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Beyond Root Canal Success: Impact of Periodontal Health and Crown Rehabilitation on the Prognosis of Endodontically Treated Teeth: A Prospective Cohort Study

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Abstract

Background: Periodontal support and definitive crown rehabilitation may influence outcomes following root canal treatment (RCT). Composite clinical-radiographic success, complete periapical healing, and tooth survival are distinct endpoints.

Objective: To compare 12-month composite clinical-radiographic success across four combinations of baseline periodontal status and subsequently assessed crown quality following primary RCT of posterior teeth, and to explore additional endodontic and restorative associations.

Methodology: This prospective observational cohort comprised 240 adults, each undergoing primary nonsurgical RCT of one posterior tooth with planned crown rehabilitation. Of these, 204 completed the 12-month follow-up. Periodontal indices were evaluated at baseline and at three, six, and 12 months. Longitudinal changes were assessed using repeated-measures analysis of variance (ANOVA) with the Greenhouse-Geisser correction; exploratory associations with treatment failure were examined using Firth penalized logistic regression.

Results: Among 204 participants with 12-month outcomes, 168 (82.4%) met the composite success definition and 36 (17.6%) experienced failure. Complete radiographic healing occurred in 111 (54.4%), with ongoing healing in 47 (23.0%). Composite success ranged from 86/91 (94.5%) in the favorable-periodontal/adequate-crown group to 20/35 (57.1%) when both were compromised ($\chi^2 = 25.89$, $df = 3$; $P < 0.001$). The adjusted odds of failure were higher with compromised baseline periodontal status (odds ratio (OR) = 5.43, 95% confidence interval (CI) = 2.27-12.98) and compromised crown quality (OR = 3.39, 95% CI = 1.45-7.92). All five periodontal parameters showed significant time effects (Greenhouse-Geisser-corrected $P < 0.001$).

Conclusions: Baseline periodontal status and subsequently assessed crown quality were associated with 12-month composite outcomes after RCT. Given the observational design, sparse failures and short follow-up, these findings should not be interpreted as causal effects or evidence of long-term tooth survival.

Categories: Therapeutics, Dentistry

Keywords: crown rehabilitation, endodontic outcome, periapical healing, periodontal health, root canal treatment, tooth survival

Introduction

Primary root canal treatment (RCT) aims to eliminate pulpal infection, control apical periodontitis, and retain a functional tooth [1]. Prognosis must be interpreted in relation to the outcome being measured. A tooth may remain functional and free of symptoms while its periapical radiolucency is still resolving; hence clinical-radiographic stability, complete periapical healing, and long-term tooth survival are not interchangeable [2]. A practice-based study of more than 71,000 root canal-treated teeth reported longer median survival when a crown was placed, although this survival endpoint differs from complete osseous healing [3].

Periodontal attachment loss and inflammation have been associated with apical disease and tooth loss in observational studies [4,5]. Definitive coronal rehabilitation may reduce leakage and provide structural protection, while delays in restoration have been associated with poorer tooth retention in other cohorts

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[6,7]. Recent clinical work has highlighted the combined relevance of periodontal measures and coronal restoration quality [8].

However, many reports are retrospective or cross-sectional and use heterogeneous definitions of clinical success, periapical healing, and tooth survival. The primary objective of the present prospective cohort was to compare 12-month composite clinical-radiographic outcomes across four strata defined by baseline periodontal status and subsequently assessed crown quality. Secondary, exploratory objectives were to assess other treatment factors, longitudinal periodontal measurements, and effect modification on the multiplicative odds-ratio scale. No causal effect of crown status is assumed because its exact timing relative to failure requires documentation.

Materials And Methods

Study design and ethical considerations

This prospective observational cohort study followed posterior teeth receiving primary nonsurgical RCT, with examinations scheduled at baseline and at three, six, and 12 months. Reporting followed the STROBE recommendations [9]. The study protocol received ethical approval from the Institutional Ethics Committee of Dental College and Hospital, Kerala (HMCH/172/Ethics/2024), in accordance with the Declaration of Helsinki. Due to logistical considerations, participant recruitment and clinical follow-up were subsequently conducted at Hi-Tech Dental College and Hospital, Bhubaneswar, Odisha, where the requisite institutional ethical permission was obtained from the Institutional Ethics Committee (HMCH/IEC/2024/172, approved April 27, 2024). Participants were recruited from June 2024 to June 2025, and follow-up continued through June 2026 to complete the 12-month assessment of the last enrolled participant. Written informed consent was obtained from all participants. Treatment was provided as part of routine clinical care and was not altered for study purposes. Participant confidentiality was maintained throughout.

