LB, van Winkelhoff AJ, Buijs JF, et al. Effects of Instrumentation, Irrigation, and Dressing with Calcium Hydroxide on Infection in Pulpless Teeth with Periapical Bone Lesions. Int Endod J 2002; 35:13.

21. Gillen B, Looney S, Gu L, Loushine B, et al. Impact of the Quality of the Coronal Restoration versus the Quality of Root Canal Fillings on Success of Root Canal Treatment: A Systematic Review and Meta-Anaylsis. J Endod 2011; 37(7): 895-902.

22. Sedley CM, Messer HH. Are Endodontically Treated Teeth more Brittle? J Endod 1992; 18(7): 332-335.

23. Reeh ES, Messer HH, Douglas WH. Reduction in Tooth Stiffness as a Result of Endodontic and Restorative Procedures. J Endod 1989; 15(11): 512-516.

24. Helfer AR, Melnick S, Shilder H. Determination of the Moisture Content of Vital and Pulpless Teeth. Oral Surg Oral Med Oral Pathol 1972; 34: 661.

25. Huang TJ, Shilder H, Nathanson D. Effect of Moisture Content and Endodontic Treatment on Some Mechanical Properties of Human Dentin. J Endod 1992; 18(5): 209-215.

26. Papa J, Cain C, Messer HH. Moisture Content of Vital versus Endodontically Treated Teeth. Endod Dent Traumatol 1994; 10:91.

27. Sim TP, Knowles JC, Ng YL, et al. Effect of Sodium Hypochlorite on Mechanical Properties of Dentine and Tooth Surface Strain. Int Endod J 2001; 33:120.

28. Weston CH, Ito S, Wadgaonkar B, Pashley DH. Effects of Time and Concentration of Sodium Ascorbate on Reversal of NaOCl-Induced Reduction in Bond Strengths. J Endod 2007; 33(7): 879-81.

29. Grigoratos D, Knowles J, Ng YL, Gulabivala K. Effect of Exposing Dentin to Sodium Hypochlorite on its Flexural Strength and Elasticity Modulus. Int J Endod J 2001; 34:113.

30. Torabinejad M, Cho Y, Khademi AA, et al. The Effect of Various Concentrations of Sodium Hypochlorite on the Ability of MTAD to Remove the Smear Layer. J Endod 2003; 29(4): 233-239.

31. Hawkins CL, Davies ML. Hypochlorite-Induced Damage to Proteins: Formation of Nitrogen-Centered Radicals from Lysine Residues and their Role in Protein Fragmentation. Biochem J 1998; 332:617.

32. Lee Y. Effect of Calcium Hydroxide Application Time on Dentin. Restor dent Endod 2013; 38(3):186.

33. Grigoratos D, Knowles J, Ng YL, Gulabivala K. Effect of Exposing Dentine to Sodium Hypochlorite and Calcium Hydroxide on its Flexural Strength and Elastic Modulus. Int Endod J 2001; 34(2): 113-9.

34. Wang JD, Hume WR. Diffusion of Hydrogen Ion and Hydroxyl Ion from Various Sources through Dentine. Int Endod J 1988; 21(1): 17-26.

35. Gomes IC, Chevitarese O, De Almeida NS, Salles MR, Gomes GC. Diffusion of Calcium through Dentine. J Endod 1996; 22(11): 590-5.

36. Nakano F, Takahashi H, Nishimura F. Reinforcement Mechanism of Dentin Mechanical Properties by Intracanal Medicaments. Dent Mater J 1999; 18(3): 304-13.

37. Savadkouhi ST, Fazlyab M. Discoloration Potential of Endodontic Sealers: A Brief Review. Iran Endod J 2016; 11(4): 250-4.

38. Reeh ES, Messer HH, Douglas WH. Reduction in Tooth Stiffness as a Result of Endodontic and Restorative Procedures. J Endod 1989; 15(11): 512-6.

39. Bassir MM, Labibzadeh A, Mollaverdi F. The Effect of Amount of Lost Tooth Structure and Restorative Technique on Fracture Resistance of Endodontically Treated Premolars. J Conserv Dent 2013; 16(5): 413-7.

40. Randow K. Glantz PO. On Cantilever Loading of Vital and Non-Vital Teeth. An Experimental Clinical Study. Acta Odontol Scand 1986; 44(5): 271-7.

