



Analyzing Prognostic Factors of Root Canal Treatment at HSDM AGE Endodontics

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“Analyzing Prognostic Factors of Root Canal Treatment at HSDM AGE Endodontics”

A Thesis Presented by Jennie Kim
to
The Faculty of Medicine
In partial fulfillment of the requirements
for the degree of
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I. Abstract

The objective of this study was to evaluate preoperative, intraoperative, and postoperative factors influencing outcomes of primary root canal treatment (RCT) performed by postgraduate residents at Harvard School of Dental Medicine (HSDM) Advanced Graduate Education (AGE) Endodontics between 2018 and 2024.

Patient charts were reviewed from the axiUm electronic dental record system. 367 cases with both treatment and recall codes were identified, and 250 had confirmed recall visits with appropriate periapical radiographs. After excluding cases with less than six months of follow-up, 122 cases were included, comprising 89 retrospective and 33 prospective recalls.

Periapical status was assessed using the Periapical Index by two blinded examiners, and cases were classified as success (healed/healing) or failure (non-healed) based on radiographic and clinical criteria. Univariable associations were evaluated using chi-square or Fisher's exact tests and t-tests, and selected variables were analyzed in a Firth penalized logistic regression model. Time-to-failure was analyzed using Kaplan–Meier and Cox proportional hazards models.

The overall success rate was 80.3% (98/122), with a tooth survival rate of 99.2% (121/122). Inter-examiner agreement was high ($\kappa = 0.85$). In univariable analyses, satisfactory coronal restoration, apical extent of gutta-percha filling, absence of symptoms at first recall, and higher provider year were associated with success. In the multivariable Firth model, absence of symptoms at recall (OR 0.01; 95% CI 0.001–0.06; $p < 0.001$) and satisfactory coronal restoration (OR 5.11; 95% CI 1.17–30.48; $p = 0.029$) remained significant predictors, whereas provider year was not independently associated with outcome. The model demonstrated excellent discrimination (AUC = 0.936). In the Cox model, satisfactory coronal restoration was associated with a 75% reduction in hazard of failure (HR 0.25; 95% CI 0.09–0.70; $p = 0.01$).

Within this postgraduate training setting, primary RCT demonstrated favorable outcomes. Coronal restoration quality and symptoms at first recall visit were the strongest predictors of success, highlighting the importance of achieving an adequate coronal seal and closely monitoring symptomatic patients. Longer-term, standardized follow-up is needed to better assess treatment durability and prognostic factors.

II. Introduction

The goal of a root canal treatment is to prevent or eliminate apical periodontitis of endodontic origin (Burns 2022). The success of root canal treatment has been analyzed by many endodontic scholars, including Strindberg (Strindberg 1956) and Ng (Ng et al. 2007, 2008) who have noted several treatment factors likely influence outcomes. Different outcomes of interests of root canals have been studied. Researchers that are interested in analyzing prognostic factors have typically focused on radiographic and clinical signs of resolution of periapical

disease (Ng et al. 2007). Patients typically focus on the resolution of symptoms (Bender et al. 1966a, b), the functionality of the treated tooth (Friedman & Mor 2004), and the impact on quality of life (Dugas et al. 2002). For health planning professionals and dental insurers, outcomes like the longevity of root canal fillings or treatments (Cheung 2002; Cheung & Chan 2003; Stoll et al. 2005; Lumley et al. 2008; Tickle et al. 2008) and tooth retention or survival (Lazarski et al. 2001; Salehrabi & Rotstein 2004) are often of greater interest. Traditionally, the success of root canal treatments has been assessed based on signs and symptoms of periapical healing.

Key prognostic indicators identified by Ng et al. include the presence of preoperative periapical lesions, the quality and apical extent of the root filling, and the status of the final coronal restoration. They also found that the aggregated success rates of primary root canal treatment with a minimum of one year of follow-up ranged from 68% to 85% (Ng et al., 2007). Success rates have been defined by absence of symptoms and radiographic healing. Employing a 'strict' success criterion (with complete healing of periapical pathology), an overall success rate of 74.7% was observed while 'loose' success criterion (with reduction in size of radiolucency), yielded a success rate of 85.2% (Ng et al., 2007).

Despite these analyses, there remains a need to understand how these factors specifically influence outcomes within different educational and clinical settings. While retrospective studies have been used to investigate factor influence on periapical healing after RCT, most of these studies describe outcomes from RCT performed by general practitioners or by endodontists. This study solely investigates cases treated by postgraduate students, allowing for evaluation of the postgraduate teaching–learning process, as well as the efficacy of the endodontic clinical activity. The Harvard School of Dental Medicine (HSDM) Advanced Graduate Education (AGE) endodontics program offers a unique environment for such a study due to its diverse patient population and advanced training protocols and education. Additionally, assessing the factors affecting the outcome of primary root canal procedures performed by AGE endodontic residents at HSDM, while comparing these factors to those reported in the literature, will provide valuable insights into the efficacy of current treatment protocols and aid in clinical decision-making. The findings of this study may be used to identify potential areas for improvement in the AGE endodontics program at HSDM and to optimize training for endodontic residents. Success of root canal treatment for this study will be measured by signs and symptoms of periapical healing (Pirani 2015). The study will also analyze the prognostic factors for periapical healing following root canal treatment (Pirani 2015).

The aim of this study is to investigate the preoperative, intraoperative, and postoperative factors that influence clinical success in teeth that underwent primary root canal treatments from 2018-2024 in patients treated by postgraduate students at Harvard AG Endodontics.

