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Research Article

Association Between Root Canal Morphology Variations and Endodontic Treatment Failure: A Radiographic and Clinical Correlation Study

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Abstract: To investigate the relationship between the variations of root canal morphology and endodontic treatment failure, using a correlation between the radiographic data and clinical outcomes. ***Methods***: A hospital-based analytical case-control study was carried out at Fatima Memorial Hospital College of Medicine and Dentistry from 01 January 2025 to 31 December 2025. There were 138 participants in total, comprising 69 cases of endodontic treatment failure and 69 controls with successful root canal treatment. Data were obtained with a structured proforma for demographic, clinical, and radiographic data. Digital periapical radiographs and cone-beam computed tomography (CBCT) were used to evaluate root canal morphology, if clinically necessary. Chi-square and independent t-tests were used to assess the association, and multivariable logistic regression was used to determine independent predictors of treatment failure. A value of $p<0.05$ was considered statistically significant. ***Results***: Root canal morphology variations were significantly more common in failed cases than controls (69.6% vs. 33.3%; $p<0.001$). The failure of treatment was significantly associated with missed canals, MB2 canals, C-shaped canals, complex Vertucci canal configuration, and severe canal curvature. Other failed cases were also more likely to have inadequate obturation, obturation voids, and coronal leakage. Root canal morphology variation, missed canals, MB2 canals, C-shaped canals, inadequate obturation, coronal leakage, complex Vertucci canal configuration, and posterior tooth location were identified as independent predictors of endodontic treatment failure ($p<0.05$) through multivariate logistic regression. ***Conclusions***: The variations in the morphology of the root canals significantly raised the risk of failure of endodontic treatment. High-quality obturation, careful canal exploration, and the use of CBCT selectively combined with careful anatomical assessment may help to decrease post-treatment disease and improve treatment outcomes.

Keywords Cone-beam computed tomography (CBCT), Vertucci classification, missed canals, endodontic treatment failure, root canal morphology.

INTRODUCTION

Endodontic treatment is among the most common dental treatments worldwide and is the most effective therapeutic option for irreversible pulpitis, pulpal necrosis, and apical periodontitis.[1] Over the last few decades, treatment outcomes have improved significantly due to advances in instrumentation, irrigation technique, magnification, and obturation techniques.[2] Despite these advances, the failure of endodontic treatment remains an issue, with published long-term success rates varying from 80%-95%, and about 5-20% experiencing persistent symptoms or post-treatment apical disease that necessitates retreatment, apical surgery, or extraction.[3] Endodontic failure is a major clinical and economic concern, contributing a large percentage of both restorative and surgical dentistry.[4]

The key factors in successful root canal therapy are the complete debridement, disinfection, and 3-dimensional obturation of the entire root canal system.[5] The internal structure of teeth, however, is very variable and often complex beyond the simple descriptions provided in standard anatomical classifications.[6] During treatment, additional roots, accessory canals, lateral canals, fins, isthmuses, C-shaped canals, bifurcated canals, apical deltas, and unusual canal configurations may not be identified.[7] The anatomical complexity can allow microorganisms and necrotic tissue that cannot be effectively instrumented and irrigated to survive, and the treatment is not successful.[8]

The frequency of root canal morphology variations varies by tooth, ethnicity, geographic location, age, and sex.[9] The presence of a second mesiobuccal (MB2) canal has been reported in about 60–90% of maxillary first molars when analyzed by cone-beam computed tomography (CBCT), and C-shaped canal systems have been reported in nearly 20–45% of mandibular second molars in many Asian populations.[10] Likewise, the mandibular premolars are also highly variable, and other canals are found in about 15–35% of cases. These variations create problems in diagnosis and therapy, especially when multiple two-dimensional radiographs do not show a complex canal pattern.[11]

