Outcomes of Nonsurgical Root Canal Therapy Completed in Children Aged 6-13 Years

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OUTCOMES OF NONSURGICAL ROOT CANAL THERAPY COMPLETED IN CHILDREN AGED 6-13 YEARS

by

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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 2021

ABSTRACT

OUTCOMES OF NONSURGICAL ROOT CANAL THERAPY COMPLETED IN CHILDREN AGED 6-13 YEARS

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Marquette University, 2021

Introduction: Tooth survival following non-surgical root canal treatment (NSRCT) in adult populations has been documented as high as 97%. However, to our knowledge, no studies have examined tooth survival following NSRCT in children. The aim of this study was to determine the long-term outcomes of non-surgical root canal treatment in children aged 6-13 years provided by both endodontists and other providers.
Methods & Materials: Insurance claims from the Delta Dental of Wisconsin Insurance database of 4927 anterior and molar NSRCT completed in children aged 6-13 years from the years 2002-2014 were analyzed. The teeth were followed during continuous insurance eligibility from the time of treatment until the occurrence of any untoward event or end of the study period. Untoward events were identified using Current Dental Terminology (CDT) codes for retreatment, apicoectomy, or extraction. Kaplan-Meier survival estimates were calculated for 1, 5, and 10 years. Cox regression models were used to analyze the effect of provider type, tooth type, and age of child on survival. Analyses were performed using SAS 9.4 (SAS Institute, Cary, NC) and R version 3.6.3.
Results: The survival was 99.3% at 1 year, 91.3% at 5 years, and 82.7% at 10 years. The survival of teeth treated by endodontists and other providers at 10 years was 86.7% and 79.4%, respectively ($p<0.05$) At 10 years, first molars have a significantly lower survival rate when compared to central and lateral incisors ($p<0.05$).
Conclusions: The survival of NSRCT in children aged 6-13 years is high at 10 years regardless of the provider. Teeth treated by endodontists have significantly higher success rates than those treated by other providers.

ACKNOWLEDGEMENTS

Lauren M. Loney, D.D.S.

The past two years at Marquette University have been a couple of the most enjoyable years of my dental education. This, of course, is largely due to the tremendous faculty I have had the honor of working with. Specifically, I would like to thank Dr. Pradeep Bhagavatula and Dr. Mohamed Ibrahim for their mentorship and encouragement in relation to my research. I also want to recognize and thank Dr. Lance Hashimoto, Dr. Joseph Gaffney, Dr. Mohamed Ibrahim, and Dr. Joseph DeGuzman. Your advice, encouragement, and kindness will not be forgotten. I can only hope that someday I will be as good of a clinician as you are.

I would also like to thank my coresidents: Enida Haxhia and Thomas Korte. You both have been there for me through it all, and I will be forever grateful I was able to spend the last two years with you. You are not just my coresidents but my forever friends. In addition, I would like to thank my coresidents: Tim Gainey, Mike Smoljan, Igor Sulim, John Jurkas, David Poe, and Andrea Tsatalis. Your clinical excellence has driven me to strive for perfection, and I could not ask for better friends.

I want to thank my parents for always encouraging me to do my best. You have always told me I can do whatever I set my heart to and your steady guidance throughout my education does not go unnoticed.

Finally, I would like to thank my husband, Matt, and daughter, Evelyn. Evelyn, although you have not been in my life for a long time, you have proven to be one of the best parts of it. I hope to always encourage you to follow your dreams. Matt, you have patiently been following me from city to city as I have been chasing my dreams. From the late nights studying to the long days at school, you have been there for me through it all. I can’t imagine a better person to do life with.

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INTRODUCTION

Outcomes of primary endodontic therapy have been well-documented in endodontic literature. Outcomes of primary endodontic therapy are reported between 80-97% (1–3). Friedman et al (1) completed a prospective study, named the Toronto Study, that evaluated the outcomes of primary endodontic therapy. They found an 81% overall success rate after 4-6 years. A retrospective study by Grossman et al (2) found a 90% success rate after 5 years. An insurance-based study by Salehrabi and Rohstein (3) found a survival rate of 97% 8 years after treatment. Other researchers have examined the difference in outcomes of primary endodontic therapy when comparing endodontists to non-endodontic specialists. An insurance-based study by Burry et al (4) found primary endodontic therapy in molars had a significantly higher success rate when completed by endodontists (89%) compared to non-endodontic specialists (85%) at 10 years. Another insurance-based study by Lazarski (5) found no significant difference in success rates when comparing endodontists with general dentists. Although outcomes of primary endodontics have been well-documented over time, to the best of our knowledge, no other studies have evaluated outcomes of primary endodontic therapy in children.

As mentioned, there are no journal articles investigating the success rates of primary endodontic treatment in children. However, pulp involvement of permanent teeth in young children is very prevalent. A retrospective study by Al-Madi (6) found 36.5% of children from Saudi Arabia aged 6-18 years had pulpal involvement of at least one tooth . When caries or trauma results in pulp involvement in young children, there are several treatment options. In teeth where the pulp remains vital, vital pulp therapy is often indicated. Vital pulp therapy includes direct pulp caps and partial or full pulpotomies. In a systematic review by Aguilar (7), the included studies had success rates of pulpotomies varying from 70-90%. Mejare and Cvek (8) found a 93.5% success rate after two years when partial pulpotomies were completed in young children. A randomized clinical trial completed by Nosrat (9) found a 100% survival at 12 months in teeth that received a pulpotomy after carious exposure. Although there appears to be high success rates for pulpotomies in young children, vital pulp therapy can only be completed when an involved pulp remains vital.

In children with permanent teeth that have nonvital pulps, there are a few treatment options: traditional non-surgical root canal treatment (NSRCT), apical barrier technique, or regenerative endodontics. Various case reports and case series have been published showing success of regenerative endodontics in teeth with immature root development. A report based on a case series showed healing of periapical lesions and increased root length and thickness after regenerative endodontic procedures were completed (10). Cotti (11) showed healing of a periapical radiolucency and increased root length and thickness associated with a maxillary central incisor 30 months after regenerative procedures were completed. In young children with pulp necrosis in permanent teeth with closed apices, traditional NSRCT is the treatment of choice. However, traditional NSRCT is very challenging due to complex pulpal anatomy and difficult patient management in children (6). Because of the challenging nature of this procedure in children, it is of great importance to understand the outcomes of NSRCT in children. Therefore, the aim of this study is to determine the long-term outcomes of non-surgical root canal treatment in children aged 6-13 years.

LITERATURE REVIEW

Outcomes of Primary Non-Surgical Root Canal Treatment

The ultimate goal of endodontic therapy is to prevent or eliminate apical periodontitis and to resolve patient symptoms (12). These goals are accomplished by elimination of microbial organisms within the root canals of the teeth (13). One way to ascertain whether the goals of primary endodontic treatment have been met is through outcome studies. Outcome studies typically examine success of nonsurgical root canal treatment or the survival of the tooth.