The hypothesis is that the outcome of primary root canal procedures among residents at Harvard AGE Endodontics is influenced by factors including but not limited to good coronal restoration, year of resident, use of orifice barrier, apical extent of root canal filling, and presence and size of pre-operative periapical radiolucency.

III. Approach:

Patient data were obtained from the axiUm electronic dental records system. Charts were systematically reviewed to identify patients who had documented endodontic recall visits, designated by the procedure code D3999R (Endodontic Recall), between 2018 and 2024. From this cohort, patients who had undergone primary root canal therapy coded as D3310 (anterior), D3320 (premolar), or D3330 (molar) during the same period were selected for inclusion.

Figure 1: Sample Selection

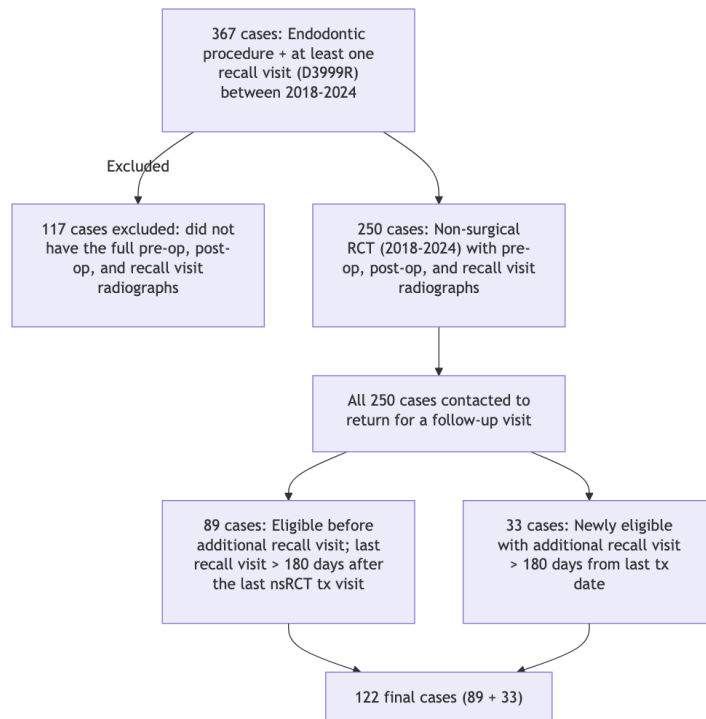


Figure 1 illustrates how the sample was selected for this study. A list of all patient cases who had both endodontic treatment and recall codes (the “bundled” codes) between 2018 and 2024 was generated, resulting in approximately 367 cases. Each of these patient records was reviewed in axiUm to confirm the presence of an actual recall visit with documented clinical notes and appropriate periapical radiographs (PAs). After this initial screening, 250 cases met these criteria. Patients with less than six months of recall data were excluded, resulting in 89 cases with a minimum recall period exceeding six months.

Subsequently, all 250 eligible patients were contacted and invited to return to the Harvard School of Dental Medicine for an in-person follow-up examination. Of these, 33 cases attended in-person recall visits, although a larger number scheduled appointments but did not attend. Thus, the final sample included 89 retrospective recalls and 33 prospective recalls, yielding a total of 122 cases with follow-up periods of at least six months.

Inclusion criteria consisted of mature permanent teeth that received primary root canal therapy between 2018 and 2024 at the Harvard School of Dental Medicine (HSDM) by an advanced graduate endodontic resident. Eligible cases required documented follow-up visits containing detailed clinical notes pertaining to the tooth of interest. Follow-up documentation could originate from different providers. Periapical radiographs were required at both the treatment and recall appointments, allowing accurate identification of the radiographic apex. Only cases with a minimum follow-up interval of six months were included.

Exclusion criteria included cases lacking comprehensive documentation or periapical radiographs that did not include accurate assessment of the radiographic apex at any appointment. Teeth with vertical root fractures noted at time of consultation or at treatment visits, or those affected by periodontal disease or previous root canal treatment were excluded.

Clinical notes were reviewed for documentation of endodontic diagnostic testing, including cold testing, percussion, palpation, and probing depth measurements, as well as the presence or absence of symptoms. The type and quality of the coronal restoration were recorded. Periapical radiographs were evaluated, and the diameter of any periapical lesion was measured.

Data variables collected included referral type (internal or external), diabetes status (yes/no), ASA classification (I–V), tooth type (anterior or posterior; coded as 1 = mandibular right posterior, 2 = mandibular anterior, 3 = mandibular left posterior, 4 = maxillary right posterior, 5 = maxillary anterior, 6 = maxillary left posterior), pulp vitality (vital or non-vital), presence of preoperative pain, sinus tract, number of visits, provider level at the initial treatment (first-, second-, or third-year resident), occurrence and type of intraoperative complications (e.g., perforation, instrument separation), preoperative CBCT acquisition (yes/no), quality of the coronal restoration at follow-up (adequate or inadequate), post placement (yes/no), presence of periapical radiolucency (PARL) preoperatively and at recall, preoperative PAI score, apical extent of root canal filling (1 = >2 mm short, 2 = 0–2 mm from apex, 3 = extrusion), presence of sealer puff, and use of an orifice barrier (yes/no).

All periapical radiographs were analyzed using the Periapical Index (PAI) system as described by Orstavik et al. Radiographic and clinical criteria were used to categorize treatment outcomes into two main groups:

- Success (Healed or Healing):
 - Healed: Teeth were functional and asymptomatic, with radiographs demonstrating normal periapical structures (PAI 1).
 - Healing: Teeth were functional and asymptomatic, with radiographs showing a reduction in the size of the preexisting periapical radiolucency (PAI of 1,2, or 3 that remained stable).
- Failure (Non-Healed):

- Non-Healed= Teeth that were symptomatic or nonfunctional, regardless of radiographic findings, or asymptomatic teeth with new, enlarged, or unchanged (from pre-op PAI score of 4 or 5) periapical radiolucencies. Spontaneous or provoked pain was classified as a symptom; however, isolated tenderness to percussion or palpation was not considered indicative of failure.

