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Development of an AI model to predict root canal treatment success using CBCT, clinical findings, and patient risk factors

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ABSTRACT
Root canal treatment (RCT) is a widely performed endodontic procedure aimed at preserving natural teeth by eliminating infection and promoting periapical healing. Despite advancements in endodontic techniques and imaging technologies, accurately predicting treatment success remains challenging because outcomes are influenced by multiple interrelated factors, including anatomical characteristics, clinical findings, treatment quality, and patient-specific risk factors. The growing adoption of artificial intelligence (AI) in healthcare presents an opportunity to improve prognostic accuracy through the integration of diverse clinical and imaging data. This study proposes the development of an AI-based predictive model that combines cone-beam computed tomography (CBCT) imaging, clinical findings, and patient risk factors to estimate the likelihood of root canal treatment success. The proposed framework involves collecting retrospective clinical records and CBCT datasets, preprocessing and extracting relevant imaging and clinical features, and training machine learning algorithms to identify patterns associated with favorable and unfavorable treatment outcomes. Model performance will be evaluated using standard predictive metrics, including accuracy, sensitivity, specificity, precision, recall, F1-score, and the area under the receiver operating characteristic curve. By integrating radiographic, clinical, and patient-related variables into a single predictive system, the proposed model is expected to enhance clinical decision-making, support personalized treatment planning, facilitate early identification of high-risk cases, and improve long-term treatment outcomes. The study further highlights the potential of AI-assisted decision support systems to advance evidence-based endodontic practice and contribute to more efficient, accurate, and patient-centered dental care.
Keywords: Artificial intelligence, machine learning, root canal treatment, cone-beam computed tomography (CBCT), endodontics, predictive modeling, clinical decision support, periapical healing, patient risk factors, treatment prognosis.

Introduction

Root canal treatment (RCT) remains one of the most effective procedures in modern endodontics for preserving natural dentition by eliminating infected pulp tissue, disinfecting the root canal system, and preventing the progression of apical periodontitis. Advances in endodontic instrumentation, irrigation protocols, obturation techniques, and restorative materials have significantly improved treatment outcomes over the past decades. Nevertheless, the long-term success of RCT continues to vary among patients due to the complex interaction of anatomical, microbiological, procedural, and patient-related factors that influence healing and disease resolution (Singh et al., 2025). Consequently, predicting treatment success before or immediately after therapy remains a significant clinical challenge.

Successful root canal therapy is generally characterized by the complete resolution of clinical symptoms, elimination of infection, and radiographic evidence of periapical healing. However, healing is influenced not only by the quality of the endodontic procedure but also by host immune responses, systemic health conditions, periodontal status, microbial composition, and patient behavioral factors. Individuals with chronic periodontal disease or systemic inflammatory conditions may experience delayed healing or persistent periapical pathology despite technically adequate treatment. The established relationship between periodontal health and overall treatment outcomes highlights the importance of incorporating patient-specific biological factors into prognostic assessments rather than relying solely on procedural variables (Papapanou et al., 2018; Di Stefano et al., 2022).

The increasing availability of cone-beam computed tomography (CBCT) has transformed endodontic diagnosis and treatment planning by providing high-resolution three-dimensional visualization of dental structures. Compared with conventional periapical radiographs, CBCT offers superior detection of periapical lesions, root canal morphology, vertical root fractures, root resorption, and anatomical variations that may otherwise remain undetected. These imaging capabilities enable clinicians to obtain more comprehensive diagnostic information that can substantially influence treatment decisions and outcome prediction. Recent developments in artificial intelligence (AI)-assisted image analysis have further enhanced the diagnostic potential of CBCT by improving the detection and classification of periapical lesions with greater consistency and efficiency, thereby reducing observer variability and supporting evidence-based clinical decision-making (Yu et al., 2025).

Artificial intelligence, particularly machine learning (ML) and deep learning techniques, has emerged as one of the most promising technological innovations in healthcare. AI systems possess the ability to analyze large and complex datasets, identify hidden relationships among variables, and generate predictive models capable of supporting clinical decisions with remarkable accuracy. In dentistry, AI applications have expanded rapidly across various specialties, including radiographic interpretation, orthodontic treatment planning, oral pathology detection, periodontal disease assessment, and endodontic diagnosis. Machine learning algorithms have demonstrated considerable success in predicting treatment responses using multidimensional clinical datasets, suggesting that similar approaches could substantially improve prognostic prediction in endodontics (Feher et al., 2025). Furthermore, technological innovations in AI-driven diagnostic systems continue to facilitate automated image interpretation and predictive analytics, providing new opportunities for personalized dental care (Patel, 2020).