Study Population and Sample Size

Adults aged at least 18 years requiring primary nonsurgical RCT of a restorable premolar or molar planned for definitive full-coverage crown rehabilitation were eligible. Retreatment cases, teeth with vertical root fracture, nonrestorable coronal destruction, and hopeless periodontal prognosis were excluded. One tooth per participant was included, and 240 participants were enrolled consecutively. Sample size planning assumed a 15-percentage-point difference in 12-month success between two broad prognostic categories (90% vs. 75%), a two-sided α of 0.05 and 80% power, with allowance for approximately 15% attrition. This calculation was not specifically powered for the final four-group, eight-predictor or interaction analyses.

Endodontic Treatment Protocol

Primary nonsurgical RCT was performed for all 240 index teeth by two calibrated endodontists, each with more than 10 years of clinical experience. Treatment was completed under rubber dam isolation. Working length was determined with an electronic apex locator (Root ZX, J. Morita Mfg. Corp., Kyoto, Japan) and confirmed radiographically. Canals were instrumented with ProTaper Next rotary nickel-titanium files (Dentsply Sirona, Charlotte, NC), generally to size X3 or X4 according to canal anatomy. Irrigation used 5.25% sodium hypochlorite and 17% ethylenediaminetetraacetic acid (EDTA) with ultrasonic activation. Obturation was performed by warm vertical compaction of gutta-percha with AH Plus sealer (Dentsply Sirona), followed by provisional composite restoration before definitive crown placement. Postoperative radiographs were used to classify root fillings as adequate when dense, void-free, and ending 0-2 mm short of the radiographic apex, or inadequate otherwise. Remaining coronal tooth structure, documented after caries and defective-restoration removal, was classified as preserved when at least two sound axial walls of at least 2 mm in height remained and limited otherwise. Treatment procedures and technical classifications were cross-checked against the clinical case record forms, radiographic logs, and departmental treatment registries.

Time from RCT completion to definitive full-coverage crown cementation was established from dated treatment logs and categorized as ≤ 120 or > 120 days. Crown quality was assessed clinically and radiographically two weeks after cementation using marginal adaptation, proximal contacts, static and dynamic occlusion, and structural integrity; a defect in any of these features resulted in a compromised classification. Crown assessments were performed relative to each tooth's actual cementation date, rather than assigning a uniform three-month assessment to teeth restored after that visit. The cementation intervals and quality classifications were cross-checked against the restorative records. Because crown quality was a post-treatment measure and its assessment did not necessarily precede every clinical event, the regression analysis treated it as an observational exposure associated with the 12-month outcome, not a baseline causal predictor.

Periodontal Measurements and Classification

Periodontal examinations were conducted by two calibrated periodontists who were blinded to endodontic and restorative outcomes. Interexaminer agreement for categorical assessments was reported as Cohen's κ =

0.88. At six sites around each index tooth, probing pocket depth (PPD) and clinical attachment level (CAL) were measured in millimeters; bleeding on probing (BOP) and plaque-positive sites were expressed as percentages, and gingival inflammation was scored using a 0-3 gingival index. Tooth mobility was graded using the Miller index, and furcation involvement was assessed using Glickman's classification [10,11]. Radiographic alveolar bone loss was recorded as a percentage of root length. Baseline periodontal categories were determined from the complete site-level clinical assessment and radiographic findings: 144 teeth were classified as favorable and 96 as compromised.

Favorable periodontal status required PPD ≤ 3 mm at each site, CAL/attachment loss ≤ 2 mm, tooth mobility no greater than Miller grade I, no furcation involvement, and radiographic alveolar bone loss $< 15\%$ of root length. Periodontal status was classified as compromised when one or more specified abnormalities were present (PPD ≥ 4 mm, attachment loss ≥ 3 mm, Miller mobility grade II or higher, Glickman furcation grade II or higher, or bone loss $\geq 15\%$). Tooth-level mean PPD, CAL, and BOP were additionally evaluated as continuous baseline measurements; these averages summarize different information than the multicriterion category and were not used alone to assign periodontal status.