Survival of the endodontically treated tooth has been defined as painless retention of the tooth (4). Numerous studies in endodontics have examined the survival rates of endodontically treated teeth (3). An epidemiologic study by Salehrabi et al. (3) examined the survival of 1,462,936 teeth treated in the United States over an 8 year period. They found an overall survival rate of 97% 8 years after initial endodontic treatment. They found teeth with full coverage restorations had significantly higher survival rates when compared to teeth without full coverage restorations (3).

Success of the endodontically treated tooth has been more complicated to define and has evolved over time. In a classic study, Strindberg (14) defined the criteria required for success of endodontic treatment. These success criteria are now commonly referred to as “Strindberg Criteria” (12). The Strindberg Criteria for success include both clinical and radiographic parameters. Clinically, the tooth should be without symptoms. Radiographically, the tooth should display normal contours and widths of the periodontal ligament, or if widening is present, it should be mainly around excess root filling material. The lamina dura should also be intact (14).

Bergenholtz (13) more loosely states that the definition of endodontic success is "absence of apical periodontitis and clinical symptoms after a period of observation" (13). The American Association of Endodontics has also more recently defined endodontic outcomes as healed, nonhealed, healing, or functional. A healed tooth is a "functional, asymptomatic tooth with no or minimal radiographic periradicular pathosis" (15). A nonhealed tooth is a "nonfunctional, symptomatic tooth with or without radiographic periradicular pathosis" (15). A healing tooth is a tooth with "periradicular pathosis, which are asymptomatic and functional" (15). A functional tooth is defined as a "treated tooth that is serving its intended purpose in the dentition" (15).

Several outcome studies have examined the success of endodontic treatment (1,2,16,17). One retrospective study by Grossman et al (2) examined the success of 432 endodontically treated teeth one to five years after treatment. They found a 90.4% success rate for teeth with pre-treatment diagnosis of irreversible pulpitis, a 89.3% success rate for teeth with a pre-treatment diagnosis of pulp necrosis, and an 85.7% success rate for teeth with a preoperative periapical radiolucency (2).

The Toronto Study (1,16) is a classic set of prospective studies that examined root canal success after 4-6 years. In phase 1 of the study, 405 teeth had nonsurgical root canal treatment performed by graduate students. Of the teeth initially treated, 277 teeth were able to be recalled at the 4-6 year recall date. The researchers found an overall success rate of 81%. The study found that the presence of a vital pulp prior to NS-RCT had a significantly higher success rate when compared to nonvital pulps. Furthermore, the absence of periapical radiolucency prior to NS-RCT had a significantly higher success rate when compared to presence of periapical radiolucency (1).

Phase III of the Toronto Study also examined the success of nonsurgical root canal treatment. In this phase of the study, 532 teeth were treated and 142 teeth were able to be recalled 4-6 years after treatment. Overall, the success rate of the treated teeth was 92%. Teeth without periapical radiolucency at the time of treatment had a success rate of 94%. Teeth with periapical radiolucency at the time of treatment had a success rate of 77%. The authors noted the other factors that seemed to influence success were tooth location (maxillary teeth had higher success rates compared to mandibular teeth) and restoration (teeth with permanent restorations had a higher success rate compared to those with temporary restorations) (16).

Finally, a prospective study be Sjogren et al (18) examined the success of nonsurgical root canal treatment 8-10 years after treatment was completed by undergraduate students. The study followed up on 356 teeth 8-10 years after treatment was completed. The overall success rate was 96% for vital teeth and 86% for necrotic teeth with periapical radiolucencies. The authors also found a significantly higher success rate in teeth where the filling reached within 2mm of the apex (94%) compared with those where the filling was more than 2mm short of the apex (68%) and those where the filling was beyond the apex (76%) (18).

From these studies on successful treatment outcomes , we are able to deduce that the teeth requiring root canal treatment have a better prognosis if they are without periapical radiolucency, have a permanent restoration, and the obturation material is within 2mm of the apex (1,3,16,18). Other studies have examined how the survival of endodontic treatment is impacted by the education of the provider (4,5,19). All general dentists are capable of providing nonsurgical root canal treatment to patients requiring this treatment. However, endodontists have two or more years of advanced training in the scope of endodontics. Endodontists also, generally, limit their practice to endodontics (15).

A study by Burry et al. (4) examined the survival of endodontically treated teeth when treated by endodontists compared to the survival of endodontically treated teeth when treated by other dental providers. The authors found that endodontists completed 31.5% of nonsurgical root canal treatment and other dental providers completed 68.5% of nonsurgical root canal treatment. The authors also found that molar root canal treatment completed by endodontists had a significantly higher survival rate (89%) when compared to molar root canal treatment completed by other providers (85%) at 10 years post-operative (4).

Another study by Alley et al. (19) compared the 5 year survival rates of teeth endodontically treated by endodontists versus general dentists. They included 350 root canal treated teeth for analysis: 195 completed by general dentists and 155 completed by endodontists. The authors in this study found that endodontists had a 98.1% success rate when compared to an 89.7% success rate of general dentists (19).

Finally, a large retrospective study by Lazarski et al. (5) examined the survival rates of teeth endodontically treated by endodontists and general dentists. 44,613 root canal treated teeth with a minimum of 2 years of follow up were included in the study with endodontists completing 14,718 (33%) of the cases and general dentists completing 29,895 (67%) of the cases. The overall survival rate was 90.6% with no statistically significant difference between the two groups. Endodontists completed significantly more molar root canals when compared to general dentists. The authors concluded that even though endodontists were completing more difficult cases, their survival rates were similar to general dentists (5).

In conclusion, teeth that have undergone root canal treatment can be evaluated for success or survival. Survival rates have been documented at 97% (3). Success rates for endodontically treated teeth have been documented between 81-96% (1,2,16,17). One item these success and survival outcome studies have in common is the age range of the population studied. All of these studies have only examined the outcome of endodontic treatment in adults. No studies have examined the success or survival of root canal treatment in children.

Tooth Eruption and Root Development of First Molars and Incisors

On average, permanent teeth begin erupting into the dentition at 6 years of age with the eruption of the first molars and central incisors. Lateral incisors erupt shortly after by the age of 7. Development of the permanent tooth continues even after the eruption of the tooth into the mouth. A tooth is considered immature until root development and apical closure have been completed. Apposition of secondary dentin is the process that permits the continued root development and apical closure of the tooth. As a general rule of thumb, apical closure of the root occurs about three years after its eruption into the mouth. For the first molars and incisors, completion of root development is expected by age 10 (20). A study by Tarpomanov et al (21) confirmed the age at which root formation is complete in children. A summary of the age in which the tooth erupts as well as the age in which root formation is completed can be found in *Table 1 and 2*.