Radiographic examination is a crucial part of the evaluation of anatomical variations before and during endodontic therapy.[12] The most commonly used imaging technique, periapical radiographs, is a two-dimensional technique that is accessible and has a relatively low radiation dose, but can potentially present superimposed anatomical structures and underestimate the complexity of the canals.[13] CBCT, on the other hand, gives three-dimensional visualization of the root canal system, which makes it easier to discover accessory canals, root curvatures, root bifurcations, and other anatomical oddities.[14] However, CBCT is not the first imaging modality to be used in all patients due to the exposure to radiation, cost, and guidelines.[15]

A thorough examination combining clinical treatment outcome and radiographic analysis may be useful to detect anatomical characteristics that increase the risk for endodontic failure and enable more personalized treatment planning. The complex morphology of canals must be recognized so that more sophisticated diagnostic tools may be used, access cavity modifications may be made, magnification is used, ultrasonic troughing is employed, more advanced irrigation techniques can be used, and endodontic specialists can be consulted at the appropriate time. This is especially important in low-resource countries where there may not be a routine protocol to use CBCT, so proper patient selection is critical. The results of the present study will help to advance knowledge of anatomical risk factors for treatment failure, aid in evidence-based radiographic risk assessment, and help develop strategies to improve long-term success of endodontic treatment. Thus, the purpose of the present study was to evaluate the relationship between the variations in root canal morphology and the failure of endodontic treatment based on the correlation of the radiographic criteria with the clinical results of endodontic treatment in patients previously treated for root canal disease.

Materials and Methods

The study was an analytical case-control study performed in the Department of Operative Dentistry and Endodontics at Fatima Memorial Hospital College of Medicine and Dentistry from 01 January 2025 to 31 December 2025.

The sample size was determined using OpenEpi version 3.01, assuming that an endodontically treated tooth with a missed canal would have 3.6 times the odds of developing a periapical lesion compared to an endodontically treated tooth without a missed canal, as reported in the study. With an odds ratio of 3.6, an exposure frequency among controls of 19.0%, a two-sided confidence level of 95%, study power of 80%, and a case/control ratio of 1, the minimum sample size was calculated to be 138 participants (69 cases and 69 controls).[16]

A non-probability consecutive sampling technique was employed. Patients were included in the study if they were 18 years and older, had received a previous non-surgical root canal therapy at least 12 months before the visit, and had a good pre- and post-treatment radiograph. Complete clinical records and diagnostic quality periapical radiographs or cone-beam computed tomography (CBCT) were considered eligible. All permanent teeth were included, both anterior and posterior, regardless of jaw position.

Teeth with vertical root fractures, external or internal root resorption, and developmental dental anomalies involving crown morphology, incomplete root formation, poor quality radiographs that did not allow the root canal morphology to be examined, previous endodontic surgery, and traumatic dental injuries were excluded. Teeth with previous endodontic treatment, external or internal root resorption, vertical root fractures, poor quality radiographs that did not allow the root canal morphology to be evaluated, developmental dental anomalies involving crown morphology, and teeth with incomplete root formation were excluded. Pregnant women who were being examined for research purposes and/or patients who did not want to be examined were also not included.

A structured proforma was used to collect data that was specially designed for the study. Demographic variables, clinical variables were documented. An experienced endodontist, who practiced with a standard definition, examined the teeth clinically. The teeth were clinically examined for spontaneous pain, percussion and palpation tenderness, and swelling, sinus tract, mobility, periodontal probing depth, and reaction. Treatment failure was considered to be the existence of at least one of the clinical signs and symptoms, along with radiographic evidence of persistent or new periapical radiolucency, inadequate healing, or the need for retreatment or apical surgery.

Two calibrated endodontists, blinded to clinical outcomes, independently assessed the radiographic outcome. The standardized digital periapical radiographs were assessed with respect to the presence of root canal morphology, number of roots, number of canals, canal configuration (Vertucci), additional canals, C-shaped canals, canal bifurcation, severe canal curve, apical delta, root fusion, and missed canals. CBCT images were examined to confirm complex anatomical variations when available and indicated. If the two observers did not agree, a consensus decision was made following a joint evaluation. Before data analysis, interobserver agreement was checked with Cohen's kappa coefficient.