Although several studies have explored AI for the detection of dental pathologies, comparatively fewer investigations have focused on integrating radiographic findings, clinical examination data, and patient-specific risk factors into a unified predictive model for estimating root canal treatment success. Traditional prognostic assessments often depend heavily on clinician experience and isolated clinical observations, which may not fully capture the complex biological interactions that determine treatment outcomes. Variables such as lesion size, canal morphology, tooth type, previous endodontic intervention, periodontal condition, smoking status, diabetes mellitus, age, and oral microbiome composition collectively influence tissue healing and long-term prognosis. The ability of AI algorithms to simultaneously process these heterogeneous datasets offers significant advantages over conventional statistical methods by recognizing complex nonlinear relationships that may otherwise remain undetected (Di Stefano et al., 2022; Papapanou et al., 2018).

Recent evidence regarding periapical healing following endodontic retreatment further emphasizes that successful clinical outcomes depend upon multiple biological and procedural determinants rather than any single therapeutic intervention. Advances in regenerative materials and adjunctive treatment strategies have improved healing potential, yet variability among patients persists because of differences in host responses and disease severity. These findings reinforce the need for predictive tools capable of integrating multiple prognostic variables to support individualized treatment planning and improve clinical outcomes (Singh et al., 2025).

The broader digital transformation of dentistry has also accelerated the integration of intelligent technologies into routine clinical practice. Digital imaging, electronic health records, tele-dentistry platforms, and AI-assisted decision support systems are increasingly complementing conventional clinical workflows, enabling more efficient diagnosis, remote consultation, and personalized patient management. The expansion of digital healthcare infrastructure provides an ideal foundation for implementing predictive AI models that utilize comprehensive clinical and radiographic information to guide endodontic treatment decisions (Saccomanno et al., 2020).

Against this background, this study proposes the development of an artificial intelligence model capable of predicting root canal treatment success by integrating CBCT imaging findings, clinical examination parameters, and patient risk factors into a comprehensive predictive framework. By combining advanced machine learning techniques with multidimensional clinical data, the proposed model seeks to enhance prognostic accuracy, facilitate evidence-based treatment planning, identify patients at increased risk of treatment failure, and support personalized endodontic care. Ultimately, the integration of AI into endodontic prognosis has the potential to improve clinical decision-making, optimize patient outcomes, and contribute to the continued advancement of precision dentistry.

Literature Review

a) Root Canal Treatment Success and Prognostic Factors

Root canal treatment (RCT) is recognized as one of the most effective procedures for preserving natural dentition affected by pulpal or periapical disease. The primary objective of treatment is the complete elimination of microbial infection from the root canal system, followed by adequate sealing of the canal space to prevent reinfection and facilitate periapical tissue healing. Clinical success is generally characterized by the absence of pain, swelling, sinus tract formation, and functional impairment, while radiographic success is demonstrated by complete or progressive healing of periapical lesions. However, treatment outcomes are influenced by numerous biological, anatomical, procedural, and patient-related factors, making prognosis difficult when relying solely on conventional clinical assessment (Singh et al., 2025).

Periapical healing is considered the most reliable indicator of long-term endodontic success because it reflects the regeneration of bone and surrounding tissues following effective infection control. Healing is affected by microbial reduction, host immune response, lesion size, treatment quality, and postoperative restoration. Comparative investigations evaluating advanced biomaterials have shown that improved healing responses may be achieved when regenerative adjuncts are incorporated during retreatment procedures, emphasizing that biological healing involves complex interactions beyond simple canal disinfection (Singh et al., 2025).

Traditional prognostic methods rely heavily on clinician experience and interpretation of radiographic findings. While these approaches remain valuable, they often fail to account for the simultaneous influence of multiple variables. Consequently, prediction accuracy may vary among clinicians, particularly in complex cases involving extensive periapical pathology, anatomical variations, or systemic health conditions. The growing availability of digital patient records and advanced imaging technologies has therefore increased interest in computational methods capable of integrating multiple predictors into objective prognostic models (Patel, 2020).

b) Role of Cone-Beam Computed Tomography (CBCT) in Endodontic Diagnosis

Cone-beam computed tomography has transformed endodontic diagnosis by providing high-resolution three-dimensional visualization of teeth and surrounding structures. Unlike conventional two-dimensional periapical radiographs, CBCT minimizes anatomical superimposition and allows clinicians to evaluate lesion dimensions, cortical bone involvement, canal morphology, root fractures, accessory canals, and other anatomical complexities with considerably greater accuracy.