Table 1- Maxillary Eruption and Root Formation Patterns in the Permanent Dentition (20)

Maxillary	Eruption	Root Formation
Central incisor	7-8 yr	10 yr
Lateral incisor	8-9 yr	11 yr
Canine	11-12 yr	13-15 yr
1st Premolar	10-11 yr	12-13 yr
2nd premolar	10-12 yr	12-14 yr
1st molar	6-7 yr	9-10 yr
2nd molar	12-13 yr	14-16 yr

Table 2- Mandibular Eruption and Root Formation Patterns in the Permanent Dentition (20)

Mandibular	Eruption	Root Formation
Central incisor	6-7 yr	9 yr
Lateral incisor	7-8 yr	10 yr
Canine	9-10 yr	12-14 yr
1st Premolar	10-12 yr	12-13 yr
2nd premolar	11-12 yr	13-14 yr
1st molar	6-7 yr	9-10 yr
2nd molar	11-13 yr	14-15 yr

Treatment of Pulpally Involved Vital Immature Teeth

Pulp involvement in children due to caries or trauma is often very difficult to manage and treat due to incomplete root development. However, pulp involvement of permanent teeth in young children is very prevalent. A retrospective study found that 36.5% of children from Saudi Arabia aged 6-18 years had pulpal involvement of at least one tooth (6). Therefore, it is imperative clinicians know what treatment options are available for pulpally involved immature teeth.

When vital teeth with pulpal involvement present for treatment, vital pulp therapy can be used for treatment. Vital pulp therapy is treatment aimed at preserving and maintaining pulp tissue that has been compromised by trauma, caries, or restorative procedures in a healthy state (15). Vital pulp therapy includes direct pulp caps, partial pulpotomies, and full pulpotomies.

A direct pulp cap involves treatment of an exposed vital pulp by sealing the pulpal wound with a dental material such as calcium hydroxide or mineral trioxide aggregate (MTA) to facilitate the formation of reparative dentin and maintenance of a vital pulp (15). A pulp cap is recommended for asymptomatic immature teeth that have had mechanical or traumatic pulp exposures (22).

Historically, calcium hydroxide has been used as a direct pulp capping agent and is considered the “gold standard” (23). Calcium hydroxide has been shown to be antibacterial and will disinfect the superficial pulp creating a favorable healing environment (17). Calcium hydroxide has a high pH and will cause liquefactive necrosis of the superficial pulp. However, the deeper layers of the pulp will heal in the absence of bacteria, and a dentinal barrier will be laid down and result in pulpal healing (22). One disadvantage to using calcium hydroxide as a pulp capping agent is that it doesn't seal the exposure site. It has also been shown that the calcified barrier formed has tunneling defect in it, which can result in bacterial leakage into the pulp (22).

Pulp capping with calcium hydroxide has been shown to be successful in several studies. One retrospective study found an 87.5% success rate after 5 years (24). Another retrospective study including 204 teeth that were direct pulp capped with calcium hydroxide paste found an overall success rate of 59.3%. Those with a mechanical exposure had a 92.2% success rate, and those with a carious exposure had a 33.3% success rate (25).

Other materials recommended as direct pulp capping agents include calcium hydroxide pastes, such as Dycal, and MTA (22). Like calcium hydroxide, MTA also will cause a calcified barrier to be placed over the pulp. However, unlike calcium hydroxide, the calcified barrier laid after MTA has been placed does not have tunneling defects (26). One systematic review showed an overall 94.5% success rate when teeth with open apices were pulp capped with MTA (7). Another meta-analysis, concluded that, overall, pulp caps with MTA had a better prognosis than pulp caps with calcium hydroxide (23).

Pulp capping is also recommended for asymptomatic teeth with open apices that have been mechanically exposed. However, for teeth that have been cariously exposed, partial or full pulpotomy is recommended (22,27). A partial pulpotomy (Cvek pulpotomy) involves the removal of a small portion of the vital coronal pulp as a means of preserving the remaining coronal and radicular pulp tissues (15). A full pulpotomy involves removing the entire coronal pulp while leaving the radicular pulp intact (15).

In general, it has been shown that pulpotomies are very successful in immature teeth diagnosed with reversible pulpitis. A prospective study including 35 asymptomatic immature teeth that were cariously exposed and treated with partial pulpotomy had a 91.4% success rate. A randomized clinical trial found a 100% survival rate in teeth that received a pulpotomy after carious exposure at 12 months (9). A systematic review found that partial pulpotomies had a range of success from 82.1-100% and full pulpotomies had a range of success from 82.7-100% (7).

It is recommended that partial and full pulpotomies only be completed in teeth with open apices diagnosed with reversible pulpitis (7,22). However, some studies have examined the success of pulpotomies in teeth diagnosed with irreversible pulpitis. One clinical trial completed partial pulpotomies in teeth with reversible and irreversible pulpitis. The teeth with reversible pulpitis had a success rate of 93.5%. The teeth with irreversible pulpitis had a success rate of 66.7% (8). Another randomized controlled trial compared success rates of two different bioactive cements (MTA and Biodentine) when used in pulpotomies of teeth diagnosed with irreversible pulpitis. The overall success rate of the pulpotomies was 90% with no significant difference between the two cements (28). Overall, more research needs to be done to determine if treating immature teeth diagnosed as irreversible pulpitis with pulpotomies is a predictable treatment.

Treatment of Nonvital Immature Teeth

Treatment of nonvital immature teeth presents as a challenge for dental practitioners. Traditional non-surgical root canal treatment (NSRCT) relies on a closed root apex to pack gutta percha against. This is not possible in immature teeth because the root apices are open. Therefore, there is nothing to pack the gutta percha against. There are a few treatment options for children who present with nonvital pulps and immature apices: long-term apexification with calcium hydroxide, apical barrier technique with MTA, or regenerative endodontic procedures (29).

Apexification is a method to induce a calcified barrier in a root with an open apex (15). Historically, this procedure has been completed by repeatedly placing calcium hydroxide until a calcified barrier is noted at the end of the root. This is followed by placement of gutta-percha within the canal space (29). In a classic retrospective study, apexification with calcium hydroxide was completed in 431 teeth with immature apices. Success of apexification varied from 28-77%. The teeth in earlier stages of root development had more failures when compared with teeth in later stages of root development (30).

There are two main disadvantages related to apexification with calcium hydroxide: no increase in root length/thickness and decreased fracture resistance (29). An animal study compared the fracture resistance of teeth treated with calcium hydroxide for 100 days versus teeth treated with saline for 100 days. The authors found a significant decrease in fracture resistance of those teeth treated with calcium hydroxide (31). An in vitro study examined fracture resistance in teeth treated with calcium hydroxide for 30 days, calcium hydroxide for 180 days, or saline for 180 days. The study found a significant decrease in fracture resistance in teeth treated with calcium hydroxide for 180 days when compared to the other groups (32).

