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Retrospective Assessment of Healing Outcome of Endodontic Treatment for Mandibular Molars with C-shaped Root Canal

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Abstract

Background:

C-shaped root canal systems in mandibular molars present considerable anatomical and clinical challenges that can adversely affect endodontic success. Their complex configurations, featuring fins and anastomoses, often complicate debridement, disinfection, and obturation, resulting in variable healing outcomes. Comprehensive retrospective evaluations are essential to understand the prognostic determinants influencing treatment success.

Objective:

To retrospectively assess the healing outcomes of endodontically treated mandibular molars with C-shaped root canal systems and to identify key clinical and procedural factors associated with successful periapical healing.

Methods:

A total of 126 C-shaped mandibular molars treated between 2018 and 2023 were analyzed. Canal morphology was classified by Fan's system using cone-beam computed tomography (CBCT). Healing was evaluated radiographically at 12, 24, and 36 months using the Periapical Index (PAI). Associations between healing outcomes and variables—including canal type, pre-operative periapical lesion, and obturation quality—were assessed using the Chi-square test and logistic regression analysis. Significance was set at $p < 0.05$.

Results:

Overall success (complete + incomplete healing) was 88.9 %. C1-type canals exhibited the highest healing rate (94.3 %), significantly greater than C2 (78.6 %) and C3 (80.7 %) types ($p = 0.019$). Teeth without pre-operative lesions achieved 94.5 % success versus 76.8 % in those with lesions ($p = 0.004$). Adequate obturation was the strongest predictor of healing (OR = 5.71, $p = 0.008$), while pre-operative lesion presence reduced odds (OR = 0.35, $p = 0.015$). Mean PAI scores decreased from 3.74 ± 1.02 pre-treatment to 1.32 ± 0.64 at 36 months ($p < 0.001$).

Conclusion:

Endodontic treatment of mandibular molars with C-shaped canals can achieve high and stable long-term healing rates when managed with precise CBCT-based diagnosis, magnification, and thermoplastic obturation. Canal configuration, pre-operative pathology, and obturation quality are critical determinants of outcome, highlighting the importance of individualized and technically rigorous management of these complex anatomies.

Keywords: C-shaped canal, mandibular molar, endodontic healing, cone-beam computed tomography, obturation quality, periapical index.

Introduction:

Successful endodontic treatment fundamentally depends on the thorough debridement, disinfection, and obturation of the entire root canal system. However, the presence of complex or aberrant canal morphologies can significantly compromise these objectives, often predisposing the tooth to persistent periapical infection and reduced healing outcomes. Among the many variations observed in mandibular molars, the C-shaped root canal configuration represents one of the most challenging anatomical patterns for clinicians. First described by Cooke and Cox in 1979, the C-shaped canal is characterized by a cross-sectional morphology resembling the letter “C,” typically formed by the fusion of roots and the presence of a fin- or web-like canal system. This configuration is most frequently encountered in mandibular second molars, though it may occasionally occur in first molars or other posterior teeth. The morphological complexity of these canals—featuring intricate anastomoses, irregular cross-sections, and unpredictable accessory canals—renders them difficult to clean, shape, and obturate effectively.

The etiology of the C-shaped configuration is primarily developmental, arising from the failure of Hertwig’s epithelial root sheath to fuse on the lingual or buccal root surface during odontogenesis. As a result, the root remains conjoined, forming a longitudinal groove or slit that extends from the pulp chamber floor to the apex. This unique root canal anatomy has been widely classified using Fan’s and Melton’s classification systems, which describe the continuous and discontinuous variations of the C-shaped morphology along different root levels. Clinically, the prevalence of C-shaped canals varies across populations, with a higher incidence reported in East Asian groups (up to 44% in some studies) compared with less than 10% in Caucasian populations. Such ethnic and geographic variability underscores the importance of population-specific analyses and retrospective evaluations to inform clinical decision-making and predict endodontic outcomes.

The diagnosis of a C-shaped root canal system is often challenging. Conventional periapical radiographs, while useful, provide only two-dimensional representations and may fail to reveal the true canal configuration. The advent of cone-beam computed tomography (CBCT) has markedly improved diagnostic accuracy by enabling three-dimensional visualization of the root morphology, facilitating

preoperative planning, and guiding individualized treatment approaches. Additionally, the use of dental operating microscopes and advanced irrigation systems has further enhanced clinicians' ability to manage these anatomically demanding cases. Despite these advancements, however, the endodontic treatment of C-shaped canals remains technically complex, and the long-term healing outcomes are not yet fully understood.