PAs were independently evaluated by two examiners who were blinded to all study information. Each examiner assigned PAI scores based solely on the radiographs. Discordant scores were later identified and resolved through a third independent examiner.

For analysis, a correlation matrix was first generated to visualize relationships among all collected variables and treatment outcome. Then, chi-squared tests or independent t-tests were conducted to assess the presence of statistically significant associations between individual variables and outcome; Fisher's exact test was applied when categorical cell sizes were insufficient for chi-squared assumptions. Variables demonstrating significant associations and clinical relevance were included in a Firth penalized regression model to estimate the magnitude and direction of their associations with the outcome. Odds ratios and F1 scores were calculated from the fitted model. Model performance was additionally compared with a random forest classifier to evaluate potential non-linear relationships. A survival analysis was then conducted to examine time-to-event outcomes.

IV. Results

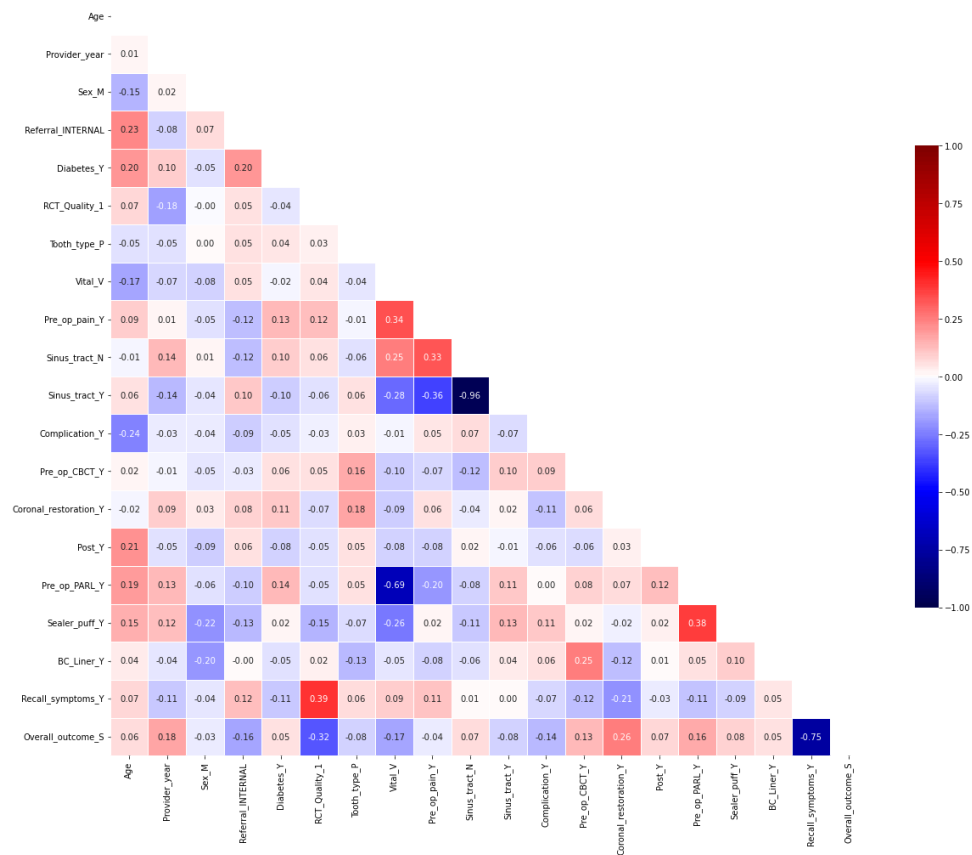
Overall treatment outcomes and reliability

Of 122 patients, the success rate of non-surgical RCTs was found to be 80.33% (98/122) and a failure rate of 19.67% (24 /122). Survival rate (retention of the tooth regardless of disease status) was found to be 99.2% (121/122). Of 122 periapical radiograph sets, only 11 PAI change scores were initially discordant between the two examiners, resulting in a high overall agreement of 90.9%. The corresponding Cohen's kappa was 0.85, indicating strong inter-examiner reliability. Discrepancies were resolved through a third party examiner.

Correlation analysis

A correlation matrix was generated for all predictors and the overall outcome (Figure 2). Overall outcome showed a strong negative correlation with recall symptoms ($r = -0.75$). Correlations between overall outcome and all other predictors were weak ($|r| \leq \sim 0.26$). Correlations among the remaining predictors were generally low to moderate, indicating no substantial multicollinearity.

Figure 2: Correlation Matrix for Predictors and Outcome



Univariable analyses

Chi-square tests or Fisher's exact tests and independent t-tests were used to assess univariable associations with treatment outcome.

Table 1: Contingency Table for Coronal Restoration

Contingency table for Coronal_restoration vs Overall_outcome:		
Overall_outcome	F	S
Coronal_restoration		
N	17	38
Y	7	60
Chi-squared test p-value: 0.0093		
All expected counts ≥ 5. Chi-squared test results are valid.		