Apical barrier technique is a procedure that involves placement of a matrix in the apical region to prevent extrusion of endodontic filling materials in teeth with open apices (15). Mineral trioxide aggregate (MTA) is a material that has more recently been suggested for this technique (33). Historically, dentin chips, calcium hydroxide powder, and tricalcium phosphate have also been used for the technique with varying success rates (34,35).

Apical barrier technique using MTA involves accessing the tooth, cleaning & shaping the canals, and placing calcium hydroxide. After 1 week, the calcium hydroxide is removed and 3-4mm of MTA is placed at the apex of the root. A moist cotton pellet is placed for 3-4 hours. After the MTA has set, the cotton pellet is removed and the tooth is obturated with gutta-percha (33).

When the apical barrier technique using MTA has been utilized, the success rates appear to be very good. One study showed 90% of teeth treated this way were healing or had healed after apical barrier techniques with MTA were used (36). Another large retrospective study included 252 teeth treated using the apical barrier technique with MTA. The study found an overall success rate of 90% with an average follow-up of 21 months (37). While both of these studies report very high success rates, the main disadvantage to this technique is that no additional root length or thickness can be achieved (29). This leaves the treated teeth prone to fracture and early loss.

The third type of procedure that can be utilized in nonvital teeth with immature root apices is regenerative endodontics. Regenerative endodontics is a biologically-based procedure designed to physiologically replace damaged tooth structures, including dentin and root structures, as well as cells of the pulp-dentin complex (15). The main advantage of regenerative endodontic procedures compared with the other procedures discussed is that regenerative endodontics allows for the continued development of the root (38).

The treatment protocol for regenerative endodontic procedures involves accessing the tooth, followed by working length determination with a loose-fitting file. Once working length is achieved, the canals are irrigated with 1.5% NaOCl and 17% EDTA. Canals are dried and calcium hydroxide or triple antibiotic paste (TAP) is placed in the canals. After 2-4 weeks, the tooth is anesthetized with an anesthetic that does not contain epinephrine. The intracanal medicament is removed with 17% EDTA and the canals are dried. Bleeding is induced in the canals by instrumenting with a small file beyond the apex of the tooth. Once a blood clot is established within the canal, Collaplug is placed on top of the clot and 3mm of MTA is placed. A 3-4mm thick layer of glass ionomer is then placed over the MTA followed by a composite resin restoration (38).

Several case reports, case series, and retrospective studies examining success of regenerative endodontic procedures have been published. A retrospective study comparing apical barrier techniques and regenerative endodontic procedures showed that regenerative endodontic procedures result in significantly more root length and thickness (39). A case series showed success of regenerative endodontic procedures in 8 patients 1-5 years after treatment (10). Another case report showed healing of a periapical radiolucency and increased root length and thickness associated with a maxillary central incisor 30 months after regenerative endodontic procedures were completed (11).

In summary, teeth in children with pulpal involvement due to caries, trauma, or other reason have several treatment options that are dependent on the pulpal diagnosis. In vital teeth, partial or full pulpotomies can be completed. In necrotic teeth, apical barrier technique or regeneration are treatment options. All these techniques have been shown to have good outcomes in endodontic literature (7, 9, 10-11, 36-37). When these treatment modalities cannot be utilized, NSRCT is the treatment of choice. However, NSRCT in children is challenging due to the complex root anatomy, incomplete root development, and difficult behavioral management often witnessed in children.

MATERIALS & METHODS

The data for this study was obtained via insurance enrollment and claims data from Delta Dental of Wisconsin. The dataset contained demographic information on enrollees, start and end dates of dental insurance coverage, as well as all dental claims with date of service, and procedures performed. The database contained patient encounters that occurred between the years of 2002-2014. The database was searched for children 6-13 years of age who received nonsurgical root canal treatment (NSRCT) on permanent first molars (#3, 14, 19, 30) or permanent incisors (#7, 8, 9, 10, 23, 24, 25, 26) as denoted by the appropriate Current Dental Terminology (CDT) code. For the CDT codes searched for NSRCT on permanent first molars and permanent incisors, please reference *Table 3.*

Table 3- Initiating Event CDT codes

ROOT CANAL	CDT CODE
Anterior NSRCT	D3310
Molar NSRCT	D3330

The database search for NSRCT completed on permanent incisors and first molars yielded 4927 teeth in 4433 unique children aged 6-13 years. As with the study by Burry et al (4), information regarding the provider type and tooth type was collected for each procedure. Provider type included endodontist, pediatric dentist, and non-endodontic/non-pediatric specialists. Endodontist was defined as those who completed an American Dental Association accredited endodontic residency program. Similarly, pediatric dentist was defined as those who completed an American Dental Association accredited pediatric dentistry residency program. Non-endodontic/non-pediatric specialists included all dental providers who had not completed either a pediatric or endodontic residency program and will, from here on, be referred to as "other providers".

The teeth were followed from time of treatment until completion of the study, loss of enrollment in the insurance program, or occurrence of any untoward events. Untoward events were defined as extraction, nonsurgical retreatment, or apical surgery. Untoward events were tracked via the appropriate CDT code. *Table 4* contains the unique CDT codes that were used to define untoward events. As with the study completed by Lazarski et al (5), the occurrence of any untoward event after initial NSRCT indicated failure of the tooth. Likewise, the lack of any untoward event at the completion of the study period or loss of insurance enrollment indicated survival of the tooth.

Table 4- Untoward Event CDT Codes

UNTOWARD EVENT	**CDT CODE**
Retreatment of previous root canal therapy	D3346 D3348
Apicoectomy	D3410 D3425
Extraction	D7140 D7210

Kaplan-Meier analysis was completed. Plots and survival estimates at 1-, 5-, and 10-years were provided for each variable of interest including age (6-9 years vs 10-13 years), provider type (endodontist, pediatric dentist, other provider), and tooth location (maxillary first molar, mandibular first molar, maxillary central/lateral incisor, mandibular central/lateral incisor). Cox proportional hazards regression was used to compare survival distributions between categories for each predictor and the p-value from robust score test was obtained. Analyses were performed using SAS 9.4 (SAS Institute, Cary, NC) and R version 3.6.3. A significance level (alpha) of $p< 0.05$ was used throughout all analyses.

RESULTS

The data set contained information of 4927 teeth in 4433 unique children aged 6-13 years old who had nonsurgical root canal treatment (NSRCT) between the years of 2002-2014. Of the 4927 teeth included in the study, 2314 (47.0%) were anterior NSRCTs and 2613 (53.0%) were molar NSRCTs. There were 299 total failures (6.1%) noted. *Table 5* contains baseline data.