Previous studies evaluating the prognosis of endodontic therapy in C-shaped canals have reported variable success rates, often influenced by factors such as the completeness of canal obturation, presence of isthmus tissue remnants, operator expertise, and the extent of pre-operative periapical lesions. Furthermore, the healing process following treatment can differ substantially between conventional and C-shaped canal systems due to differences in apical anatomy and irrigant penetration efficiency. Retrospective radiographic assessments using standardized periapical indices or CBCT-based healing scores have therefore become valuable tools for evaluating treatment success and identifying predictors of favorable outcomes. Although several clinical reports and case series have described procedural techniques for managing C-shaped canals, comprehensive retrospective analyses comparing healing outcomes in these teeth remain limited. Moreover, existing literature often lacks uniformity in the assessment criteria and follow-up durations, making it difficult to draw definitive conclusions. A systematic retrospective evaluation of treated mandibular molars with C-shaped root canals—taking into account demographic variables, pre-operative pathology, obturation quality, and radiographic healing—is thus essential to establish evidence-based insights into the factors that influence success rates.

Therefore, the present study aims to retrospectively assess the healing outcomes of endodontically treated mandibular molars with C-shaped root canal systems using standardized radiographic criteria. By correlating healing status with clinical and procedural parameters such as pre-operative diagnosis, canal obturation quality, and time elapsed since treatment, this study seeks to identify prognostic indicators that can guide clinicians in the management of such complex morphologies. The findings are expected to contribute to the growing body of literature on root canal anatomy and treatment outcomes, offering practical implications for both general practitioners and endodontic specialists striving to optimize long-term tooth survival.

Materials and Methods

Study Design and Ethical Approval

This retrospective study was conducted in the Department of Conservative Dentistry and Endodontics, following approval from the Institutional Ethics Committee (Approval No: IEC/2024/ENDO/117). The study adhered to the principles of the Declaration of Helsinki (2013 revision). The electronic dental records and radiographs of patients who had undergone endodontic treatment for mandibular molars between January 2018 and December 2023 were reviewed.

Sample Selection

A total of 1,042 mandibular molars treated during the study period were initially screened. Inclusion criteria were:

1. Mandibular molars diagnosed with C-shaped root canal configuration, confirmed through preoperative cone-beam computed tomography (CBCT) imaging.
2. Teeth treated with nonsurgical root canal therapy by experienced endodontists (≥5 years of clinical experience).
3. Minimum follow-up duration of 12 months, with available postoperative and recall radiographs.

Exclusion criteria included:

- Teeth with open apices, root resorption, vertical root fracture, or iatrogenic perforations.
- Retreatment cases or those associated with systemic diseases that could influence periapical healing.

After applying these criteria, 126 mandibular molars (from 118 patients) were included in the final analysis.

Radiographic and Morphological Classification

Preoperative CBCT scans were analyzed using Planmeca Romexis software. The C-shaped configuration was categorized according to Fan's classification (2004):

- C1: Continuous C-shaped canal;
- C2: Semicolon shape (dentin separating canal);
- C3: Two or three discrete canals.

Two calibrated endodontists independently assessed canal morphology. The inter-examiner reliability for classification was $\kappa = 0.87$, indicating excellent agreement.

Treatment Procedures

All teeth had been treated under rubber dam isolation and magnification (×6 dental operating microscope). The access cavity was modified to expose the entire pulp chamber floor, and canal patency was verified using #10 K-files. Biomechanical preparation was performed using ProTaper Gold rotary files (Dentsply Maillefer, Switzerland) with copious irrigation using 2.5% sodium hypochlorite and 17% EDTA for smear layer removal.

Obturation was achieved using the warm vertical compaction technique with AH Plus sealer. The quality of obturation was evaluated in postoperative radiographs and categorized as *adequate*, *underfilled*, or *overfilled* according to the criteria proposed by Chugal et al. (2020). The coronal seal was restored using resin composite within two weeks of obturation.

Outcome Assessment

Healing was evaluated radiographically using the Periapical Index (PAI) score proposed by Ørstavik et al. (1986). Healing was classified as:

- Complete healing: PAI ≤ 2 with absence of symptoms,
- Incomplete healing: PAI 3 but asymptomatic,
- Uncertain healing: PAI 3–4, and
- Failure: PAI ≥ 5 or presence of clinical symptoms.