The increased diagnostic capability of CBCT has significant implications for treatment planning and outcome prediction. Quantitative imaging features such as lesion volume, lesion density, cortical plate perforation, root curvature, root length, and proximity to anatomical structures provide objective information that may influence healing potential after treatment. These imaging biomarkers can be extracted and incorporated into machine learning algorithms to improve predictive performance.

Recent developments have demonstrated the feasibility of artificial intelligence-assisted CBCT interpretation. Yu et al. (2025) evaluated a no-code artificial intelligence system for detecting periapical lesions across different anatomical regions and reported promising diagnostic performance, indicating that AI can assist clinicians in identifying pathological findings consistently. Such systems reduce observer variability while enabling rapid processing of large imaging datasets, thereby supporting the development of automated prognostic tools (Yu et al., 2025).

Patent developments further illustrate the expanding role of intelligent imaging technologies in dental diagnosis. Patel (2020) described automated systems capable of integrating imaging analysis with decision-support algorithms, providing a technological foundation for AI-driven diagnostic platforms that may eventually support individualized endodontic prognosis.

c) Clinical Findings Affecting Root Canal Treatment Outcomes

Clinical examination remains indispensable in evaluating the likelihood of successful root canal treatment. Several preoperative findings influence prognosis, including pulp vitality, percussion sensitivity, palpation tenderness, tooth mobility, periodontal probing depth, previous restorations, presence of sinus tracts, and the extent of periapical infection.

Teeth presenting with irreversible pulpitis generally exhibit more favorable healing outcomes than teeth with extensive apical periodontitis or persistent infections following previous treatment. Likewise, retreatment cases often involve persistent microorganisms, procedural complications, or inadequate previous obturation, all of which may compromise long-term healing despite technically acceptable retreatment procedures (Singh et al., 2025).

Procedural variables also contribute significantly to treatment success. Adequate cleaning and shaping, irrigation effectiveness, working length determination, canal obturation quality, and coronal restoration integrity collectively influence bacterial elimination and reinfection prevention. Since these variables interact simultaneously rather than independently, predicting treatment outcomes using conventional statistical methods becomes increasingly challenging, thereby supporting the adoption of machine learning techniques capable of modeling complex nonlinear relationships.

d) Patient Risk Factors Influencing Healing

Successful endodontic treatment depends not only on local dental conditions but also on patient-specific biological and behavioral factors. Age influences tissue regenerative capacity and immune responsiveness, while systemic diseases such as diabetes mellitus may delay wound healing and impair immune function. Smoking further compromises vascular supply and inflammatory regulation, negatively affecting periapical tissue repair.

Periodontal status represents another important determinant because periodontal inflammation shares common pathogenic mechanisms with endodontic infections. The current classification of periodontal diseases emphasizes the importance of disease staging and grading in assessing long-term prognosis and treatment planning, highlighting the close relationship between periodontal health and overall oral healing capacity (Papapanou et al., 2018).

Increasing evidence also suggests that the oral microbiome plays a central role in both periodontal disease progression and endodontic infections. Alterations in microbial diversity influence host inflammatory responses, tissue destruction, and regenerative potential.

A comprehensive understanding of microbial interactions therefore provides valuable biological information for predictive modeling aimed at estimating treatment outcomes (Di Stefano et al., 2022).

Behavioral factors including oral hygiene practices, treatment compliance, regular dental attendance, and socioeconomic characteristics may further influence healing by affecting postoperative maintenance

Table 1. Major Variables Reported in the Literature for Predicting Root Canal Treatment Success

Predictor Category	Representative Variables	Influence on Treatment Success	Supporting Literature
CBCT Imaging Variables	Lesion size, lesion volume, cortical bone involvement, root morphology, canal anatomy, root fractures	Improve diagnostic accuracy and quantify disease severity for prediction models	Yu et al. (2025); Patel (2020)
Clinical Findings	Pulp vitality, percussion pain, sinus tract, previous endodontic treatment, obturation quality, restoration integrity	Determine baseline disease severity and procedural quality	Singh et al. (2025)
Patient Demographics	Age, sex, medical history	Influence tissue regeneration and immune response	Papapanou et al. (2018)
Systemic Risk Factors	Diabetes mellitus, smoking, immunocompromised conditions	Affect healing capacity and inflammatory response	Papapanou et al. (2018)
Periodontal Variables	Periodontal pocket depth, attachment loss, periodontal diagnosis	Reflect surrounding tissue health and healing potential	Papapanou et al. (2018)
Microbiological Factors	Oral microbial diversity, inflammatory bacterial profile	Influence infection persistence and periapical healing	Di Stefano et al. (2022)
Treatment Variables	Irrigation protocol, instrumentation technique, intracanal medication, obturation quality	Affect bacterial elimination and long-term treatment success	Singh et al. (2025)

and reinfection risk. Although these variables are sometimes overlooked during conventional prognosis, artificial intelligence systems can incorporate them simultaneously with clinical and radiographic information to produce individualized predictions.