Table 2: Contingency Table for Root Canal Quality, or Apical Extent of Filling

Contingency table for RCT_quality vs Overall_outcome:			
Overall_outcome	0	1	
RCT_quality			
1	3	0	
2	18	95	
Chi-squared test p-value: 0.0029			
Expected cell counts:			
[[0.54310345 2.45689655]			
[20.45689655 92.54310345]]			
Some expected counts < 5. Running Fisher's Exact Test.			
Fisher's Exact Test p-value: 0.0052			

Table 3: Contingency Table for Symptoms at First Recall Visit

Contingency table for Recall_symptoms vs Overall_outcome:			
Overall_outcome	F	S	
Recall_symptoms			
N	7	94	
Y	14	1	
Chi-squared test p-value: 0.0000			
Expected cell counts:			
[[18.28448276 82.71551724]			
[2.71551724 12.28448276]]			
Some expected counts < 5. Running Fisher's Exact Test.			
Fisher's Exact Test p-value: 0.0000			

Table 4: Contingency Table for Provider Year (1st and 2nd year combined vs. 3rd year)

Contingency table for Provider_year vs Overall_outcome:			
Overall_outcome	F	S	
Provider_year			
1,2	21	63	
3	3	35	
Chi-squared test p-value: 0.0290			
All expected counts $\geq$ 5. Chi-squared test results are valid.			

Tables 1–4 present the contingency tables for coronal restoration status, root canal quality (apical extent of filling), symptoms at first recall visit, and provider year (first- and second-year providers combined vs. third-year providers). All four variables were significantly associated with outcome (all $p < 0.05$).

The presence of a satisfactory coronal restoration at follow-up was significantly associated with root canal treatment outcomes ($p = 0.0093$) (table 1). Root canal quality, assessed by the apical extent of gutta-percha (GP) filling, was significantly associated with outcome. All cases in which the GP filling terminated more than 2 mm short of the radiographic apex (underfilled canals) resulted in treatment failure (100% failure; $n = 3$). Cases with GP fillings extending beyond the apex (overfills) were observed in six cases, with three successes and three failures (50% failure rate). Because of the small cell counts and complete separation, apical extent was only summarized descriptively and not included in multivariable models (table 2). The presence of symptoms at the first recall visit was significantly associated with outcome ($p < 0.001$) (table 3).

When provider year was dichotomized into first- and second-year providers versus third-year providers, a statistically significant difference in success rates was observed ($\chi^2(1) = 4.84$, $p = 0.029$) (table 4). Success rates were 75.0% (63/84) for years 1–2 and 92.1% (35/38) for year 3 (table 5).

Table 5: Provider Year Crude Analysis

Provider Year	Failures (F)	Success (S)	Total	Success Rate
1-2	21	63	84	75.0%
3	3	35	38	92.1%

Patient- and treatment-related variables showed no statistically significant associations with overall treatment outcome in unadjusted analyses (all $p > 0.05$). Sex at birth was not associated with success ($p = 0.6114$), with 80 females and 42 males demonstrating success rates of 81% and 79%, respectively. Referral sources showed a non-significant trend ($p = 0.1109$), with 61 internally and 61 externally referred patients, and success rates of 74% and 87%, respectively. Diabetes status was not significantly associated with outcome (Fisher's exact $p = 0.6782$), with 8 patients with diabetes having an 88% success rate compared to 80% among 114 non-diabetic patients. ASA classification (1 ASA III, 52 ASA II, 69 ASA I) was also not associated with success ($p = 1.0000$), with success rates of 100%, 79%, and 81% for ASA III, II, and I, respectively. Tooth type (3 anterior, 119 posterior) did not demonstrate a significant association with outcome (Fisher's exact $p = 1.0000$), although success was 100% in anterior teeth and 80% in posterior teeth. Pulp vitality status was also not significant ($p = 0.2504$), with 65 vital and 57 non-vital teeth, and success rates of 74% and 88%, respectively. Pre-operative pain (77 with pain, 45 without) was not associated with outcome ($p = 0.6492$), with success rates of 79% and 82% in painful and non-painful cases, respectively. Presence of a sinus tract (108 yes, 14 no) was likewise non-significant (Fisher's exact $p = 0.3302$), with success of 71% versus 81% for cases with and without a sinus tract, respectively.

The number of treatment visits showed no statistically significant association ($p = 0.0932$), although cases completed in 1, 2, and 3 visits (75, 38, and 9 cases, respectively) had success rates of 75%, 87%, and 100%. Intra-operative complications were uncommon (4 cases vs. 118 without) and not significantly associated with outcome (Fisher's exact $p = 0.2532$); success was 50% with complications versus 81% without. Having a pre-operative CBCT (62 yes, 60 no) was not associated with success ($p = 0.2568$), with success rates of 85% and 75%, respectively. Post placement (10 yes, 112 no) was also non-significant (Fisher's exact $p = 1.0000$), with success rates of 90% versus 79%.

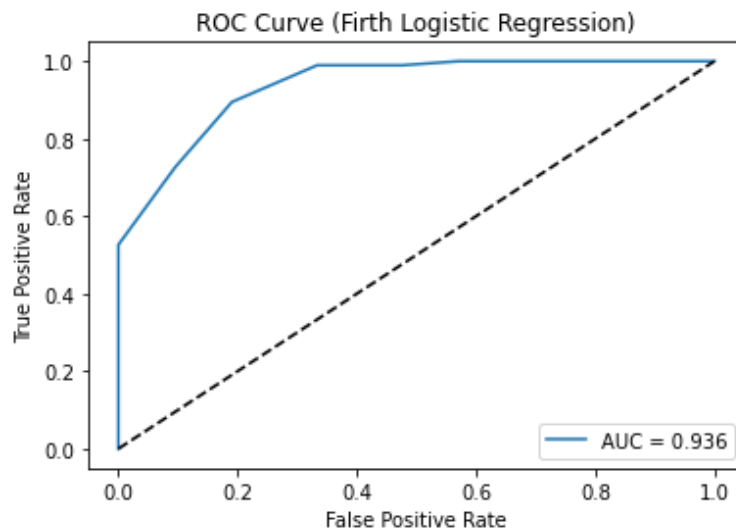
Radiographic variables similarly did not reach statistical significance in univariable analyses. The presence of a pre-operative periapical radiolucency (60 yes, 62 no) was not associated with