Radiographic Assessment and Composite Outcome

Standardized two-dimensional periapical radiographs were taken using the paralleling technique with a beam-aiming device at baseline and during follow-up. At 12 months, periapical radiographic status was classified as healed (complete resolution of the radiolucency), healing (decreased but persistent radiolucency), unchanged, or worsened. The primary outcome was composite clinical-radiographic success, defined as an asymptomatic, functional, retained index tooth without radiographic lesion progression, retreatment, periapical surgery, or extraction. Failure was coded for persistent index-tooth symptoms, radiographic progression, retreatment, periapical surgery, or extraction. This composite endpoint was distinguished from complete radiographic healing and long-term tooth survival.

Each of the 36 composite failures was adjudicated using the clinical case report forms and radiographic records and assigned one mutually exclusive primary manifestation for reporting: nonsurgical retreatment ($n = 11$), extraction ($n = 10$), persistent index-tooth symptoms ($n = 10$), or persistent/worsening periapical radiolucency ($n = 5$). Three initial discrepancies between electronic symptom flags and the index-tooth composite classification (study IDs 16, 18, and 24) were resolved through senior-author review of the dated clinical notes and periapical radiographs. The documented symptoms arose from adjacent, non-index teeth; the treated index teeth were asymptomatic at the outcome assessment, negative to percussion and palpation, and radiographically nonprogressive. The index-tooth composite success classifications were therefore retained. Extraction indications were not separately categorized in the analysis dataset.

Follow-Up, Missing Data, and Statistical Analysis

The enrolled cohort comprised 240 participants; the attendance registers and clinical case report forms documented that 225 attended at three months, 214 at six months, and 204 completed all scheduled visits through 12 months. The primary-outcome and Firth regression analyses were restricted to the 204 participants with documented 12-month outcomes (36 failures); no outcomes were imputed for the 36 noncompleters. Baseline descriptive analyses used all 240 records. Repeated-measures analyses included only the 204 participants with documented attendance and observed measurements at baseline and at three, six, and 12 months. Electronic measurements associated with visits recorded as missed were excluded, regardless of the values displayed in those cells. No imputation was applied in the reported outcome or longitudinal analyses. These were complete-case analyses and should not be interpreted as multiple-imputation analyses.

Continuous variables were summarized as mean $\pm$ standard deviation (SD) and compared between outcome groups using Welch's t-test. Categorical variables were compared using Pearson's chi-square test or Fisher's exact test, as appropriate. The within-subject effect of time across baseline and three, six, and 12 months was tested using one-factor repeated-measures analysis of variance (ANOVA) for PPD, CAL, BOP, plaque-positive sites, and gingival index. Mauchly's test assessed sphericity. Because sphericity was violated for all five indices (each $P < 0.001$), Greenhouse-Geisser-adjusted numerator and denominator degrees of freedom and corresponding P values were reported. Friedman tests were additionally used as rank-based sensitivity analyses. All longitudinal comparisons used the recorded complete-visit cohort; values for missed visits were excluded.

Associations with treatment failure were examined using Firth penalized-likelihood logistic regression [12-14]. Eight clinically selected binary indicators were entered into the exploratory main-effects model: baseline periodontal status, post-treatment crown quality, crown timing, root filling quality, remaining coronal structure, smoking, diabetes, and baseline periapical lesion. With 36 failures, the model had approximately 4.5 events per predictor. Odds ratios (ORs), approximate Wald 95% confidence intervals (CIs), and two-sided Wald P values were calculated from a Jeffreys-information-penalized likelihood fit using Python (version 3.13.5) and SciPy (version 1.17.0). A separate nine-parameter model added a periodontal-status $\times$ crown-quality product term to evaluate multiplicative interaction. All analyses were considered exploratory owing

to the limited number of failure events.

Results

Participant recruitment and baseline characteristics

Of the 240 participants enrolled, 225 (93.8%) attended the three-month review, 214 (89.2%) attended the six-month review, and 204 (85.0%) completed the 12-month follow-up (Figure 1). The 36 participants without a documented 12-month endpoint were excluded from outcome analyses. The proportion of participants with diabetes was higher among noncompleters (10/36, 27.8%) than among completers (28/204, 13.7%), suggesting potential attrition bias. The overall composite success proportion among all 240 enrollees would range from 168/240 (70.0%), if all noncompleters were assumed to have failed, to 204/240 (85.0%), if all noncompleters were assumed to have succeeded. These values represent sensitivity bounds, not imputed estimates.