Table 5- Baseline Data

Variable	All (N = 4927)
CDT code	
3310: Anterior NSRCT	2314 (47.0%)
3330: Molar NSRCT	2613 (53.0%)
Event	
Censor	4628 (93.9%)
Fail	299 (6.1%)

The median age of the children and the time of treatment was 12 years with 576 (11.7%) of the root canals being completed in children aged 6-9 years and 4351 (88.3%) of the root canals being completed in children aged 10-13 years. Endodontists completed 1956 (39.7%) root canals, pediatric dentists completed 200 (4.1%) root canals, and other providers completed 2771 (56.2%) root canals. In reference to root canals completed by tooth location, 1612 (32.7%) were on mandibular first molars, 255 (5.2%) were on mandibular central/lateral incisors, 1001 (20.3%) were on maxillary first molars, and

2059 (41.8%) were on maxillary central/lateral incisors. *Table 5a* contains additional baseline data.

The survival of teeth 1 year after treatment was 99.25% [98.94%, 99.48%] with a total on 3744 teeth at risk. The survival of teeth 5 years after treatment was 91.27% [90.00%, 92.39%] with a total of 1354 teeth at risk. The survival of teeth 10 years after treatment was 82.66% [80.10%, 84.93%] with a total of 202 teeth at risk. *Figure 1* represents this data.

When examining the survival of teeth after NSRCT was completed by different providers, NSRCT completed by endodontists had a 99.53% survival at 1 year, 92.29% survival at 5 years, and 86.68% survival at 10 years. Likewise, NSRCT completed by pediatric dentists had a 100.00% survival at 1 year, 97.45% survival at 5 years, and 88.45% survival at 10 years. Finally, NSRCTs completed by other providers had a 99.01% survival at 1 year, 90.12% survival at 5 years, and 79.44% survival at 10 years. *Figure 2* displays this data. When comparing the outcomes of NSRCT completed by different providers, it was noted that endodontists had significantly better outcomes when compared to other providers (p=0.010) and pediatric dentists had significantly better outcomes when compared to other providers (p=0.035). However, no significant difference was noted when comparing pediatric dentists to endodontists (p=0.223). *Table 6* represents this data.

Table 5a- Baseline Data

Variable	All (N = 4927)
Age at NSRCT	
Mean (SD)	11.47 (1.46)
Median [Min, Max]	12.00 [6.00, 13.00]
Age at NSRCT	
6 - 9	576 (11.7%)
10 - 13	4351 (88.3%)
Provider	
Endodontist	1956 (39.7%)
Pediatric Dentist	200 (4.1%)
Non-endodontic/pediatric specialists	2771 (56.2%)
Tooth location	
Mandibular central incisors	207 (4.2%)
Mandibular first molars	1612 (32.7%)
Mandibular lateral incisors	48 (1.0%)
Maxillary central incisors	1815 (36.8%)
Maxillary first molars	1001 (20.3%)
Maxillary lateral incisors	244 (5.0%)
Tooth location	
Mandibular first molars	1612 (32.7%)
Mandibular central/lateral incisors	255 (5.2%)
Maxillary first molars	1001 (20.3%)
Maxillary central/lateral incisors	2059 (41.8%)
Tooth location	
Central/lateral incisors	2314 (47.0%)
First molars	2613 (53.0%)