e) Artificial Intelligence in Dental Prognosis

Artificial intelligence has become increasingly important in dentistry because of its ability to analyze multidimensional clinical datasets, recognize hidden patterns, and generate accurate predictions that support clinical decision-making. Machine learning algorithms including decision trees, random forests, support vector machines, gradient boosting methods, and artificial neural networks are capable of identifying nonlinear interactions among variables that are difficult to detect using conventional statistical analyses.

Within dentistry, AI applications have expanded across diagnostic imaging, disease classification, treatment planning, outcome prediction, and clinical workflow optimization. Automated image interpretation systems have demonstrated substantial potential in identifying radiographic abnormalities, while predictive algorithms increasingly assist clinicians in estimating disease progression and treatment responses (Patel, 2020).

Evidence from periodontology further demonstrates the predictive capability of machine learning models. Feher et al. (2025) developed machine learning approaches capable of predicting clinical responses to periodontal treatment using multiple patient variables, illustrating how AI can improve personalized treatment planning. Although focused on periodontal therapy, the methodological framework is directly applicable to endodontics because both specialties rely on multifactorial biological processes influenced by clinical findings, imaging characteristics, and patient-specific risk factors (Feher et al., 2025).

Artificial intelligence also supports remote clinical assessment and digital healthcare delivery. The increasing adoption of tele-dentistry has demonstrated that digital technologies can facilitate patient monitoring, consultation, and interdisciplinary collaboration beyond conventional clinical settings. Such advancements provide additional opportunities for integrating AI-based predictive models into routine dental practice, enabling clinicians to access decision-support tools regardless of geographical location (Saccomanno et al., 2020).

Despite these advancements, several challenges remain. Many existing AI models rely on limited datasets, single-center populations, or isolated imaging variables, reducing their generalizability across diverse patient populations. Furthermore, few predictive systems comprehensively integrate CBCT imaging features, detailed clinical findings, and patient-related biological risk factors within a unified framework specifically designed for predicting root canal treatment success.

Accordingly, the literature indicates a clear need for the development of an integrated artificial intelligence model capable of combining radiographic, clinical, and patient-specific information into a comprehensive predictive system. Such a model has the potential to improve prognostic accuracy, reduce subjective clinical variability, support personalized treatment planning, and enhance long-term endodontic outcomes.

Methodology

a) Research Design

This study adopted a retrospective observational research design for the development and validation of an artificial intelligence (AI) model capable of predicting the success of root canal treatment (RCT) by integrating cone-beam computed tomography (CBCT) imaging, clinical findings, and patient-specific risk factors. A retrospective design was considered appropriate because it enabled the utilization of existing patient records, radiographic datasets, and documented treatment outcomes to establish predictive relationships without influencing routine clinical practice. The study followed the standard workflow for supervised machine learning model development, encompassing data acquisition, preprocessing, feature extraction, model training, validation, and performance evaluation. This approach aligns with contemporary AI-based predictive frameworks increasingly employed in dentistry and other healthcare disciplines (Patel, 2020; Feher et al., 2025).

The overall methodology was designed to facilitate the integration of multiple data modalities into a single predictive framework. CBCT images provided detailed three-dimensional anatomical information, while clinical examination findings and patient-related characteristics supplied complementary biological and behavioral variables influencing endodontic healing. Such multimodal integration has demonstrated improved predictive capability compared with conventional single-source assessments (Yu et al., 2025).

b) Study Setting

The study utilized anonymized patient records obtained from the Department of Endodontics of a tertiary dental teaching hospital equipped with a digital electronic health record (EHR) system and CBCT imaging facilities. The institution routinely performs primary and secondary root canal treatments and maintains comprehensive clinical documentation, radiographic records, and follow-up assessments.

Clinical data were extracted from electronic patient management systems, while CBCT scans were retrieved from the institution's digital imaging archive.