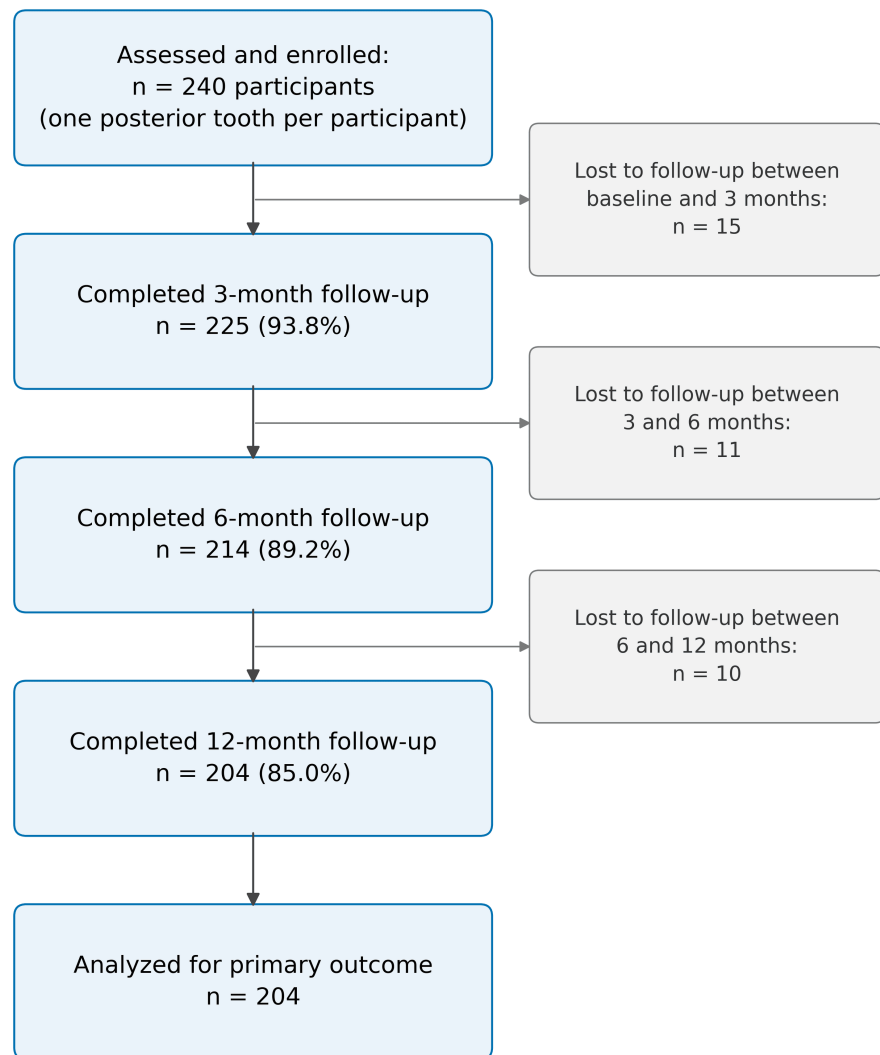


FIGURE 1: Participant recruitment and follow-up flow.

Boxes show the number of participants (n) enrolled and remaining at each assessment interval, while side boxes show the number of participants lost to follow-up between consecutive visits. The 204 participants who completed the 12-month visit constituted the complete-case primary outcome analysis set. No imputation was performed for participants lost to follow-up.

The mean age was 44.9 ± 11.7 years, and 126 (52.5%) participants were female. Molars comprised 59.2% of treated teeth, and baseline periapical radiolucency was present in 107 (44.6%). Baseline characteristics are summarized in Table 1.

Characteristic	Value
Participants/teeth	240
Age, years, mean ± SD	44.9 ± 11.7
Female	126 (52.5%)
Male	114 (47.5%)
Current smoker	34 (14.2%)
Diabetes	38 (15.8%)
Premolar	98 (40.8%)
Molar	142 (59.2%)
Maxillary	110 (45.8%)
Mandibular	130 (54.2%)
Baseline periapical radiolucency present	107 (44.6%)

TABLE 1: Baseline demographic and clinical characteristics.