41. Lowenstein WR, Rathkamp R. A Study on the Pressoreceptive Sensibility of the Tooth. J Dent Res 1955; 34(2): 287-94.

42. Ray HA, Trope M. Periapical Status of Endodontically Treated Teeth in Relation to the Technical Quality of the Root Filling and the Coronal Restoration. Int Endod J 1955; 28(1): 12-8.

43. Phillips, RW, Skinner, EW. Skinner's Science of Dental Materials. Philadelphia, PA, 1973

44. Combe EC, Shaglouf AM, Watts DC, Wilson NH. Mechanical Properties of Direct Core Build-up Materials. Dent Mater 1999; 15(3): 158-65.

45. Schwartz RS, Robbins JW. Post Placement and Restoration of Endodontically Treated Teeth: A Literature Review. J Endod 2004; 30(5): 289-301.

46. Baba N, Goodacre C, Daher T. Restoration of Endodontically Treated Teeth: The Seven Keys to Success. Endod 2009; 596-603.

47. Kwan EH, Harrington GW. The Effect of Immediate Post Preparation of the Apical Seal. J Endod 1981; 7(7): 325-9.

48. Goldfein J, Speirs C, Finkelman M, Amato R. Rubber Dam Use During Post Placement Influences the Success of Root Canal-Treated Teeth. J Endod 2013; 39(12): 1481-4.

49. Standlee JP, Caputo AA, Holcomb JP. The Dentatus Screw: Comparative Stress Analysis with Other Endodontic Dowel Designs. J Oral Rehabil 1982; 9(1): 23-33.

50. Ricketts DJ, Tait CM, Higgins AJ. Post and Core Systems: Refinements to Tooth Preparation and Cementation. British Dent J 2005: 533-541.

51. Ferrari M, Vicchi A, Maccocci F, Mason PN. Retrospective Study of the Clinical Performance of Fiber Posts. Am J Dent 2000; 13: 9-13.

52. Signore A, Benedicenti S, Kaitsas V, et al. Long-term Survival of Endodontically Treated, Maxillary Anterior Teeth Restored with Either Tapered or Parallel-Sided Glass-Fiber Posts and Full-Ceramic Crown Coverage. J Dent 2009; 37(2): 115-21.

53. Drummond JL. In Vitro Evaluation of Endodontic Posts. Am J Dent 2000; 13: 5-8.

54. Sirimai S, Riis DN, Morgano SM. An In Vitro Study of the Fracture Resistance and the Incidence of Vertical Root Fracture of Pulpless Teeth Restored with Six Post-and-Core Systems. J Prosthet Dent 1999; 81(3): 262-9.

55. Cailleteau JG, Rieger MR, Akin JE. A Comparison of Intracanal Stresses in a Post-Restored Tooth Utilizing the Finite Element Method. J Endod 1992; 18(11): 540-4.

56. Figueiredo FE, Martins-Filho PR, Faria-E-Silva AL. Do Metal Post-Retained Restorations Result in More Root Fractures than Fiber Post-Retianed Restorations? A Systematic Review and Meta-Anaylsis. J Endod 2015; 41(3): 309-16.

57. Makade C, Meshram G, Manjusha W, Patil P. A Comparative Evaluation of Fracture Resistance of Endodontically Treated Teeth Restored with Different Post Core Systems- an In-Vitro Study. J Adv Prosthodon 2011; 3(2): 90-95.

58. Sorenson JA, Martinoff JT. Endodontically Treated Teeth as Abutments. J Prosthet Dent 1985; 53: 631-636.

59. Bindl A, Richter B, Mormann WH. Survival of Ceramic Computer-aided Design/Manufacturing Crowns Bonded to Preparations with Reduced Macroretention Geometry. Int J Prosthodont 2005; 18: 219-224.

60. Linn J, Messer HH. Effect of Restorative Procedures on the Strength of Endodontically Treated Molars. J Endod 1994; 20(10): 479-85.

61. Stavropoulou AF, Koidis PT. A Systematic Review of Single Crowns on Endodontically Treated Teeth. Journal of Dentistry 2007; 35: 761-7.

62. Lazarski, MP, Walker WA, 3rd, Flores CM, Schindler WG, Hargreaves KM. Epidemiological evaluation of the outcomes of nonsurgical root canal treatment in a large cohort of insured dental patients. J Endod 2001;27(12):791-796.

63. Aquilino S, Caplan D. Relationship between Crown Placement and the Survival of Endodontically Treated Teeth. J Prosthetic Dent 2002; 87(3): 256-63.