The endodontic treatment failure was the primary outcome variable, and the primary exposure variable was the presence of root canal morphology variation. The other covariates were age, sex, type of tooth, jaw, number of roots, and number of canals, quality of root canal obturation, coronal restoration status, and missed canals.

IBM SPSS Statistics version 27.0 (IBM Corp., Armonk, NY, USA) was used to enter and analyze the data. The Shapiro-Wilk test was used to test continuous variables for normality. Data for normally distributed variables were reported as mean ± SD and for non-normally distributed variables as median ± IQR. Categorical variables were described in terms of frequencies and percentages. Comparisons of continuous variables were carried out using the independent samples t-test, and the Chi-square test or Fisher's exact test was used to compare categorical variables between the two groups. To determine independent factors associated with endodontic treatment failure, a multivariable binary logistic regression model was created and statistically analyzed using variables with a p-value <0.20 on univariate analysis. Adjusted odds ratios (AORs) with 95% confidence intervals (CIs) were calculated. The fitness of the model was checked with the Hosmer-Lemeshow goodness-of-fit test, and the multicollinearity of the independent variables was tested with the variance inflation factor. A p-value of less than 0.05 two-tailed was considered statistically significant.

RESULTS

The study involved 138 patients: 69 patients in the endodontic treatment failure group and 69 patients in which the endodontic treatment was successful. There were no differences between the two groups in terms of age and sex distribution. Most treated teeth were posterior and multi-rooted, with more teeth in the mandible than the maxilla. There was a greater rate of coronal leakage and recurrent caries in the failure group, but no significant differences in the periodontal characteristics. (Table 1)

The results of the radiographic evaluation revealed that there was a significant difference in the occurrence of root canal system anatomic variations between teeth with failed endodontic treatment and teeth with normal endodontic treatment. The number of additional canals, missed canals, MB2 canals, C-shaped canals, Vertucci Type IV-VIII, and severe canal curvature was higher in cases compared to controls. In addition, the quality of root canal treatment varied, with a high percentage of failed treatment cases having inadequate working length or poor obturation, underfilled canals, and voids in the failed cases, whereas good obturation was mainly observed in the successfully treated cases. (Table 2)

The most frequent clinical and radiographical findings among those who had endodontic treatment failure were tenderness to percussion and persistent periapical radiolucency. The majority of involved teeth were painful with food intake, and of these, a smaller number exhibited swelling, sinus tract development, and/or persistent symptoms. While the majority of teeth that were broken could have been treated without surgery, a few were not suitable for preservation and were removed. Cone-beam computed tomography was only used for clinically challenging cases for additional canal morphology assessment. (Table 3)

Several anatomical and treatment-related variables were found to be significant in univariate logistic regression analysis. Variations in the orthocone morphology of the tooth, particularly missed canals, MB2 canals, C-shaped canals, complex Vertocci configurations and severe canal curvature, were associated with a significantly higher likelihood of tooth failure. Similarly, unsuccessful treatment outcomes were associated with lack of obturation, underfilled canals, voids in the obturation, leakage at the coronal level, and secondary caries. There were no statistically significant associations for demographic characteristics of age and sex. (Table 4)

Root canal morphology variation, missed canals, MB2 canals, C-shaped canal configuration, inadequate obturation, coronal leakage, posterior tooth location, and complex Vertucci canal configurations were independent predictors of endodontic treatment failure, as determined by multivariable logistic regression after adjustment for potential confounding variables. The regression model had good prediction performance in terms of good calibration and good discrimination for the detection of teeth with a higher risk of failure following treatment. (Table 5)

Radiographic evaluation demonstrated strong inter–calibrator agreement between the two calibrated examiners. The high agreement rates in the identification of canal morphology, Vertucci classification, canal curvature, MB2 canals, missed canals, and evaluation of obturation quality showed the reliability of the radiographic evaluations during the study. (Table 6)

Table 1. Demographic, clinical and tooth-related characteristics of the study participants (n=138)