Figure 1- Survival of teeth after NSRCT in children aged 6-13 years

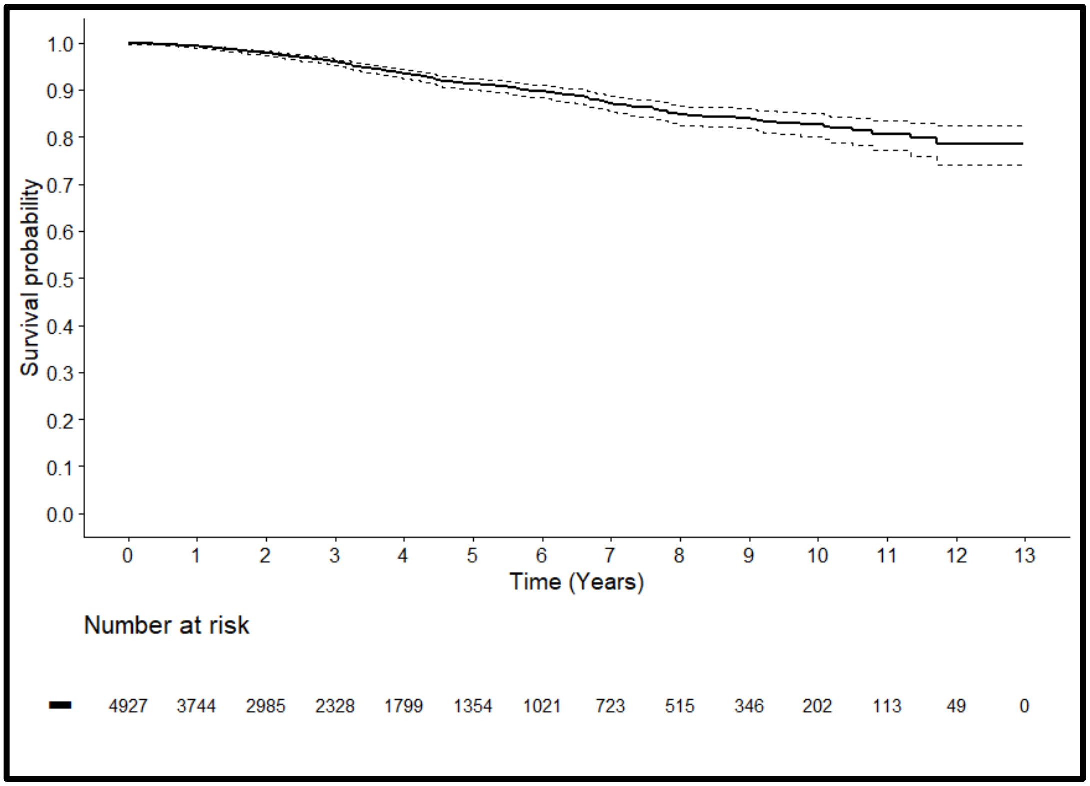

Figure 2- Survival of NSRCT in teeth completed by different providers

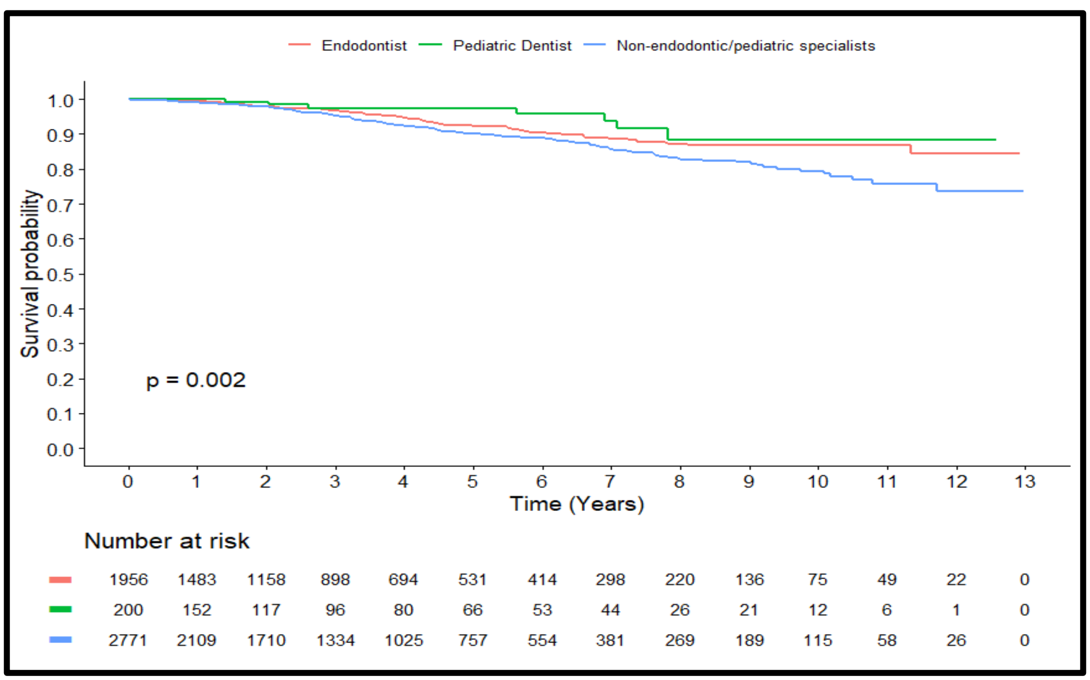

Table 6- Survival of NSRCT in teeth completed by different providers

Univariate (unadjusted) CoxPH Regression			
Variable	HR	95% CI	p-value
Provider (N = 4927, Events = 299)			
Endodontist vs. Non-endodontic/pediatric Specialists	0.72	[0.56, 0.92]	0.010
Pediatric Dentist vs. Non-endodontic/pediatric Specialists	0.45	[0.21, 0.95]	0.035
Pediatric Dentist vs. Endodontist	0.62	[0.29, 1.34]	0.223

When examining the survival of teeth after NSRCT based on tooth type, it was noted that mandibular first molars had a 99.24% survival 1 year after NSRCT, 87.68% survival 5 years after NSRCT, and 77.92% survival 10 years after treatment. Mandibular central/lateral incisors had a 99.09% survival 1 year after NSRCT, 95.46% survival 5 years after NSRCT, and 92.38% survival 10 years after NSRCT. Maxillary first molars had a 99.52% survival 1 year after NSRCT, 90.26% survival 5 years after NSRCT, and 78.97% survival 10 years after NSRCT. Maxillary central/lateral incisors had a 99.16% survival 1 year after NSRCT, 93.71% survival 5 years after NSRCT, and 86.17% survival 10 years after NSRCT. *Figure 3* shows this data. *Table 7* shows the survival rates when the different tooth types are compared. It should be noted that central/lateral incisors had significantly higher survival rates when compared to first molars.

Figure 4 shows the survival of teeth after NSRCT based on tooth type when endodontists provide the treatment. While maxillary and mandibular incisors have higher survival rates compared to maxillary and mandibular molars, this difference is not significant. *Table 8* shows the relevant p-values associated with this.

Figure 3- Survival of teeth after NSRCT by tooth type

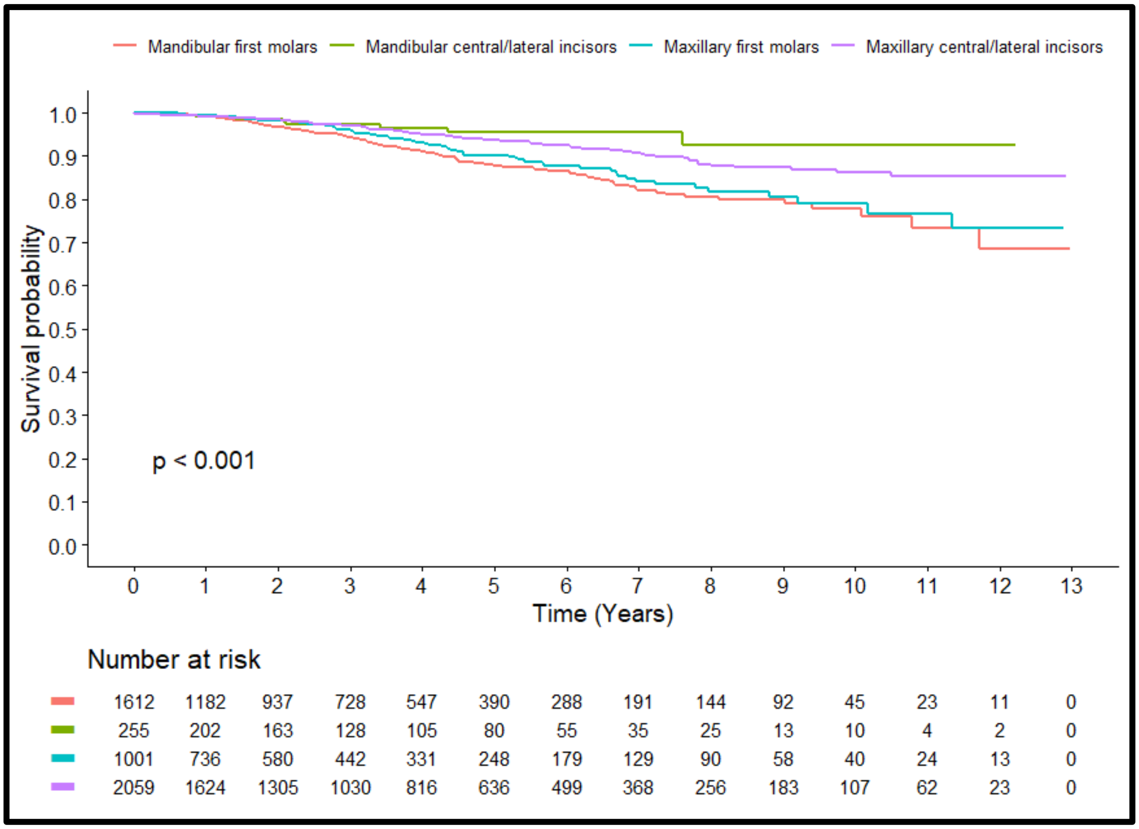

Table 7-Survival of teeth after NSRCT by tooth type

contrast	HR	95% CI	p-value
(Maxillary central/lateral incisors) / Mandibular first molars	0.55	[0.38 , 0.78]	<0.001
(Maxillary central/lateral incisors) / (Mandibular central/lateral incisors)	1.51	[0.58 , 3.95]	0.686
(Maxillary central/lateral incisors) / Maxillary first molars	0.66	[0.44 , 1.00]	0.052
Mandibular first molars / (Mandibular central/lateral incisors)	2.77	[1.07 , 7.20]	0.031
Mandibular first molars / Maxillary first molars	1.21	[0.82 , 1.80]	0.597
(Mandibular central/lateral incisors) / Maxillary first molars	0.44	[0.16 , 1.16]	0.131