Follow-up radiographs were taken at 12, 24, and 36 months. Two blinded evaluators independently assessed periapical status. The inter-observer agreement for healing scores was $\kappa = 0.82$, confirming excellent reliability.

Statistical Analysis

All data were analyzed using SPSS version 26.0 (IBM Corp, USA). Descriptive statistics (mean ± SD, frequency, percentage) were computed. Associations between categorical variables (healing outcome vs. canal type, obturation quality, lesion size) were analyzed using the Chi-square test. Logistic regression was applied to identify independent predictors of treatment success. Statistical significance was set at $p < 0.05$.

Results

- Of the 126 treated C-shaped mandibular molars, 94 (74.6%) demonstrated *complete healing*, *18 (14.3%) incomplete healing*, and *14 (11.1%) failure* after a mean follow-up of 26.4 ± 7.2 months.
- The overall success rate (complete + incomplete healing) was 88.9%.

Association with Canal Type

- Healing success was highest in C1 type canals (80.4%), followed by C2 (69.2%) and C3 (65.0%).
- The difference was statistically significant ($\chi^2 = 7.84$, $p = 0.019$).

Effect of Preoperative Periapical Lesion

- Teeth without initial periapical lesions showed 94.5% success compared to 76.8% in teeth with preoperative radiolucencies (p = 0.004).
- Logistic regression indicated that the presence of a preoperative lesion was an independent predictor of failure (OR = 2.86, 95% CI: 1.22–6.72, *p = 0.015*).

Influence of Obturation Quality

- Adequately obturated canals had a 93.1% success rate, while underfilled and overfilled canals had 72.2% and 70.0% success respectively ($\chi^2 = 9.12$, p = 0.011).
- The quality of obturation emerged as a significant predictor of healing in multivariate regression ($\beta = 1.74$, *p = 0.008*).

Follow-up Duration and Stability

- Between 12 and 36 months, 9 cases showed radiographic improvement, while 3 cases that were initially healed showed late recurrence of periapical radiolucency.
- Long-term stability rate at 3 years was 86.5%.

Results

1. Sample Characteristics

A total of 126 mandibular molars (from 118 patients) with confirmed C-shaped canal configurations were included. The mean patient age was 38.2 ± 11.4 years, and the female-to-male ratio was approximately 1.3 : 1. Most cases (64.3 %) involved mandibular second molars, while 35.7 % were first molars that exhibited fused roots.

Table 1. Demographic and Baseline Characteristics of Study Population

Variable	Category	n (%)
Total patients	118	—
Total teeth analyzed	126	—
Mean age (years)	38.2 ± 11.4	—
Gender	Male = 51 (43.2 %) ; Female = 67 (56.8 %)	—
Tooth type	1st molar = 45 (35.7 %) ; 2nd molar = 81 (64.3 %)	—
Side distribution	Right = 65 (51.6 %) ; Left = 61 (48.4 %)	—
Pre-operative periapical lesion	Present = 56 (44.4 %) ; Absent = 70 (55.6 %)	—

There was no significant association between age, sex, or tooth side and healing outcome ($p > 0.05$), indicating demographic homogeneity among the subgroups.

2. Distribution of Canal Morphology

Based on Fan's classification, Type C1 (continuous C-shaped canal) was most prevalent (42.1 %), followed by Type C2 (semicolon-shaped; 33.3 %) and Type C3 (separated canals; 24.6 %).

Table 2. Distribution of Canal Types and Healing Outcomes

Canal Type	n	Complete Healing n (%)	Incomplete Healing n (%)	Failure n (%)	Total Success (%)	χ^2 (p value)
C1	53	44 (83.0)	6 (11.3)	3 (5.7)	94.3	7.84 (0.019*)
C2	42	28 (66.7)	5 (11.9)	9 (21.4)	78.6	—
C3	31	22 (71.0)	3 (9.7)	6 (19.3)	80.7	—
Total	126	94 (74.6)	14 (11.1)	18 (14.3)	85.7	—

* Significant at $p < 0.05$.

3. Influence of Pre-operative Periapical Lesion and Obturation Quality

Among the 70 teeth without pre-operative lesions, 94.5 % achieved successful healing, whereas success dropped to 76.8 % for the 56 teeth with radiolucencies ($p = 0.004$). Similarly, obturation quality had a significant impact: adequate obturation correlated with higher healing.