SD, standard deviation

Baseline Periodontal, Endodontic, and Restorative Characteristics

At enrollment, 144 teeth (60.0%) had favorable baseline periodontal status, while 96 (40.0%) were compromised. Mean baseline PPD and CAL were 3.18 ± 0.90 mm and 2.36 ± 1.23 mm, respectively, in the full enrolled cohort (Table 2). Endodontic and subsequent crown measures are presented separately from pretreatment periodontal characteristics (Table 2).

Characteristic	Value
Favorable periodontal status	144 (60.0%)
Compromised periodontal status	96 (40.0%)
Baseline PPD, mm	3.18 ± 0.90
Baseline CAL, mm	2.36 ± 1.23
Baseline BOP, %	27.92 ± 13.64
Baseline plaque-positive sites, %	30.18 ± 14.07
Baseline gingival index	1.10 ± 0.41
Adequate root filling	207 (86.3%)
Inadequate root filling	33 (13.8%)
Preserved coronal structure	173 (72.1%)
Limited coronal structure	67 (27.9%)
Crown placement ≤120 days	166 (69.2%)
Crown placement >120 days	74 (30.8%)
Time to definitive crown, days	110.4 ± 59.4
Crown assessed as adequate	165 (68.8%)
Crown assessed as compromised	75 (31.3%)

TABLE 2: Baseline periodontal, endodontic, and crown rehabilitation characteristics of the enrolled participants (n = 240).

Periodontal values refer to baseline, whereas endodontic and crown variables reflect assessments conducted during or after treatment. Percentages are rounded to one decimal place and may not total exactly 100%; *n* values are exact.

PPD, probing pocket depth; CAL, clinical attachment level; BOP, bleeding on probing

Longitudinal Periodontal Measurements

Among the 204 participants with documented attendance and observed measurements at all four visits, mean PPD decreased from 3.17 to 2.70 mm, CAL from 2.35 to 2.11 mm, and BOP from 27.69% to 15.97% between baseline and 12 months (Table 3). All five repeated-measures omnibus time effects were significant after Greenhouse-Geisser correction ($P < 0.001$). For PPD, $F(1.94, 393.46) = 5531.89$; for CAL, $F(1.83, 371.75) = 3297.03$. Sphericity was violated for all five indices (Mauchly's $P < 0.001$). Friedman sensitivity analyses also indicated changes over time for each index (all $P < 0.001$). The unusually large F values reflect low recorded within-person variability in change (baseline-to-12-month change SDs of approximately 0.073 mm for PPD and 0.050 mm for CAL), despite modest absolute mean changes.

Parameter	Baseline	3 months	6 months	12 months	F	GG ϵ	Corrected df	P-value
PPD (mm)	3.17 $\pm$ 0.90	2.95 $\pm$ 0.90	2.80 $\pm$ 0.90	2.70 $\pm$ 0.90	5531.89	0.646	(1.94, 393.46)	<0.001
CAL (mm)	2.35 $\pm$ 1.24	2.24 $\pm$ 1.24	2.17 $\pm$ 1.23	2.11 $\pm$ 1.24	3297.03	0.610	(1.83, 371.75)	<0.001
BOP (%)	27.69 $\pm$ 13.61	22.33 $\pm$ 13.43	18.69 $\pm$ 13.09	15.97 $\pm$ 12.62	2710.80	0.556	(1.67, 338.44)	<0.001
Plaque-positive sites (%)	29.87 $\pm$ 13.99	24.31 $\pm$ 13.81	20.44 $\pm$ 13.56	17.75 $\pm$ 13.13	3038.41	0.561	(1.68, 341.48)	<0.001
Gingival index	1.10 $\pm$ 0.41	1.00 $\pm$ 0.41	0.92 $\pm$ 0.40	0.86 $\pm$ 0.40	4180.22	0.594	(1.78, 361.77)	<0.001

TABLE 3: Repeated-measures analysis of variance (ANOVA) of periodontal indices across four scheduled assessments in participants with complete-visit records (n = 204).