outcome ($p = 0.2112$), although success was higher in teeth with a pre-operative lesion (87%) than in those without (74%). Pre-operative PAI score, analyzed as a continuous predictor from 1 to 5, was not significantly associated with failure ($p = 0.824$); the odds ratio was 1.04 (95% CI, 0.76–1.40), indicating that each 1-point increase in PAI corresponded to only a 4% increase in the odds of failure. The presence of a sealer puff (56 yes, 66 no) showed no significant association ($p = 0.1724$), with success rates of 84% versus 77%. Similarly, use of an orifice barrier (50 yes, 72 no) was not significantly related to outcome ($p = 0.5406$), with success of 64% compared with 78% in teeth without an orifice barrier.

Multivariable Firth penalized logistic regression

In order to quantify the strength and direction of association between predictors and outcome, a Firth penalized logistic regression was used to address class imbalance. Predictor variables were selected based on the events-per-variable (EPV) principle. The final model assessed variables including coronal restoration status, provider year, presence of symptoms at recall, and referral status. Quality of root canal filling, or apical extent of filling was unable to be used due to issues of complete separation.

Figure 3: Firth Logistic Regression ROC Curve



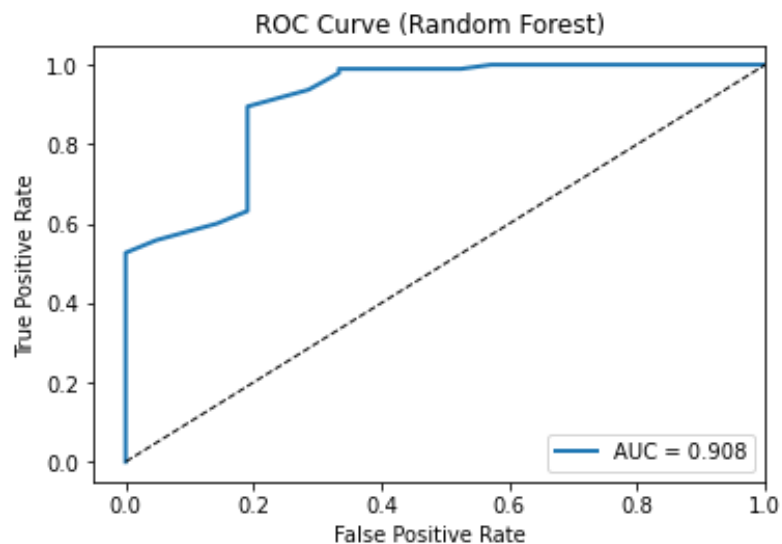
The model showed strong overall performance ($F1 = 0.959$, $AUC = 0.936$, $accuracy = 0.931$), with high sensitivity (Figure 3).

Table 6: Firth Logistic Regression Analysis

Variable	Coefficient	Odds Ratio (OR)	95% CI for OR	p-value
Intercept	0.02	1.02	0.04 – 15.59	0.987
Referral	-0.93	0.39	0.08 – 1.67	0.206
Recall symptoms	-4.38	0.01	0.001 – 0.06	<0.001 *
Provider year	1.85	6.37	0.80 – 157.47	0.086
Coronal restoration	1.63	5.11	1.17 – 30.48	0.029 *

A random forest model trained on the same predictors achieved a mean cross-validated F1 score of 0.928 (Figure 4), which was lower than that of the Firth model (figure 4).

Figure 4: Random Forest Model ROC Curve

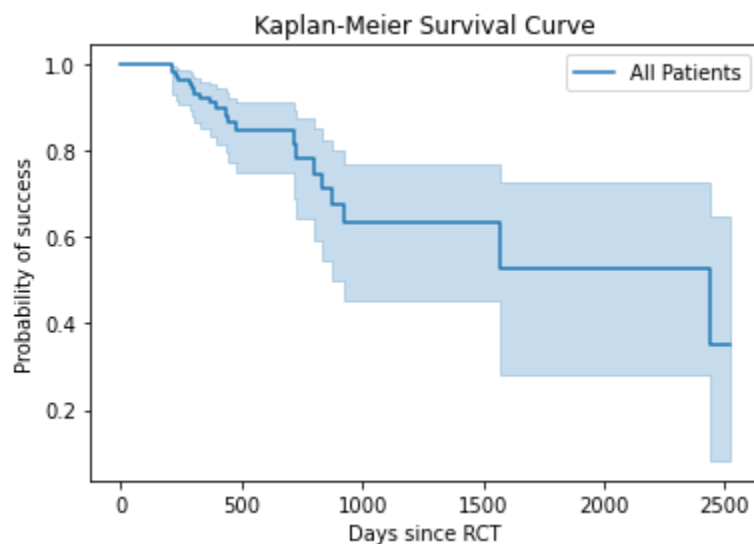


Random Forest mean CV ROC AUC: 0.9082105263157895
Random Forest mean CV F1: 0.9284236231604652
Random Forest mean CV Sensitivity: 0.9157894736842106
Random Forest mean CV Specificity: 0.76

Time-to-event analysis

Kaplan–Meier survival analysis was conducted and demonstrated that the majority of root canal treatments remained successful over time, with failures occurring gradually rather than all at once. The overall survival curve showed a steady decline in probability, indicating that long-term success decreases progressively with time (figure 5).