Treatment outcome evaluations were based on standardized follow-up examinations conducted by experienced endodontists using established clinical and radiographic success criteria (Singh et al., 2025).

c) Study Population

The study population consisted of patients who had undergone non-surgical root canal treatment or endodontic retreatment and possessed complete clinical documentation together with preoperative CBCT examinations and documented follow-up outcomes.

Inclusion Criteria

The following patients were included:

- Adults aged 18 years and above.
- Patients who underwent primary root canal treatment or nonsurgical retreatment.
- Availability of high-quality preoperative CBCT images.
- Complete clinical examination records.
- Documented treatment outcomes following adequate clinical follow-up.
- Complete demographic and medical history information.

Exclusion Criteria

Patients were excluded if they had:

- Incomplete clinical or radiographic records.
- Poor-quality CBCT scans with imaging artifacts.
- Teeth presenting with vertical root fractures.
- Patients with incomplete follow-up documentation.
- Cases involving surgical endodontic treatment only.

The inclusion criteria ensured that only complete and reliable datasets were used for model development, thereby minimizing information bias and improving prediction accuracy (Yu et al., 2025).

d) Data Collection

Patient information was extracted from institutional electronic records using a standardized data collection protocol. Three major categories of variables were collected: CBCT imaging characteristics, clinical findings, and patient-related risk factors.

CBCT images were independently reviewed by calibrated endodontists to identify radiographic features associated with treatment prognosis. Imaging variables included lesion dimensions, lesion location, cortical bone perforation, number of canals, root morphology, canal curvature, root resorption, and the presence of previous endodontic filling materials. Recent advances have demonstrated that AI-assisted CBCT analysis significantly enhances the identification of periapical lesions and anatomical variations compared with conventional assessment methods (Yu et al., 2025).

Clinical findings included tooth vitality, percussion sensitivity, palpation findings, sinus tract presence, mobility, periodontal probing depth, preoperative diagnosis, previous endodontic treatment, obturation quality, and restoration status. Periapical healing outcomes were categorized based on clinical symptoms and radiographic evidence of lesion resolution according to established endodontic healing criteria (Singh et al., 2025).

Patient-related variables included demographic characteristics, age, sex, smoking history, diabetic status, hypertension, systemic diseases, medication history, periodontal condition, oral hygiene status, and relevant lifestyle factors. Since periodontal health and inflammatory status significantly influence periapical healing, periodontal findings were incorporated as important predictive variables (Papapanou et al., 2018; Di Stefano et al., 2022).

e) Data Preprocessing

Before model development, all collected datasets underwent preprocessing to improve data quality and ensure compatibility with machine learning algorithms. Missing values were assessed, and variables with excessive missing information were excluded. Numerical variables were normalized using Min-Max scaling, while categorical variables were transformed through one-hot encoding.

CBCT images were standardized to consistent image resolution and grayscale intensity to minimize scanner variability. Image segmentation techniques were applied to isolate the region of interest surrounding the treated tooth and periapical tissues. Radiographic features were extracted using automated image processing algorithms prior to machine learning analysis (Patel, 2020).

Table 2. Variables Used for AI Model Development

Category	Variables	Purpose in Prediction Model
Demographic Variables	Age, sex	Baseline patient characteristics influencing healing
Medical Risk Factors	Diabetes mellitus, hypertension, smoking status, systemic diseases, medication history	Assessment of host healing capacity and systemic risk
Periodontal Variables	Periodontal diagnosis, probing depth, attachment loss, oral hygiene status	Evaluation of periodontal influence on endodontic prognosis
Clinical Findings	Tooth type, pulp status, percussion pain, palpation tenderness, sinus tract, tooth mobility, previous RCT, restoration quality	Clinical indicators associated with treatment success
CBCT Imaging Variables	Lesion size, lesion location, cortical bone involvement, canal morphology, canal curvature, root resorption, number of canals, previous filling quality	Three-dimensional anatomical predictors extracted from CBCT
Treatment Variables	Irrigation protocol, instrumentation technique, obturation method, intracanal medicament	Variables related to treatment quality
Outcome Variable	Successful healing or treatment failure	Target variable for supervised machine learning

Outlier detection was performed using interquartile range analysis to reduce the influence of abnormal observations. Duplicate patient records were removed, and all identifying patient information was anonymized before analysis.

f) Feature Selection

Feature selection was performed to identify variables contributing most significantly to treatment outcome prediction while minimizing redundancy. Correlation analysis, recursive feature elimination (RFE), and feature importance ranking were employed to determine the most informative predictors.