Variable	Cases (n=69)	Controls (n=69)	Total (n=138)	p-value
Age (years), Mean ± SD	42.8 ± 11.2	40.3 ± 10.8	41.6 ± 11.0	0.182
18–30 years	12 (17.4)	16 (23.2)	28 (20.3)	
31–45 years	29 (42.0)	31 (44.9)	60 (43.5)	0.637
>45 years	28 (40.6)	22 (31.9)	50 (36.2)	
Male	38 (55.1)	35 (50.7)	73 (52.9)	0.603
Female	31 (44.9)	34 (49.3)	65 (47.1)	
Maxillary teeth	31 (44.9)	37 (53.6)	68 (49.3)	0.306
Mandibular teeth	38 (55.1)	32 (46.4)	70 (50.7)	
Anterior teeth	14 (20.3)	26 (37.7)	40 (29.0)	0.024
Premolars	19 (27.5)	18 (26.1)	37 (26.8)	
Molars	36 (52.2)	25 (36.2)	61 (44.2)	
Multi-rooted teeth	47 (68.1)	38 (55.1)	85 (61.6)	0.114
Time since RCT (months), Mean ± SD	25.1 ± 9.8	22.7 ± 8.9	23.9 ± 9.4	0.128
Crown present	36 (52.2)	54 (78.3)	90 (65.2)	0.001
Coronal leakage	22 (31.9)	8 (11.6)	30 (21.7)	0.004
Recurrent caries	18 (26.1)	7 (10.1)	25 (18.1)	0.014
Tooth mobility	10 (14.5)	3 (4.3)	13 (9.4)	0.041
Periodontal pocket >4 mm	13 (18.8)	6 (8.7)	19 (13.8)	0.083

Table 2. Radiographic assessment of root canal morphology and quality of endodontic treatment

Variable	Cases n (%)	Controls n (%)	p-value
Root canal morphology variation	48 (69.6)	23 (33.3)	<0.001
Additional root	14 (20.3)	6 (8.7)	0.049
Additional canal	27 (39.1)	14 (20.3)	0.016
Missed canal	31 (44.9)	10 (14.5)	<0.001
MB2 canal	18 (26.1)	8 (11.6)	0.030
C-shaped canal	12 (17.4)	4 (5.8)	0.033
Vertucci Type I	17 (24.6)	31 (44.9)	0.012
Vertucci Type II	8 (11.6)	12 (17.4)	0.337
Vertucci Type III	6 (8.7)	9 (13.0)	0.421
Vertucci Type IV	18 (26.1)	9 (13.0)	0.049
Vertucci Type V–VIII	11 (15.9)	4 (5.8)	0.048
Severe canal curvature	20 (29.0)	9 (13.0)	0.022
Canal calcification	17 (24.6)	9 (13.0)	0.082
Isthmus	13 (18.8)	5 (7.2)	0.041
Lateral canal	15 (21.7)	7 (10.1)	0.063
Apical delta	9 (13.0)	3 (4.3)	0.071
Root fusion	6 (8.7)	5 (7.2)	0.754
Adequate working length	33 (47.8)	60 (87.0)	<0.001
Adequate obturation	29 (42.0)	56 (81.2)	<0.001
Underfilled canal	24 (34.8)	8 (11.6)	0.001
Overfilled canal	10 (14.5)	4 (5.8)	0.087
Voids in obturation	26 (37.7)	9 (13.0)	0.001
Missed obturation	17 (24.6)	5 (7.2)	0.005
Instrument separation	7 (10.1)	2 (2.9)	0.086
Ledge formation	9 (13.0)	3 (4.3)	0.071

Table 3. Clinical and radiographic findings among cases with endodontic treatment failure (n=69)

Variable	n (%)
Pain on chewing	39 (56.5)
Tenderness to percussion	45 (65.2)
Tenderness to palpation	32 (46.4)
Swelling	15 (21.7)
Sinus tract	11 (15.9)
Periapical radiolucency	61 (88.4)
Lesion >5 mm	27 (39.1)

Persistent symptoms >6 months	34 (49.3)
Retreatment advised	49 (71.0)
Extraction advised	12 (17.4)
CBCT performed	30 (43.5)

Table 4. Univariate logistic regression analysis of factors associated with endodontic treatment failure