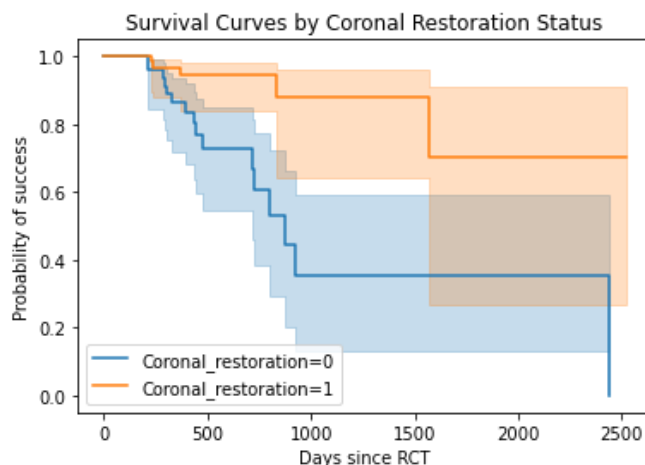
Figure 5: Kaplan–Meier Survival Analysis



When stratified by coronal restoration, teeth without a proper restoration failed more rapidly, whereas cases with a proper restoration maintained higher survival probabilities throughout follow-up, highlighting the positive impact of a proper coronal restoration after RCT.

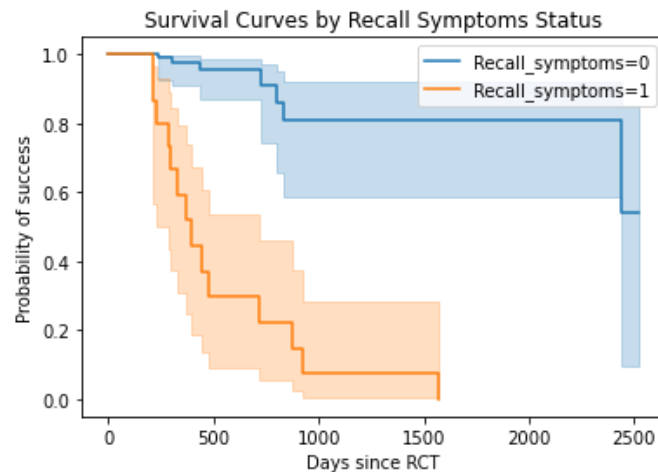
The stepwise pattern of the curves reflects prolonged periods without events for most patients, and widening confidence bands at later time points indicate increased uncertainty due to smaller numbers of patients remaining under observation. Overall, the data suggest sustained treatment durability across the cohort, strongly influenced by coronal restoration status.

Figure 6: Kaplan–Meier Survival Analysis Stratified by Coronal Restoration Status



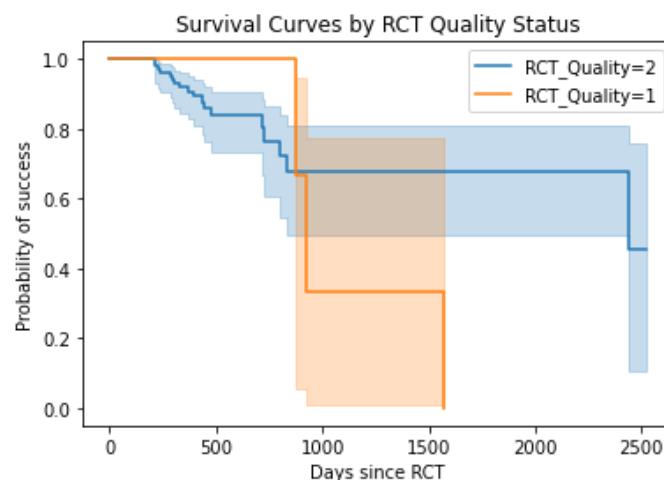
Stratification by recall symptoms showed an even clearer effect. Patients with reported symptoms at first recall visits experience very rapid declines in survival, with failure rates increasing sharply within the first year. In contrast, asymptomatic patients maintain high success probabilities for far longer.

Figure 7: Kaplan–Meier Survival Analysis Stratified by Symptoms at First Recall Visit



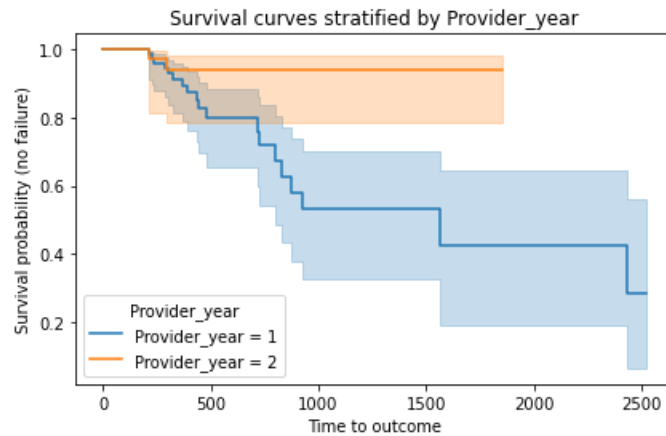
Cases with GP filling >2mm from radiographic apex (underfilled teeth) were associated with poorer survival compared to those with GP filling 0-2mm from apex, particularly beyond the first year of follow-up. Cases where GP Filling was extruded past the radiographic apex were not included due to sparse data (wide confidence interval) and unstable estimates that could produce misleading statistical contrasts, and was therefore reported descriptively only.