The final feature set represented an integrated combination of CBCT imaging biomarkers, clinical examination findings, and patient-specific risk factors. This multidimensional approach was expected to improve predictive performance compared with

traditional prognostic methods relying solely on radiographic interpretation (Feher et al., 2025).

g) AI Model Development

The predictive model was developed using supervised machine learning algorithms. The complete dataset was randomly divided into training (70%), validation (15%), and testing (15%) subsets.

Several classification algorithms were evaluated, including:

- Random Forest
- Support Vector Machine (SVM)
- Extreme Gradient Boosting (XGBoost)

- Artificial Neural Network (ANN)
- Logistic Regression

Hyperparameter optimization was conducted using grid search combined with five-fold cross-validation to improve model performance and reduce overfitting. The algorithm demonstrating the highest validation performance was selected as the final predictive model.

The development workflow followed established AI implementation principles in healthcare predictive modeling and clinical decision-support systems (Patel, 2020; Feher et al., 2025).

h) Model Evaluation

Model performance was evaluated using multiple classification metrics to ensure comprehensive assessment of predictive capability.

Performance indicators included:

- Accuracy
- Sensitivity
- Specificity
- Precision
- Recall
- F1-score
- Area Under the Receiver Operating Characteristic Curve (AUC-ROC)

Confusion matrices were generated to visualize classification performance, while receiver operating characteristic (ROC) curves were constructed to evaluate discrimination ability across different probability thresholds.

Model calibration was assessed using calibration plots and Brier scores to determine agreement between predicted probabilities and observed outcomes.

i) **Statistical Analysis**

Descriptive statistics were used to summarize patient characteristics and predictor variables. Continuous variables were presented as means and standard deviations, while categorical variables were expressed as frequencies and percentages.

Comparisons between successful and unsuccessful treatment groups were conducted using independent sample t-tests for continuous variables and chi-square tests for categorical variables. Statistical significance was established at $p < 0.05$.

Machine learning analyses were performed using Python programming language with Scikit-learn, TensorFlow, and XGBoost libraries. Data preprocessing and statistical analyses were conducted using SPSS version 29 and Python-based analytical packages.

j) Ethical Considerations

Ethical approval for the study was obtained from the institutional research ethics committee before commencement. Since the study utilized retrospective anonymized patient records, informed consent requirements were waived in accordance with institutional guidelines.

Patient confidentiality was maintained throughout data collection and analysis by removing all personal identifiers before model development. Data security procedures complied with institutional policies governing electronic health records and digital imaging archives.

The development of the AI prediction model emphasized transparency, reproducibility, and clinical interpretability to facilitate responsible integration into evidence-based endodontic practice. The potential incorporation of AI-assisted decision support into digital dentistry and remote consultation frameworks further reflects emerging trends in technology-enabled oral healthcare delivery (Saccomanno et al., 2020).

Expected Results and Discussion

The proposed artificial intelligence (AI) model is expected to demonstrate strong predictive capability for determining the success of root canal treatment (RCT) by integrating cone-beam computed tomography (CBCT) imaging, clinical findings, and patient-related risk factors into a unified analytical framework. Unlike conventional prognostic methods that primarily rely on clinician interpretation of radiographic findings and clinical experience, the proposed model is anticipated to simultaneously evaluate numerous interacting variables, thereby providing a more objective and individualized prediction of treatment outcomes (Patel, 2020).

The integration of CBCT-derived imaging features is expected to substantially improve predictive performance because three-dimensional imaging provides more comprehensive visualization of periapical lesions, root canal anatomy, cortical bone involvement, and anatomical complexities than conventional two-dimensional radiographs. Advanced image analysis is likely to enable the AI model to identify subtle radiographic patterns associated with healing or persistent disease that may not be

Table 3. Expected Performance and Clinical Contributions of the Proposed AI Prediction Model

Component	Expected Outcome	Clinical Significance
CBCT Image Analysis	Accurate identification of lesion size, anatomical complexity, cortical bone involvement, and healing characteristics	Improves radiographic interpretation and diagnostic precision
Clinical Findings	Integration of pulp status, symptoms, tooth anatomy, retreatment history, and treatment quality	Provides comprehensive assessment of disease severity
Patient Risk Factors	Evaluation of age, systemic diseases, smoking, periodontal condition, and oral hygiene	Supports personalized prognosis and individualized treatment planning
Machine Learning Algorithm	Identification of nonlinear relationships among multiple prognostic variables	Enhances predictive accuracy beyond conventional statistical methods
Prediction Output	Probability of treatment success or failure with associated risk classification	Assists clinicians in evidence-based decision making
Clinical Workflow	Automated decision-support integrated with electronic patient records	Improves efficiency, consistency, and treatment planning
Patient Management	Early identification of high-risk patients requiring closer follow-up	Enhances long-term treatment success and resource allocation

consistently recognized through manual interpretation. These expectations align with recent developments demonstrating the effectiveness of AI-assisted CBCT analysis in detecting periapical lesions across different anatomical regions (Yu et al., 2025).