Values are presented as mean $\pm$ SD. Repeated-measures ANOVA was used to assess changes across the four visits. The uncorrected degrees of freedom were (3, 609). As the assumption of sphericity was violated, the Greenhouse-Geisser (GG) correction was applied. The corrected numerator and denominator degrees of freedom are presented in parentheses. The *F*-statistics remain unchanged after correction, whereas the corrected degrees of freedom were used to calculate the *P*-values. All *P*-values represent the overall effect of time rather than individual between-visit comparisons.

PPD, probing pocket depth; SD, standard deviation; CAL, clinical attachment level; BOP, bleeding on probing; ϵ , epsilon; df, degrees of freedom

Clinical, Radiographic, and Composite Endpoints

Among the 204 participants assessed at 12 months, 168 (82.4%) met the composite clinical-radiographic success definition, while 36 (17.6%) met the failure definition. Complete periapical radiographic healing was recorded in 111 (54.4%), ongoing healing in 47 (23.0%), unchanged radiographic status in 24 (11.8%), and progression in 22 (10.8%). The adjudicated, mutually exclusive primary failure manifestations were retreatment (11, 5.4%), extraction (10, 4.9%), persistent index-tooth symptoms (10, 4.9%), and persistent or worsening radiolucency (5, 2.5%). The three symptom flags originating from adjacent teeth were not counted as index-tooth failures after review of the dated clinical and radiographic records. These results are presented in Table 4.

Measure	n (%)
Composite clinical-radiographic success	168 (82.4%)
Composite treatment failure	36 (17.6%)
Complete periapical radiographic healing	111 (54.4%)
Partial/ongoing periapical healing	47 (23.0%)
Radiographically unchanged	24 (11.8%)
Radiographically worsened	22 (10.8%)
Primary failure: retreatment	11 (5.4%)
Primary failure: extraction	10 (4.9%)
Primary failure: persistent symptoms	10 (4.9%)
Primary failure: persistent/worsening lesion	5 (2.5%)

TABLE 4: Twelve-month coded clinical and radiographic outcomes (n = 204).

Radiographic categories total 204, and primary failure manifestations total 36. All percentages are calculated using the 204 participants with 12-month outcomes as the denominator. Complete radiographic healing is distinct from composite clinical-radiographic success.

Combined Periodontal Status and Crown Quality

Composite success differed across the four combined baseline periodontal/post-treatment crown groups (Pearson's $\chi^2 = 25.89$, *df* = 3; *P* < 0.001; Table 5). Success was highest among teeth with favorable periodontal status and adequate crown quality (86/91, 94.5%) and lowest among teeth with both measures compromised

(20/35, 57.1%). These comparisons are observational.

Baseline periodontal status/crown quality	Total	Success	Failure	Success (%)	Crude Firth OR (Wald 95% CI)	P (Wald)
Favorable/adequate	91	86	5	94.5	Reference	-
Favorable/compromised	32	27	5	84.4	3.15 (0.88-11.21)	0.077
Compromised/adequate	46	35	11	76.1	5.09 (1.70-15.26)	0.004
Compromised/compromised	35	20	15	57.1	11.89 (3.98-35.54)	<0.001
Total	204	168	36	82.4	-	-

TABLE 5: Composite success by combined periodontal and crown profile (n = 204)

Firth odds ratios (ORs) compare each group with the reference group (favorable periodontal status and adequate crown quality). Wald confidence intervals and P values are derived from separate binary penalized logistic regression models, not from penalized likelihood-ratio tests.

Exploratory Regression and Interaction

In the exploratory eight-predictor Firth regression model, compromised periodontal status, compromised crown quality, crown placement after 120 days, inadequate root filling, and limited residual coronal structure were associated with higher odds of composite failure (Table 6). The adjusted estimates were imprecise because of the small number of events and should not be interpreted as causal effects or ranked measures of relative clinical importance.

Predictor (reference)	Crude OR (95% CI)	P	Adjusted OR (95% CI)	P
Compromised periodontium (favorable)	5.16 (2.35-11.34)	<0.001	5.43 (2.27-12.98)	<0.001
Compromised crown (adequate)	3.18 (1.53-6.62)	0.002	3.39 (1.45-7.92)	0.005
Crown placement >120 days (≤120)	2.06 (0.99-4.29)	0.054	2.55 (1.08-6.01)	0.033
Inadequate root filling (adequate)	2.37 (0.99-5.70)	0.054	3.04 (1.06-8.69)	0.038
Limited coronal structure (preserved)	2.98 (1.42-6.22)	0.004	4.43 (1.86-10.55)	0.001
Smoker (nonsmoker)	0.82 (0.27-2.43)	0.716	0.71 (0.20-2.55)	0.600
Diabetes (absent)	1.39 (0.53-3.66)	0.508	1.94 (0.61-6.23)	0.264
Baseline periapical lesion (absent)	0.85 (0.41-1.75)	0.662	1.00 (0.44-2.31)	0.993

TABLE 6: Exploratory univariable and adjusted Firth logistic regression models for coded 12-month failure (n = 204; 36 failures).