Figure 4- Survival of teeth after NSRCT by tooth type treated by endodontists

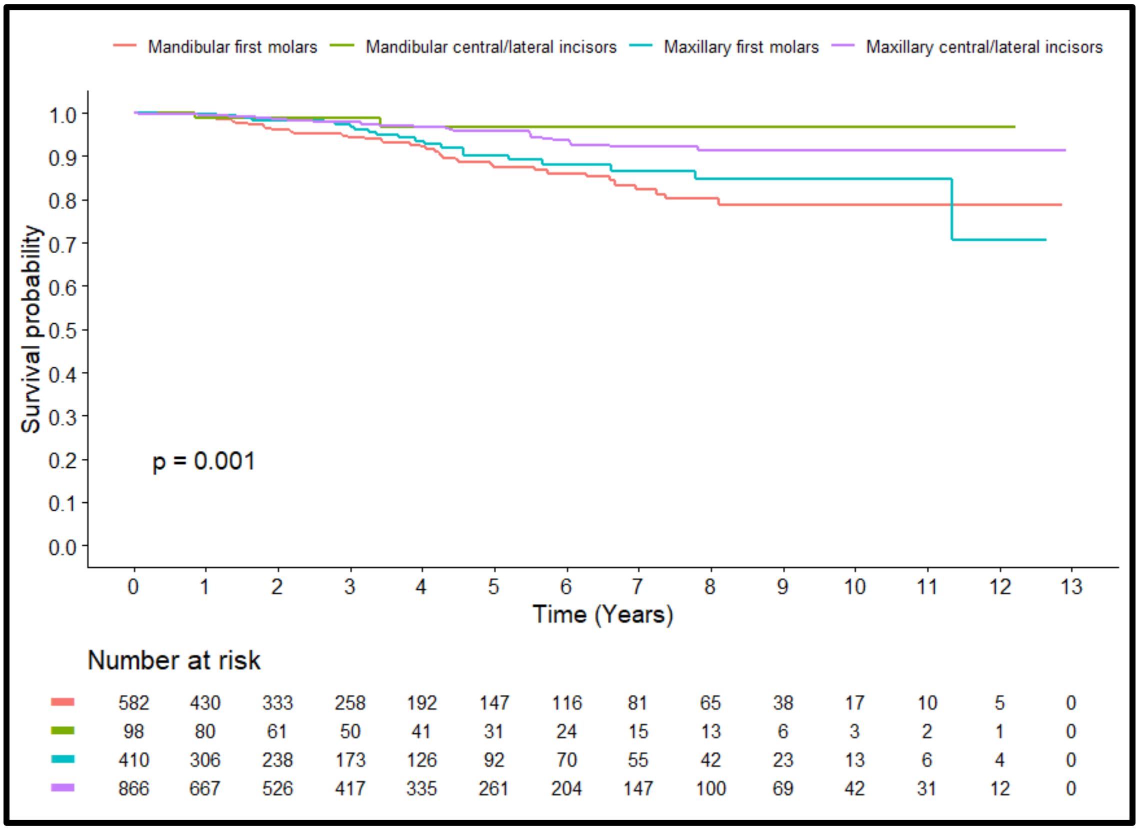

Table 8- Survival of teeth after NSRCT by tooth type treated by endodontists

contrast	HR	95% CI	p-value
Mandibular first molars / (Mandibular central/lateral incisors)	4.27	[0.64 , 28.29]	0.199
Mandibular first molars / Maxillary first molars	1.35	[0.69 , 2.65]	0.669
Mandibular first molars / (Maxillary central/lateral incisors)	2.45	[1.29 , 4.64]	0.002
(Mandibular central/lateral incisors) / Maxillary first molars	0.32	[0.05 , 2.17]	0.416
(Mandibular central/lateral incisors) / (Maxillary central/lateral incisors)	0.57	[0.08 , 3.88]	0.878
Maxillary first molars / (Maxillary central/lateral incisors)	1.82	[0.87 , 3.80]	0.161

Figure 5 shows data comparing survival of teeth after NSRCT when age is a factor. Teeth receiving NSRCT in children aged 6-9 had a survival of 99.15% after 1 year, 90.11% after 5 years, and 78.14% after 10 years. Teeth receiving NSRCT in children aged 10-13 years had a survival of 99.27% after 1 year, 91.40% after 5 years, and 83.20% after 10 years. As demonstrated in *Table 9,* although NSRCT completed in children aged 10-13 had a higher survival rate than NSRCT completed in children aged 6-9, this finding was not significant.