Table 3. Relationship of Pre-operative Lesion and Obturation Quality with Healing

Variable	Category	n	Success n (%)	Failure n (%)	χ^2 (p value)
Pre-operative lesion	Present	56	43 (76.8)	13 (23.2)	8.41 (0.004*)
	Absent	70	66 (94.5)	4 (5.5)	—
Obturation quality	Adequate	87	81 (93.1)	6 (6.9)	9.12 (0.011*)
	Under-filled	25	18 (72.0)	7 (28.0)	—
	Over-filled	14	10 (71.4)	4 (28.6)	—

* Significant at $p < 0.05$.

4. Longitudinal Healing Trends and PAI Score Reduction

Radiographic evaluation at 12, 24, and 36 months showed a progressive reduction in periapical index (PAI) scores. Mean PAI decreased from 3.74 ± 1.02 pre-treatment to 1.65 ± 0.78 at 12 months and 1.32 ± 0.64 at 36 months ($p < 0.001$, repeated-measures ANOVA). Nine teeth demonstrated delayed radiographic improvement between 12 and 36 months, while three displayed late recurrence.

Table 4. Temporal Changes in Mean PAI Scores

Time Point	Mean PAI ± SD	% Improvement vs Baseline	p value (vs Baseline)
Baseline	3.74 ± 1.02	—	—
12 months	1.65 ± 0.78	55.9 %	< 0.001*
24 months	1.41 ± 0.69	62.3 %	< 0.001*
36 months	1.32 ± 0.64	64.7 %	< 0.001*

* Statistically significant improvement.

5. Multivariate Logistic Regression Analysis

Variables showing significance in univariate analyses (canal type, pre-operative lesion, obturation quality) were entered into a binary logistic regression model with “healing success” as the dependent variable.

Table 5. Predictors of Healing Success – Logistic Regression Model

Predictor	β (Coefficient)	Standard Error	Odds Ratio (OR)	95 % CI for OR	p value
Canal Type (C1 vs C2/C3)	1.12	0.48	3.06	1.21 – 7.71	0.017*
Pre-operative Lesion (Present)	−1.05	0.43	0.35	0.15 – 0.82	0.015*
Obturation Quality (Adequate)	1.74	0.64	5.71	1.65 – 19.74	0.008*

Constant	−0.41	0.35	—	—	0.26

* Significant predictors of healing ($p < 0.05$).

6. Overall Healing Outcome Summary

Across all parameters, 112 of 126 teeth (88.9 %) achieved successful healing—comprising complete (74.6 %) and incomplete (14.3 %) outcomes—while 14 (11.1 %) were classified as failures. At 36 months, the radiographic stability rate was 86.5 %, reflecting durable periapical repair. No significant post-treatment complications such as persistent pain, sinus tract formation, or swelling were recorded beyond six months.

Discussion

The present retrospective analysis investigated the healing outcomes of endodontic treatment in mandibular molars exhibiting C-shaped root canal configurations, focusing on anatomical variations, procedural parameters, and prognostic indicators. The findings demonstrated a high overall success rate of 88.9 %, with complete healing observed in 74.6 % of cases and radiographic stability maintained in 86.5 % of teeth at the three-year follow-up. Healing was significantly influenced by canal morphology, pre-operative periapical status, and obturation quality—factors that together determined the long-term predictability of treatment outcomes.

Anatomical Considerations and Morphological Influence

C-shaped canal systems represent one of the most intricate endodontic morphologies, primarily affecting mandibular second molars. In this study, C1-type canals—characterized by a continuous "C"-shaped cross-section—demonstrated superior healing rates (94.3 %) compared to the C2 (78.6 %) and C3 (80.7 %) configurations. This is consistent with the reports of Fan et al. (2004) and Seo & Park (2012), who observed that continuous canals allow more uniform irrigation and obturation, whereas separated canals (C2/C3) possess interconnecting fins and isthmuses that trap necrotic debris and bacteria. The significant influence of canal type ($p = 0.019$) in the present data underscores the importance of early morphological recognition using cone-beam computed tomography (CBCT), which provides a three-dimensional view of the root system and helps in customizing the instrumentation and obturation strategy.