Figure 8: Kaplan–Meier Survival Analysis Stratified by Root Canal Quality or Apical Extent of Filling



When stratified by provider year (1= years 1 and 2, and 2= year 3) survival curve shows that cases treated by year-3 providers maintain a very high probability of remaining failure-free over the entire follow-up, with almost no drop in survival, whereas cases treated by year-1 + 2 providers experience earlier and more frequent failures.

Figure 9: Kaplan–Meier Survival Analysis Stratified by Provider Year



Cox proportional hazards model

A Cox proportional hazards model was used to account for differences in follow-up time and to evaluate how clinical variables influenced the timing of root canal treatment failure, rather than failure status alone.

Table 7: Cox Proportional Hazards Model

covariate	coef	HR (exp(coef))	95% CI (HR)	p
Referral	0.31	1.36	0.54 -3.44	0.51
Coronal Restoration	-1.41	0.25	0.09 -0.70	0.01 *
RCT Quality	0.34	1.41	0.38 -5.19	0.60
Provider year	-0.93	0.40	0.09 -1.80	0.23

Externally referred cases had an estimated 36% higher instantaneous hazard of failure than internally referred cases; however, the confidence interval was wide and included 1, indicating that this association was not statistically significant. In contrast, the presence of a satisfactory coronal restoration was associated with approximately a 75% lower hazard of failure at any time point compared with teeth lacking an adequate coronal restoration, and this effect was statistically significant. Teeth with gutta-percha fillings more than 2 mm short of the radiographic

apex demonstrated an estimated 41% higher hazard of failure than those with fillings 0–2 mm from the apex, but the confidence interval was wide and crossed 1, providing no clear evidence of a true effect. Treatment rendered by third-year providers was associated with an estimated 60% lower hazard of failure compared with treatment by first- and second-year providers; however, the confidence interval included 1, and this trend did not reach statistical significance (table 7).

Follow-up time and failure patterns

Success rates by follow-up period are shown in table 8. Success was 75% for 6 months–1 year, 83% for >1 year, and 80% for >3 years. Failures were further classified into radiographic versus symptomatic failures (table 9). Causes of treatment failure were also explored (figure 10), and subsequent management of failures (e.g., retreatment, apicoectomy, extraction) is summarized in figure 11.

Table 8: Success Rates by Follow-up Period

Follow-up Period	Count	% of Patients	Success Rate
6 mo – 1 yr	40	32.79%	0.75
>1 yr	72	59.02%	0.83
>3 yr	10	8.20%	0.80

Table 9: Assessing Failures

Failures with F (radio) and N (symptoms):	5
Failures with S (radio) and Y (symptoms):	9
Failures with F (radio) and Y (symptoms):	7
Failures with S (radio) and N (symptoms):	3
Total failures	24

Figure 10: Bar Graph of Inferred Treatment Failure Causes

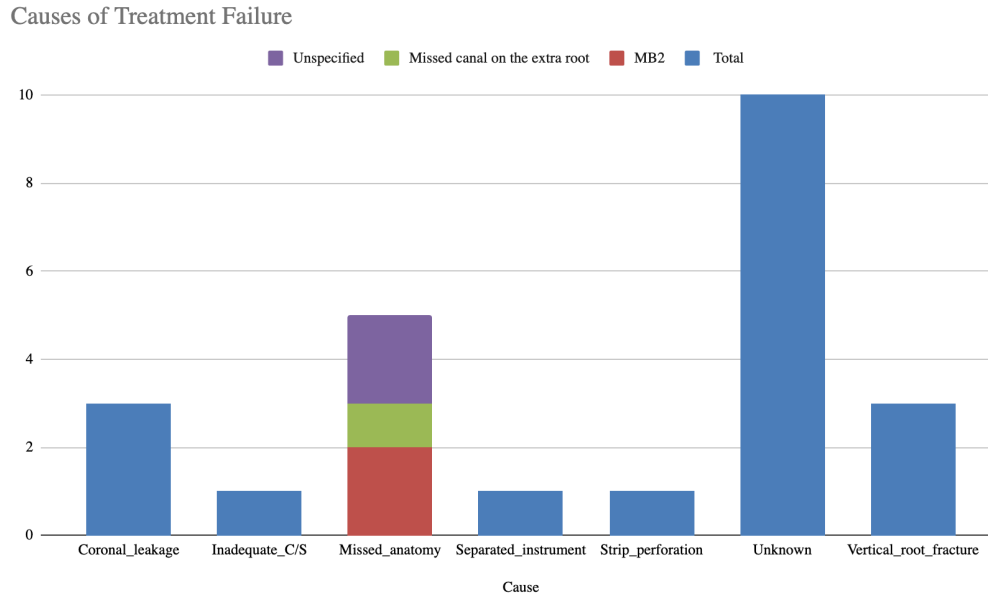
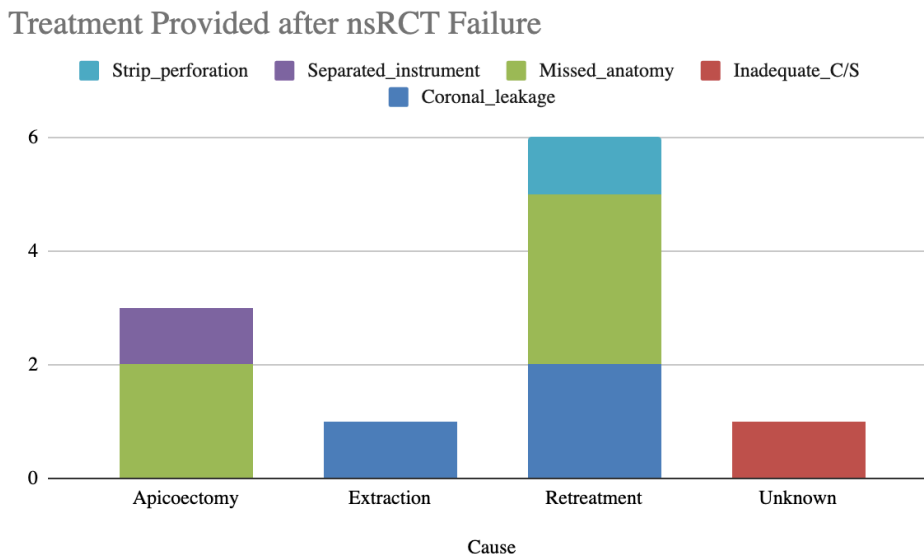