Clinical variables are also expected to contribute significantly to prediction accuracy. Factors such as preoperative pulpal diagnosis, lesion size, presence of sinus tracts, tenderness to percussion, previous endodontic treatment, canal morphology, and quality of obturation collectively influence healing following root canal therapy. By incorporating these variables alongside imaging findings, the proposed model is anticipated to generate individualized risk estimates that more accurately reflect real-world clinical scenarios. The importance of biological healing processes following endodontic therapy has been emphasized in studies evaluating periapical tissue regeneration and retreatment outcomes, highlighting the need for multifactorial prognostic assessment (Singh et al., 2025).

Patient-specific risk factors are expected to further strengthen the predictive capability of the model. Age, smoking status, diabetes mellitus, immune function, periodontal condition, oral hygiene, and systemic inflammatory burden have all been associated with tissue healing following dental treatment. Rather than evaluating these variables independently, the AI model is expected to quantify their combined influence on treatment prognosis. Such integration supports the principles of precision dentistry by recognizing that treatment outcomes depend not only on technical quality but also on patient biology and overall health status (Papapanou et al., 2018; Di Stefano et al., 2022).

The proposed framework is expected to achieve clinically meaningful predictive performance across multiple evaluation metrics, including accuracy, sensitivity, specificity, precision, recall, F1-score, and the area under the receiver operating characteristic (ROC) curve. Although actual performance would depend on dataset characteristics and model optimization, it is anticipated that combining heterogeneous clinical and radiographic variables will outperform prediction models based solely on imaging or clinical observations. Similar improvements have been observed in machine learning applications developed for predicting periodontal treatment responses, where integrating multiple patient variables enhanced predictive reliability and clinical applicability (Feher et al., 2025).

The discussion further suggests that explainable AI techniques could enhance clinician confidence by identifying the variables that contribute most strongly to individual predictions. Rather than functioning as an autonomous diagnostic system, the proposed model is expected to serve as a clinical decision-support tool that complements professional judgment. Such transparency is essential for promoting clinician acceptance, improving accountability, and facilitating integration into routine endodontic practice (Patel, 2020).

From a clinical perspective, the implementation of AI-assisted prognostic models may improve treatment planning before initiation of root canal therapy. Patients predicted to have favorable outcomes may proceed with conventional treatment protocols, whereas those classified as high risk may benefit from enhanced treatment strategies, closer postoperative monitoring, adjunctive regenerative procedures, or earlier consideration of alternative therapeutic interventions. These individualized approaches have the potential to improve patient satisfaction while reducing treatment failures and unnecessary retreatment (Singh et al., 2025).

The proposed model is also expected to facilitate interdisciplinary collaboration between endodontists, periodontists, prosthodontists, and general dental practitioners. Since periodontal status and systemic inflammatory conditions influence periapical healing, incorporating comprehensive patient information into predictive algorithms supports holistic treatment planning. Current understanding of periodontal disease classification and oral microbial interactions further reinforces the importance of considering periodontal health during endodontic prognosis (Papapanou et al., 2018; Di Stefano et al., 2022).

Another anticipated benefit involves the integration of the AI model within digital dental ecosystems. Modern dental practices increasingly utilize electronic health records, digital radiography, and cloud-based imaging systems. Embedding predictive algorithms into these workflows could enable real-time prognostic assessment immediately following CBCT acquisition and clinical examination. Furthermore, integration with tele-dentistry platforms may facilitate remote specialist consultation, particularly in underserved areas where access to endodontic expertise is limited (Saccomanno et al., 2020).

Despite these expected advantages, several challenges are anticipated during model development and implementation. Variability in CBCT acquisition protocols, differences in scanner resolution, incomplete clinical records, inconsistent follow-up periods, and class imbalance between successful and unsuccessful treatment outcomes may influence model performance. Additionally, external validation using datasets collected from multiple institutions would be necessary to confirm the model's generalizability across diverse patient populations and clinical environments. Ethical considerations related to patient privacy, data security, algorithm transparency, and regulatory approval would also require careful attention before widespread clinical deployment (Patel, 2020).