Firth logistic regression with Jeffreys-information penalization was used. Reported odds ratios (ORs), 95% confidence intervals (CIs), and p values are based on approximate Wald statistics calculated from the penalized coefficients and the inverse information matrix; they are not profile penalized-likelihood confidence intervals or likelihood-ratio P values. The adjusted main-effects model included eight binary predictors. A separate exploratory interaction model yielded an interaction OR of 0.83 (95% Wald CI, 0.15-4.43; P = 0.823).

In the separate interaction model, the periodontal status × crown quality coefficient was not statistically significant (OR 0.83; 95% Wald CI 0.15-4.43; P = 0.823). This only indicates that no statistically significant multiplicative interaction was detected; it does not prove additivity, an absence of interaction on other scales, or comparable biological importance of exposures.

Comparisons by Outcome

Participants experiencing composite failure had higher mean baseline PPD, CAL, and BOP than participants with successful index teeth (Table 7). The comparisons of periodontal status and crown quality are observational and do not establish the direction of causation for post-treatment crown findings.

Characteristic	Success (n = 168)	Failure (n = 36)	Test	P
Age, years	44.71 ± 11.16	45.93 ± 13.18	Welch <i>t</i> = -0.52	0.608
Female sex	91 (54.2%)	17 (47.2%)	$\chi^2 = 0.57$	0.449
Current smoker	24 (14.3%)	4 (11.1%)	Fisher	0.792
Diabetes	22 (13.1%)	6 (16.7%)	Fisher	0.595
Molar	103 (61.3%)	20 (55.6%)	$\chi^2 = 0.41$	0.522
Baseline lesion	77 (45.8%)	15 (41.7%)	$\chi^2 = 0.21$	0.648
Compromised periodontal	55 (32.7%)	26 (72.2%)	$\chi^2 = 19.31$	<0.001
Compromised crown	47 (28.0%)	20 (55.6%)	$\chi^2 = 10.22$	0.001
Crown >120 days	47 (28.0%)	16 (44.4%)	$\chi^2 = 3.77$	0.052
Inadequate filling	21 (12.5%)	9 (25.0%)	$\chi^2 = 3.69$	0.055
Limited coronal structure	42 (25.0%)	18 (50.0%)	$\chi^2 = 8.93$	0.003
Baseline PPD, mm	3.05 ± 0.87	3.70 ± 0.87	Welch <i>t</i> = -4.06	<0.001
Baseline CAL, mm	2.19 ± 1.20	3.09 ± 1.17	Welch <i>t</i> = -4.12	<0.001
Baseline BOP, %	25.90 ± 13.09	36.03 ± 13.06	Welch <i>t</i> = -4.22	<0.001

TABLE 7: Baseline characteristics and treatment factors by coded 12-month composite outcome (n = 204).

Continuous data are presented as mean ± SD and compared using Welch's *t* test. Categorical comparisons use Pearson's χ^2 test (df = 1) or Fisher's exact test, as appropriate. Percentages are calculated using the number of participants with the specified outcome as the denominator.

Discussion

Composite clinical-radiographic success was recorded in 168 of 204 teeth (82.4%), whereas only 111 (54.4%) showed complete periapical radiographic healing. These results capture different aspects of outcome: a clinically stable tooth with a non-progressing lesion may remain functional while radiographic repair continues. Complete periapical healing may require longer follow-up [15], and a 12-month composite endpoint cannot establish long-term tooth survival [2,16,17].

Compromised baseline periodontal status and subsequently assessed crown quality were associated with composite failure in the exploratory adjusted analysis. These observations are broadly consistent with studies relating periodontal inflammation, attachment loss, and coronal restorative quality to endodontic outcomes [4,5,8,18,19]. However, periodontal status and crown quality were not randomized exposures. Crown quality was determined after treatment and, particularly for late crowns, might not have been established before some clinical events; reverse causation and residual confounding cannot be excluded. Consequently, the findings describe associations rather than definitive prognostic or treatment effects.