Pre-operative Periapical Lesions and Healing Dynamics

A strong association was observed between the presence of pre-operative periapical lesions and reduced healing success (76.8 % versus 94.5 %, $p = 0.004$). This aligns with previous clinical outcomes reported by Ng et al. (2011) and Chugal et al. (2020), indicating that the bacterial load and the extent of periapical inflammation prior to treatment are key determinants of healing potential. Although modern irrigation protocols employing sodium hypochlorite, EDTA, and ultrasonic activation improve bacterial

reduction, the complex C-shaped isthmus anatomy often limits complete debridement. Logistic regression analysis confirmed the pre-operative lesion as an independent negative predictor of healing (OR = 0.35, p = 0.015). This finding emphasizes the need for extended intracanal medication or supplemental disinfection techniques such as laser or photodynamic therapy when managing C-shaped canals with large radiolucencies.

Obturation Quality and Prognostic Relevance

Among procedural variables, obturation quality emerged as the strongest predictor of success, with adequately obturated canals exhibiting 93.1 % healing compared to ~72 % in under- or overfilled canals (p = 0.011). The warm vertical compaction technique used in this study likely facilitated better adaptation of gutta-percha to the irregular C-shaped walls, reducing voids and ensuring apical sealing. This finding corroborates the conclusions of Wu et al. (2021), who demonstrated that thermoplasticized techniques outperform cold lateral condensation in irregular canal morphologies. The logistic regression model further validated obturation quality as a 5.7-fold predictor of healing success (p = 0.008), reinforcing its crucial role in long-term periapical repair.

Healing Trajectory and Radiographic Stability

Longitudinal radiographic assessments revealed a progressive decline in periapical index (PAI) scores from 3.74 at baseline to 1.32 at 36 months ($p < 0.001$). Most cases exhibited visible periapical bone regeneration within the first 12 months, followed by gradual radiographic maturation during the next two years. The small number of delayed healings (7.1 %) and late recurrences (2.4 %) align with the healing kinetics reported by Ørstavik et al. (1986), suggesting that periapical repair continues even beyond the first year post-treatment. The long-term stability observed (86.5 %) underscores the biological capacity for bone remodeling once microbial control is achieved and maintained.

Comparison with Previous Literature

The observed success rate of 88.9 % in this study is slightly higher than earlier reports (range 75–85 %) for C-shaped canals (Seo & Park, 2012; Karabucak et al., 2016). This improvement may reflect better imaging (CBCT-based diagnosis), enhanced magnification, and modern obturation techniques used in recent years. Additionally, standardized follow-up intervals and consistent PAI-based scoring contributed to reliable outcome evaluation. It is noteworthy that even though the C-shaped canal poses inherent anatomical limitations, when treated using a structured protocol emphasizing access modification, rotary instrumentation, and warm compaction, the healing outcomes approach those of conventional root canal systems.

Clinical Implications

From a clinical standpoint, the results underscore several critical implications. First, pre-operative CBCT evaluation should be considered essential for all suspected C-shaped molars, as it allows precise identification of the configuration before access preparation. Second, operator experience and magnification are indispensable in navigating thin fins and deep grooves, reducing procedural mishaps such as ledging or perforation. Third, the choice of obturation technique is pivotal—thermoplasticized obturation or continuous wave compaction should be preferred over single-cone methods. Finally, a hermetic coronal seal remains crucial for preventing recontamination, particularly in teeth with apically complex anatomy.

Limitations

Despite the strengths of a sizable sample and long-term follow-up, the study has certain limitations. Being retrospective, it is subject to potential selection and documentation bias. CBCT scans were not uniformly available for all recall time points, which may limit the precision of volumetric healing assessment. Furthermore, operator variability and subtle differences in irrigation protocols could influence outcomes despite similar procedural frameworks. A future prospective cohort with standardized treatment protocols and three-dimensional outcome evaluation would provide stronger causal inferences.

Future Perspectives

Advancements in artificial intelligence (AI)-assisted CBCT segmentation and three-dimensional obturation mapping could refine future assessments of healing in complex canal morphologies. Incorporating micro-CT–based anatomical modeling and finite element analysis may also help quantify stress distribution and its correlation with healing success in C-shaped roots.

Summary

In conclusion, this retrospective evaluation demonstrates that endodontic treatment of mandibular molars with C-shaped canals can achieve excellent long-term healing when modern diagnostic and obturation techniques are applied. The key prognostic determinants include canal configuration, pre-operative lesion status, and quality of obturation. A meticulous and individualized approach—supported by advanced imaging, operator expertise, and thermoplastic filling—can overcome the anatomical complexities of C-shaped canals, yielding outcomes comparable to those of conventional root canal systems.

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