Figure 5- Survival of teeth after NSRCT by age group

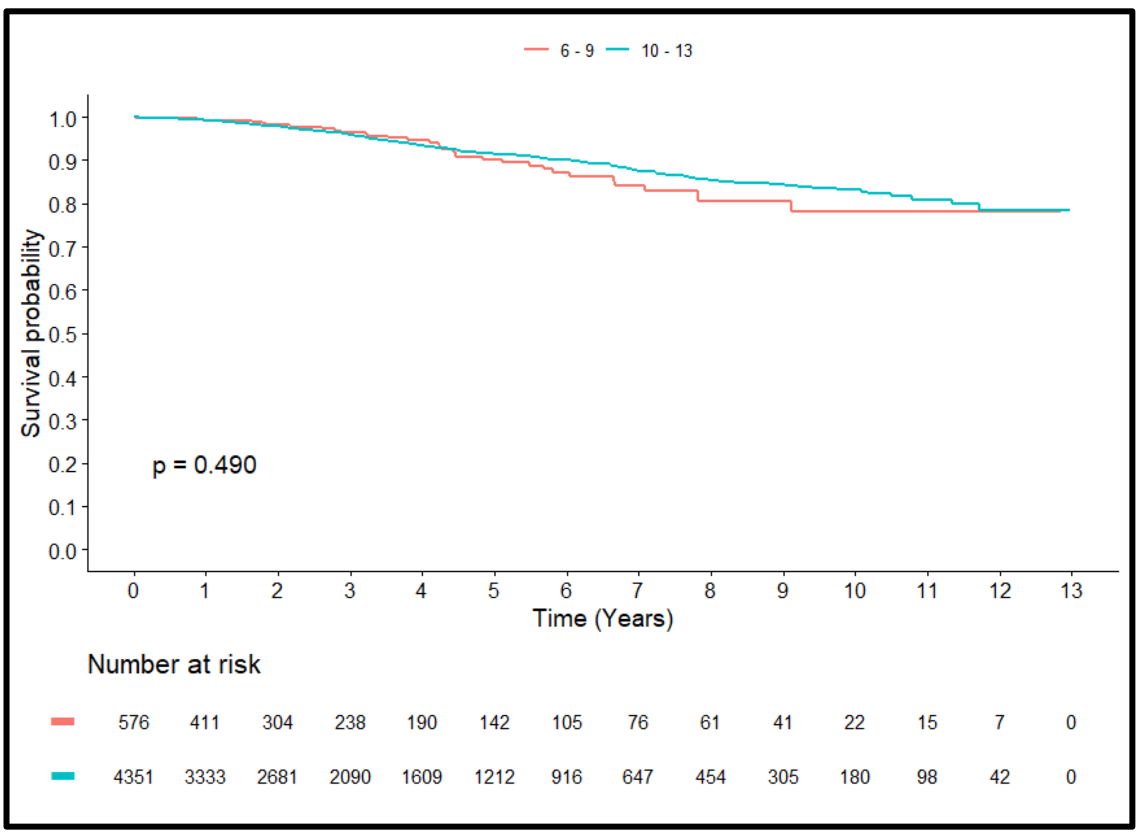

Table 9- Survival of teeth after NSRCT by age group

Univariate (unadjusted) CoxPH Regression			
Variable	HR	95% CI	p-value
Age (N = 4927, Events = 299)			
6 - 9 vs. 10 - 13	1.13	[0.80, 1.60]	0.490

DISCUSSION

Survival rates following nonsurgical root canal treatment are of importance both to providers as well as patients. Survival following endodontic therapy has been well-documented in endodontic literature in adult populations at 85-97% survival (3,4). However, to the best of our knowledge, no previous study has examined outcomes of endodontic therapy in children. Due to complex anatomy and incomplete root development, it is of utmost importance to understand outcomes of endodontic therapy to provide the best possible care for children who require this treatment (6). Therefore, the aim of this study was to determine the long-term outcomes of non-surgical root canal treatment in children aged 6-13 years.

This study found the survival rates of endodontically treated teeth in children are 99.25%, 91.27%, and 82.66% at 1-, 5-, and 10- years respectively. While these survival rates are high and therefore desirable, these outcomes have lower survival when compared to other similar studies in adult populations. An insurance based study in an adult population by Burry et al (4) found a survival of 86% at 10 years. Another insurance based study in an adult population found a 97% survival at 8 years (3). When comparing these findings of studies in adult populations to the findings of this study, it appears that root canal treatment in children has a lower survival than in adults. The reason for the lower survival may be explained by the aforementioned complex root anatomy and incomplete root development seen in children (6).

In terms of provider type, endodontists and pediatric dentists had significantly higher survival outcomes when compared to other providers ($p<0.05$, $p<0.05$). A possible explanation for why endodontists have higher survival outcomes when compared to other providers may be that endodontists have additional training in the field of endodontics. This may make endodontists more equipped to deal with the challenging anatomy and incomplete root development that we know is present in the teeth of children (6). Likewise, pediatric dentists may have higher survival outcomes when compared to other providers because they have advanced training in dealing with behavioral management in children.

Endodontists completed 39.7% of the treatment in this study, whereas, pediatric dentists completed 4.1% and other providers completed 56.2% of the treatment. Other insurance based studies that examined the effect of provider type in adult populations found endodontists completed around 32-34% of the treatment and other providers completed around 66-68% of the treatment (4,5). Based on this information, it can be inferred that other providers are referring more NSRCT in children to providers with more training. This may imply other providers are recognizing the challenging nature of the treatment in children and are, therefore, referring these cases to clinicians with more training.

It is of note that pediatric dentists have high survival rates, however, they only completed 4.1% of the NSRCTs in children. Due to their ability to provide treatment with high survival, pediatric dentists should provide more of this treatment to their patients. If necessary, additional training should be provided during the pediatric dentistry residency to increase provider acceptance of the treatment.

When comparing the effect of survival on tooth type, it is of note that, overall, NSRCT in incisors has better outcomes when compared to NSRCT in molars ($p<0.05$).

One possible explanation for this is that molars have more roots and more canals and, therefore, more complex anatomy when compared to incisors. Another possible explanation is that incisors, especially maxillary incisors, undergo more trauma when compared to molars (40). In teeth that undergo trauma, bacteria is not the primary reason NSRCT is a necessity. However, in teeth with caries, bacteria is the primary factor that necessitates NSRCT (41). This may play a role in the long-term survival of endodontically treated teeth and may be a reason anterior NSRCT is more successful than molar NSRCT.

When only endodontists' treatment is examined, tooth type does not appear to have as much of an effect on overall survival. While the trend still is that incisors have higher survival rates than molars, this finding is not significant when only endodontists provide the treatment. This indicates that endodontists may be capable of providing more consistent work regardless of tooth type.

Perhaps one of the more surprising findings of the study was the effect of age on survival of teeth treated with NSRCT. This study found no difference in survival of teeth treated with NSRCT in children aged 6-9 versus children aged 10-13. This was surprising due to the fact that the roots are still developing in children aged 6-9 (20). Therefore, the treatment is expected to be more challenging and as such, the survival rates were expected to be worse. Perhaps a reason the survival rates were not different in the two age groups is due more to the behavioral management challenge. Children aged 10-13 may also be difficult to manage behaviorally, making treatment more challenging on providers and preventing adequate work necessary for long-term survival.

Insurance-based retrospective studies have several advantages, namely related to size and, thus, power of study. The study size also serves to limit potential bias that could be present. However, insurance-based studies have limitations mainly associated with inability to examine certain prognostic factors we know impacts survival after endodontic treatment. Such prognostic factors include pretreatment diagnosis (with necrotic teeth with periapical lesions having a lower survival compared to teeth with irreversible pulpitis), restorability of the tooth, presence of final restoration being placed, and obturation material within 2mm of the radiographic apex (1,3,16,18).

Another important limitation of this study is that only survival can be evaluated. Success is impossible to determine from insurance-based studies. This is because in order to be considered “successful” the tooth in question must be free of patient symptoms and have a healing or healed periapex with no periapical radiolucency (14). These criteria are impossible to assess without access to patient records and radiographs.

In summary, the primary focus of this study was to determine outcomes of primary endodontic treatment in children by different providers. While the survival is not as high as in adults, it appears that endodontic therapy in children still results in high survival rates. Given this data, it is up to the clinician on how these cases should be managed based on experience/willingness to provide treatment, restorability of the tooth, and patient preference. Given that endodontists and pediatric dentists have higher survival rates compared to other providers, referring children requiring root canal treatment to a provider with advanced training may be indicated.

CONCLUSION

This is the first insurance-based study that aimed to assess the survival of primary endodontic treatment in children when delivered by different providers. Regardless of provider, survival of root canal treatment in children is high at 82.66% at the 10-year mark. This implies NSRCT is a good treatment option in children pending provider treatment acceptance, patient treatment acceptance, and tooth restorability. Given the fact that endodontists and pediatric dentists have significantly higher survival rates when compared to other providers, referring pediatric endodontic cases to providers with more advanced training should be considered.

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