Future investigations are expected to expand the proposed framework through incorporation of deep learning architectures capable of automated feature extraction directly from CBCT volumes. Integration of genomic information, salivary biomarkers, oral microbiome profiles, and longitudinal electronic health records may further improve predictive precision. Federated learning approaches could enable collaborative model training across multiple healthcare institutions while preserving patient confidentiality. Continued refinement of explainable AI methods is also anticipated to improve clinician trust and facilitate regulatory acceptance of intelligent clinical decision-support systems (Feher et al., 2025; Yu et al., 2025).

Overall, the expected findings suggest that integrating CBCT imaging, clinical findings, and patient risk factors into an AI-driven predictive model could substantially improve the ability to forecast root canal treatment success. By combining advanced imaging analytics with patient-centered clinical information, the proposed model has the potential to enhance diagnostic accuracy, optimize treatment planning, support personalized endodontic care, and contribute to improved long-term clinical outcomes. The study therefore provides a foundation for the continued integration of artificial intelligence into evidence-based endodontic practice and digital dentistry (Yu et al., 2025; Singh et al., 2025; Feher et al., 2025).

Conclusion

The development of an artificial intelligence (AI) model to predict root canal treatment success using cone-beam computed tomography (CBCT), clinical findings, and patient risk factors represents a significant advancement in evidence-based endodontic care. By integrating radiographic information with comprehensive clinical assessments and patient-specific risk profiles, the proposed predictive framework addresses the limitations of conventional prognosis, which often relies heavily on clinician experience and isolated diagnostic indicators. The incorporation of multidimensional data into machine learning algorithms has the potential to generate more accurate, objective, and individualized predictions of treatment outcomes, thereby supporting improved clinical decision-making and patient management (Patel, 2020; Yu et al., 2025).

The findings synthesized in this study indicate that CBCT imaging provides valuable diagnostic information regarding lesion characteristics, root canal anatomy, and periapical conditions that may not be fully appreciated through conventional radiography. When combined with clinical variables such as pulp status, treatment history, procedural quality, and patient-related factors—including systemic health, periodontal condition, and behavioral risks—the predictive capability of AI models can be substantially enhanced. These integrated approaches align with emerging evidence demonstrating the effectiveness of machine learning in predicting treatment responses across dental specialties and underscore the growing role of AI in precision dentistry (Feher et al., 2025; Yu et al., 2025).

Furthermore, biological factors influencing periapical healing remain fundamental determinants of endodontic success. Contemporary evidence highlights the importance of tissue regeneration, infection control, and host inflammatory responses in promoting favorable healing outcomes following root canal therapy and retreatment (Singh et al., 2025). Likewise, periodontal health and systemic inflammatory conditions have been recognized as significant modifiers of oral healing capacity, emphasizing the need to incorporate comprehensive patient risk assessments into predictive algorithms (Papapanou et al., 2018; Di Stefano et al., 2022). The integration of these variables enables AI models to provide more clinically meaningful prognostic assessments that reflect the multifactorial nature of endodontic treatment success.

Beyond improving prognostic accuracy, AI-assisted predictive systems have the potential to facilitate personalized treatment planning, optimize resource allocation, and enhance communication between clinicians and patients. The increasing adoption of digital technologies and telehealth applications in dentistry further supports the integration of intelligent decision-support tools into routine clinical workflows, expanding opportunities for remote consultation, continuous patient monitoring, and data-driven treatment strategies (Saccomanno et al., 2020). Such innovations are expected to strengthen the consistency and efficiency of endodontic practice while promoting more patient-centered care.

Despite these promising developments, successful implementation of AI-based prognostic models will require access to high-quality multicenter datasets, standardized CBCT imaging protocols, robust external validation, and careful consideration of ethical, regulatory, and data privacy requirements. Continuous model refinement, interdisciplinary collaboration, and prospective clinical validation will be essential to ensure reliability, transparency, and generalizability across diverse patient populations.

In conclusion, the integration of CBCT imaging, clinical findings, and patient risk factors within an AI-driven predictive framework offers a promising approach for improving the prediction of root canal treatment success. As artificial intelligence continues to evolve within dental medicine, such models are expected to become valuable clinical decision-support tools that enhance diagnostic precision, promote personalized endodontic care, and contribute to improved long-term treatment outcomes (Feher et al., 2025; Singh et al., 2025; Yu et al., 2025).

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