Figure 11: Bar Graph of Treatment Provided after RCT Failure



X

V. Discussion and future direction

This study demonstrated a success rate of 80.3% and tooth survival rate of 99.2% following primary non-surgical RCT in a postgraduate endodontic residency program. These outcomes are consistent with endodontic literature. Burns et al. (2022) reported pooled success rates of 92.6% using a loose criterion (reduction in radiolucency size) and 82.0% using a strict criterion (complete periapical healing). Similarly, Ng et al. (2007) found aggregated strict and loose

success rates of approximately 74.7% and 85.2%, respectively. The high inter-examiner reliability ($\kappa = 0.85$) in this study also supports the robustness of the radiographic outcome assessment.

Across multiple analyses, coronal restoration status and symptoms at first recall visit emerged as the most consistent predictors of outcome. The significant association between satisfactory coronal restoration and both higher success rates and lower hazard of failure aligns with extensive evidence that coronal sealing is critical for preventing reinfection and maintaining long-term success. Systematic reviews (Ng et al. 2007) and longitudinal observational studies (Yee et al. 2018) have consistently identified coronal restoration quality as a critical postoperative determinant of periapical healing and tooth survival, with any delays or deficiency in restoration increasing adjusted hazard of failure.

Similarly, the strong association between symptoms at first recall visits and failure suggests that early post-treatment symptomatology may serve as a clinically meaningful indicator of compromised prognosis. Long-term outcome studies (Ng et al. 2007) illustrate that persistent symptoms at recall visits are among the major negative prognostic indicators.

Apical extent of filling showed patterns suggestive of poorer outcomes with underfilled canals. However, these results were limited by sparse data and complete separation for some categories, which prevented full inclusion in multivariable models and resulted in wide, imprecise confidence intervals. Larger samples are needed to confirm if these trends represent true underlying effects.

Although unadjusted success rates were higher among third-year residents, provider year was not independently associated with outcomes after adjustment. Nevertheless, from a clinical standpoint, increased experience may still contribute to improved RCT outcomes.

Several potential reasons may have contributed to the observed failure rate. One important consideration is the use of the PAI index and the decision to classify lesions that remained at scores 4 or 5 as failures. The interpretation of radiographic “failure” must be considered in light of established healing timelines. Previous studies indicate that many periapical lesions require at least 6–12 months to show radiographic signs of healing, that only about half of lesions that ultimately heal demonstrate radiographic improvement at 6 months, and that complete radiographic resolution may take up to several years (Orstavik 1996). In the present study, 5 of the 24 failures were classified solely on radiographic criteria in asymptomatic patients, and 4 of these had follow-up between 6 months and 2 years. It is therefore possible that some of these cases represent incomplete or delayed healing rather than true biological failure, which may partly explain the observed failure rate.

The failed cases were examined further to infer possible contributing factors and subsequent management. Likely contributors included coronal leakage, missed canals, inadequate cleaning and shaping, instrument separation, strip perforation, and vertical root fracture, although for many cases no definitive cause could be identified (figure 10). These inferences are limited by

the retrospective nature of the review and incomplete documentation. Management strategies after failure included nonsurgical retreatment, apicoectomy, and, less frequently, extraction (figure 11).

This study has a few limitations. The overall sample size, especially the number of failures, was small, which reduced statistical power and the precision of effect estimates for some variables. Follow-up duration varied, and some cases were assessed within the first year after treatment, when radiographic healing may be incomplete. This may have led to misclassification of some healing lesions as failures. Additionally, the retrospective design introduces the possibility of information bias. Finally, the study was conducted in a single academic institution, which may limit the generalizability of findings to other clinical settings or postgraduate training programs.

Future research should address these limitations by increasing sample size and extending follow-up duration to better capture the full course of periapical healing. Prospective, multi-center studies with standardized recall intervals and detailed procedural documentation would allow more robust evaluation of prognostic factors, including provider experience, apical extent of filling, and specific intra-operative complications.

VI. Conclusion

Primary root canal treatment performed by postgraduate residents demonstrated generally favorable outcomes within an academic training environment, with an overall success rate of 80.3%. The strongest predictor of treatment failure was the presence of symptoms at the first recall visit, highlighting the importance of following up with symptomatic patients. The presence of a satisfactory coronal restoration significantly improved the odds of treatment success by approximately fivefold and was also associated with enhanced long-term durability, reducing the hazard of failure by nearly 75% in time-to-event analysis. Although crude success rates were higher among third-year residents, provider year was not independently associated with treatment outcomes after multivariate adjustment. Nonetheless, clinically, increased experience may still contribute to improved performance and outcomes.

VII. References

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