64. Salehrabi R, Rotstein I. Endodontic Treatment Outcomes in a Large Patient Population in the USA: An Epidemiological Study. J Endod 2004; 30(12): 846-50.

65. Panitvisai P, Messer HH. Cuspal Deflection in Molars in Relation to Endodontic and Restorative Procedures. J Endod 1995; 21(2): 57-61.

66. Sailer I, Pjetursson B, Zwahlen M, Hammerle C. A Systematic Review of the Survival and Complication Rates of All-Ceramic and Metal-Ceramic Reconstructions after an Observation Period of at least 3 years. Part II: Fixed Dental Prostheses Clin Oral Impl Res 2007; 18(3): 86-96.

67. Rinke S, Schaffer S, Roediger M. Complication Rate of Molar Crowns: A Practice-Based Clinical Evaluation. Int J Comput Dent 2011; 14(3): 203-18.

68. Randall R. Preformed Metal Crowns for Primary and Permanent Molar Teeth: Review of the Literature. Ped Dent 2002; 24(5): 489-500.

69. Balto H. An Assessment of Microbial Coronal Leakage of Temporary Filling Materials in Endodontically Treated Teeth. J Endod 2002; 28(11): 762-4.

70. Deveaux E, Hildelbert P, Neut C, Romond C. Bacterial Microleakage of Cavit, IRM, TERM, and Fermit: a 21-day In-Vitro Study. J Endod 1999; 25: 653-9.

71. Ricucci D, Bergenholtz G. Bacterial Status in Root-Filled Teeth Exposed to the Oral Environment by Loss of Restoration and Fracture or Caries- A Histobacteriological Study of Treated Cases. Int Endod J 2003; 36(11): 787-802.

72. Williamson A, Dawson D, Drake D, Walton R, Rivera E. Effect of Root Canal Filling/Sealer Systems on Apical Endotoxin Penetration: A Coronal Leakage Evaluation 2005; 31(8): 599-604.

73. Ng YL, Mann V, Rahbaran S, Lewsey J, Gulabivala K. Outcome of Primary Root Canal Treatment: Systematic Review of the Literature- Part 1. Effects of Study Characteristics on Probability of Success. Int Endod J 2007;40:921-39.

74. Cheung W. A Review of the Management of Endodontically Treated Teeth: Post, Core, and the Final Restoration. J Am Dent Assoc 2005; 136: 611-619.

75. Strindberg LZ. The Dependence of the Results of Pulp Therapy on Certain Factors. An Analytic Study based on Radiographic and Clinical Follow-up Examination. Acta Odontol Scand 1956; 14: 21.

76. Bender IB, Seltzer S, Soltanoff W. Endodontic Success- A Reappraisal of Criteria 1. Oral Surg Oral Med Oral Pathol 1966; 22(6): 780-9.

77. Van Nieuwenhuysen JP, Aouar M, D'Hoore W. Retreatment or Radiographic Monitoring in Endodontics. Int Endod J 1994; 27(2): 75-81.

78. Fristad I, Molven O, Halse A. Nonsurgically Retreated Root Filled Teeth-Radiographic Findings after 20-27 years. Int Endod J 2004; 37(1):12-8.

79. Gutmann JL. Clinical, Radiographic, and Histologic Perspectives on Success and Failure in Endodontics. Dent Clin North Am 1992; 36(2): 379-92.

80. Orstavik D. Time-Course and Risk Analyses of the Development and Healing of Chronic Apical Periodontitis in Man. Int Endod J 1996;29: 150-5.

81. Pekruhn RB. The Incidence of Failure Following Single-Visit Endodontic Therapy. J Endod 1986; 12: 68-72.

82. Friedman S. Prognosis Of Initial Endodontic Therapy Endodontic Topics 2002(2):59-88.

83. Sjogren U, Hagglund B, Sundqvist G, Wing K. Factors Affecting the Long-term Results of Endodontic Treatment. Journal of Endodontics 1990;16(10):498-504.

84. Cheung GSP. Survival of first-time nonsurgical root canal treatment performed in a dental teaching hospital. Oral Surg, Oral Med, Oral Pathol, Oral Radio, Endod 2002;93(5):596-604.

85. Doyle SL, Hodges JS, Pesun IJ, Law AS, Bowles WR. Retrospective Cross Sectional Comparison of Initial Nonsurgical Endodontic Treatment and Single-Tooth Implants. J Endod 2006; 32(9): 822-7.