Crown placement after 120 days, inadequate root filling, and limited coronal tooth structure were also associated with higher odds of failure after adjustment, although the corresponding univariable and multivariable estimates should be interpreted cautiously. Earlier cohorts have highlighted the contribution of definitive restoration timing and technical filling quality to survival or periapical healing [6,7,16,20,21]. Differences in follow-up length, radiographic criteria, and treatment populations limit direct comparison. A restricted number of failures and correlated prognostic factors may have increased model instability and uncertainty, and statistical significance does not establish clinical causality.

The exploratory periodontal-status × crown-quality product term was not statistically significant. This does not demonstrate that the combined effects are additive, that no interaction exists on another scale, or that the exposures have comparable biological effects. In addition, adjusted OR magnitudes should not be used to rank factors by clinical importance. Confirmation in a larger prospective cohort with dated exposure assessments and prespecified modeling is needed.

Radiographic assessment also influences how endodontic success is defined. Two-dimensional periapical radiography differs from cone-beam computed tomography in its sensitivity for residual defects, as

illustrated in endodontic microsurgery research [22]. Micro-computed tomographic investigations of aged root fillings and retreatment methods [23,24], together with ex vivo assessments of the antibacterial properties of calcium silicate-based sealers [25], provide technical and biological context; they cannot be taken as direct evidence that a particular material improves clinical prognosis.

Strengths and limitations

The main strengths of this study include its prospective cohort design, repeated periodontal assessments, and evaluation of multiple periodontal, endodontic, and restorative factors associated with treatment outcomes. The combined assessment of periodontal status and crown quality provides useful insight into the short-term prognosis of endodontically treated posterior teeth. Another strength is the clear distinction between composite clinical-radiographic success, complete periapical healing, and tooth survival.

However, several limitations should be acknowledged. The 12-month follow-up may be insufficient to assess complete periapical healing and long-term tooth survival. The 15% loss to follow-up may have introduced attrition bias, particularly because diabetes was more common among noncompleters. With only 36 treatment failures for eight regression predictors, the adjusted estimates may be unstable and imprecise. Although crown quality was assessed after cementation, its timing relative to clinical failure may have varied, introducing potential temporal ambiguity and reverse causation. The composite outcome included different causes of failure, while the use of two-dimensional radiographs may have limited the detection of residual periapical lesions. Furthermore, the unusually large ANOVA *F* statistics reflected highly uniform within-patient changes despite modest absolute improvements in periodontal measurements, highlighting the need to distinguish statistical significance from clinical importance. Residual confounding and the observational design limit causal interpretation, while complete-case analysis without imputation of missing outcomes may have introduced additional bias. Larger prospective studies with longer follow-up, more treatment failures, and time-updated restorative assessments are needed to validate these findings.

Conclusions

Among posterior teeth receiving primary RCT, 12-month composite clinical-radiographic success varied by baseline periodontal status and later crown quality. Compromised periodontal status, compromised crown quality, delayed crown placement, inadequate root filling, and limited remaining coronal structure were associated with higher adjusted odds of failure in an exploratory model. These observational findings do not demonstrate causality or long-term tooth survival. Larger studies with longer follow-up, complete outcome ascertainment, and prospectively timed restorative measurements are needed to confirm these associations.

Additional Information

Author Contributions

All authors have reviewed the final version to be published and agreed to be accountable for all aspects of the work.

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Disclosures

Human subjects: Informed consent for treatment and open access publication was obtained or waived by all participants in this study. The Institutional Ethical Committee (IEC) of MES Dental College and Hospital issued approval HMCH/172/Ethics/2024. **Animal subjects:** All authors have confirmed that this study did not involve animal subjects or tissue. **Conflicts of interest:** In compliance with the ICMJE uniform disclosure form, all authors declare the following: **Payment/services info:** All authors have declared that no financial support was received from any organization for the submitted work. **Financial relationships:** All authors have declared that they have no financial relationships at present or within the previous three years with any organizations that might have an interest in the submitted work. **Other relationships:** All authors have declared that there are no other relationships or activities that could appear to have influenced the submitted work.

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