Variable	OR	95% CI	p-value
Age >45 years	1.47	0.74–2.91	0.263
Male gender	1.19	0.61–2.34	0.604
Posterior tooth	2.39	1.11–5.15	0.026
Multi-rooted tooth	1.74	0.88–3.43	0.113
Root canal morphology variation	4.58	2.21–9.47	<0.001
Additional root	2.68	0.96–7.45	0.059
Additional canal	2.53	1.18–5.42	0.016
Missed canal	4.80	2.07–11.12	<0.001
MB2 canal	2.69	1.08–6.70	0.034
C-shaped canal	3.43	1.04–11.35	0.043
Vertucci Type IV–VIII	2.87	1.34–6.12	0.006
Severe canal curvature	2.73	1.15–6.47	0.022
Canal calcification	2.18	0.91–5.21	0.079
Isthmus	2.97	1.02–8.68	0.046
Poor obturation	5.96	2.82–12.59	<0.001
Underfilled canal	4.05	1.69–9.70	0.002
Voids in obturation	4.04	1.78–9.16	0.001
Coronal leakage	3.58	1.48–8.63	0.004
Recurrent caries	3.13	1.22–8.05	0.018

Table 5. Multivariable logistic regression analysis

Variable	Adjusted OR	95% CI	p-value
Root canal morphology variation	3.61	1.62–8.05	0.002
Missed canal	3.18	1.32–7.69	0.010
MB2 canal	2.36	1.01–5.54	0.047
C-shaped canal	2.91	1.04–8.12	0.041
Poor obturation	4.41	2.01–9.68	<0.001
Coronal leakage	2.74	1.11–6.76	0.029
Posterior tooth	2.12	1.01–4.45	0.046
Vertucci Type IV–VIII	2.31	1.02–5.23	0.044
Model performance: *Hosmer-Lemeshow $\chi^2 = 6.14$ ($p = 0.631$); Nagelkerke $R^2 = 0.41$; Cox & Snell $R^2 = 0.31$; Overall classification accuracy = 79.7%; Area under the ROC curve = 0.84 (95% CI: 0.77–0.90).*			

Table 6. Interobserver agreement for radiographic assessment

Variable	Cohen's κ	Interpretation
Number of roots	0.90	Excellent
Number of canals	0.92	Excellent
Vertucci classification	0.88	Excellent
MB2 canal	0.91	Excellent
Missed canal	0.93	Excellent
Canal curvature	0.87	Excellent
C-shaped canal	0.89	Excellent
Quality of obturation	0.90	Excellent
Overall agreement	0.90	Excellent

DISCUSSION

The present study showed that there was a significant relationship between the variations of the root canal morphology and endodontic treatment failures. Teeth with complex tooth anatomy, such as teeth with missed canals, MB2 canals, C-shaped canals, Vertucci Type IV–VIII canal configuration, and teeth that were very curved, were associated with significantly higher odds of treatment failure. In addition, the failure rate was increased by poor obturation quality, as well as coronal leakage alone. The results highlight the importance of complete identification and management of the entire root canal system in addition to microbial control in the success of endodontic therapy.

The significantly greater prevalence of root canal morphology variations in failed cases when compared with controls was one of the major findings of this study. This finding is similar to the CBCT assessment made by Mashyakhy et al. (2021), who found that untreated canals in root-filled posterior teeth amounted to 18%, and that about 90% of teeth with missed canals exhibited signs of apical periodontitis, emphasizing that there is a close correlation between anatomical complexity and treatment failure.[17] Similarly, another CBCT study from 2023 determined that untreated canals were highly correlated with the presence of persisting periapical lesions, which confirms the results of the present study that anatomical variations significantly affect treatment success.[18]

One of the most significant independent risk factors for treatment failure in the current study was missed canals. This has been consistently observed in recent literature. Central India did a CBCT study in 2026, which showed that 11% of endodontically treated molars in the mandible had missed canals, and that teeth with additional roots were 11 times more likely to have untreated canals than teeth without additional roots.[19] Furthermore, a new systematic review and meta-analysis that encompassed almost 10,000 root-filled teeth showed that teeth with missed canals were over seven times more likely to experience post-treatment apical periodontitis than teeth that were well treated.[20] All these findings reinforce the value of the identification of all canals before the onset of root canal treatment.