86. Firedman S, Abitbol S, Lawrence H. Treatment Outcome in Endodontics: The Toronto Study. Phase 1: Initial Treatment. J Endod 2003; 29(12): 787-93.

87. Bender IB, Seltzer S, Freedland JB. The Relationship of Systemic Disease to Endodontic Failures and Treatment Procedures. Oral Surg Oral Med Oral Pathol 1963; 16: 1102-15.

88. Marending M, Peters OA, Zehnder M. Factors Affecting the Outcome of Orthograde Root Canal Therapy in a General Dentistry Hospital Practice. Oral Surg Oral Med Oral Pathol Oral Radiol Endod 2005; 99(1): 119-24.

89. Marx RE. Osteoradionecrosis: A New Concept of its Pathophysiology. J Oral Maxillofac Surg 1083; 41(5): 283-8.

90. Morsani JM, Aminoshariae A, Han YW, Montagnese T, Mickel A. Genetic Predisposition to Persistent Apical Periodontitis. J Endod 2011; 37(4): 455-9.

91. Nair PNR. On the Causes of Persistent Apical Periodontitis: A Review. Int Endod J 2006; 39:249-81.

92. Bystrom A, Sundqvist G. Bacteriologic Evaluation of the Efficacy of Mechanical Root Canal Instrumentation in Endodontic Therapy. Scand J Dent Res 1981; 89: 321-8.

93. Basrani B, Santos J, Tjaderhani L. Substantive Antimicrobial Activity in Chlorhexidine Treated Human Root Dentin. Oral Surg Oral Med Oral Pathol Oral Radiol Endod 2002; 94:240-5.

94. Koppang HS, Koppang R, Solheim T, Aarnes H, Stolen SO. Cellulose Fibers from Endodontic Paper Points as an Etiological Factor in Postendodontic Periapical Granulomas and Cysts. J Endod 1989; 15(8): 369-72.

95. Serene TP, Vesely J, Boackle RJ. Complement Activation as a Possible In-Vitro Indication of the Inflammatory Potential of Endodontic Materials. Oral Surg 1988; 65(3): 354.

96. Vire DE. Failure of Endodontically Treated Teeth: Classification and Evaluation. J Endod 1991; 17(7): 388-42.

97. Ray HA, Trope M. Periapical Status of Endodontically Treated Teeth in Relation to the Technical Quality of the Root Filling and the Coronal Restoration. Int Endod J 1995; 28(1): 12-8.

98. De Chevigny, Dao TT, Basrani BR, Marquis V, Farzaneh M, Abitbol S, Friedman S. Treatment Outcome in Endodontics: The Toronto Study- Phase 3 and 4: Orthograde Retreatment. J Endod 2008; 34(2): 131-7.

99. Crump MB, Natkin E. Relationship of Broken Root Canal Instruments to Endodontic Case Prognosis: A Clinical Investigation. J Am Dent Assoc 1970; 80: 1341-7.

100. Woodmansey KF, Ayik M, Buschang PH, White CA, He J. Differences in Masticatory Function in Patients with Endodontically Treated Teeth and Single-Implant-Supported Prostheses: A Pilot Study. J Endod 2009; 35(1).

101. Pennington MW, Vernazza CR, Shackley P, Armstrong NT, Whitworth JM, Steele JG. Evaluation of the Cost-Effectiveness of Root Canal Treatment Using Conventional Approaches versus Replacement with an Implant. Int Endod J 2009; 42(10): 874-83.

102. McComb D. Restoration of the Endodontically Treated Tooth. Dispatch: Royal College of Dental Surgeons of Ontario 2008: 1-20.

103. Bernardo M, Luis H, Martin MD, Leroux BG, Rue T, Leitao J, et al. Survival and Reasons for Failure of Amalgam versus Composite Posterior

Restorations Placed in a Randomized Clinical Trial. J Am Dent Assoc 2007; 138(6): 775-83.

104. Christensen GJ. Longevity of Posterior Tooth Dental Restorations. J Am Dent Assoc. 2005; 136(2): 201-3.

105. Leinfelder KF. Do Restorations Made of Amalgam Outlast though Made of Resin-Based Composite? J Am Dent Assoc 2000; 131(8): 1186-7.

106. Hmaidouch R, Weigl P. Tooth Wear Against Ceramic Crowns in Posterior Region: A Systematic Literature Review. Int J Oral Sci 2013; 5(4): 183-90.