The current study further showed that canals of type MB2 and C-shaped canals were independently associated with treatment failure. Due to their complex morphology and the fact that they are hard to clinically access, these anatomical variations are often ignored during conventional treatment. Mashyakhy et al reported that the MB2 canal in the maxillary first molar was the most frequently overlooked and was significantly linked with apical periodontitis.[21] In several published CBCT studies conducted, MB2 canals were always found as one of the main reasons for incomplete cleaning and obturation, leading to persistent disease following treatment. [18, 22]

Unsuccessful treatment was also strongly related to the presence of a complex Vertucci configuration and severe canal curvature in our study. The biological plausibility is based on the fact that the more complex the canal system, the more difficult it will be for the canal to be negotiated, instrumented, irrigated, and obturated, and the greater will be the likelihood of residual microbial contamination. More recently, systematic evidence has shown that complex canal anatomy, as observed on CBCT, is a significant risk factor for post-treatment failure, and thus should be taken into account in the treatment plan, particularly in anatomically difficult teeth.[22]

In addition to anatomical variations, the present study found poor obturation quality to be the best treatment-related predictor of treatment failure. Patient teeth with poor working length, underfilled canals, and obturation voids had a significantly higher likelihood of failure. These results are in accord with the current concepts of endodontics in which thorough chemomechanical preparation and three-dimensional obturation are required for long-term success. In several of the observational studies, the most frequently encountered technical errors in the presence of persistent periapical disease were also inadequate obturation and missing canal fillings. [15, 18]

Multivariable adjustment did not change this finding, with coronal leakage still being an independent risk factor for failure. Even when endodontic treatment is technically "good" coronal seal is lost, and reinfection of the root canal system occurs. A similar study has been conducted by CBCT for several previous investigations which has shown that lack of coronal restoration is associated with a higher prevalence of AP in RFTs, especially with unfilled canals. The overall effects seen in the present study indicate that good endodontics and a long-lasting coronal restoration are essential for predictable clinical success. [18, 20]

In the present study, excellent interobserver agreement was achieved, adding further support to the validity of the radiographic findings. The high degree of reproducibility observed may have been attributable to standardized assessment criteria, examiner calibration and the use of CBCT for a small proportion of the patients, examining highly complex cases. Three-dimensional imaging is useful in detecting complex anatomic variations that may not be seen in two-dimensional imaging, as has been reported in contemporary CBCT studies evaluating root canal morphology.

There are some limitations of this study. First, because of its single-center case-control design, the results of the study may not be generalizable to other populations and clinical contexts. Secondly, CBCT was employed in some complicated cases, but most of the radiographic assessment was made from digital periapical radiographs, which could have underestimated some anatomical variations due to the two-dimensional nature of the image. Third, the information about the operator's experience, instrumentation system, irrigation protocol, and obturation technique used for the initial root canal treatment was not always available and could not be assessed as potential confounders. Lastly, the observational design makes it difficult to draw a cause-and-effect link between the different root canal morphologies and treatment failure.

CONCLUSION

The variations in root canal morphology were significantly associated with endodontic treatment failure. Independent predictors of failure for treatment included coronal leakage, inadequate obturation, C-shaped systems of canals, MB2 canals, and missed canals. Coronal leakage, inadequate obturation, C-shaped systems of canals, MB2 canals, and missed canals were independent predictors of unsuccessful treatment. To ensure long-term success of RCT, careful examination of canal anatomy, careful exploration for additional canals, careful chemomechanical preparation of the canal, and adequate coronal sealing are of special importance. Early identification of anatomical variations and improvements in treatment planning may be possible through selective cone-beam computed tomography for teeth with suspected complex anatomy. Additional multicenter prospective studies with larger patient numbers and regular 3D imaging are recommended to confirm the results of the present study and enhance evidence-based endodontics practice.

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