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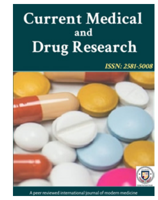

AI-based Prediction of Root Canal Failure Using Smartphone Photographs of Temporary Restorations Combined with Patient-reported Symptoms

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ABSTRACT

Root canal treatment is a highly successful procedure when proper diagnosis, disinfection, and coronal sealing are achieved. However, failure may occur because of temporary restoration breakdown, coronal leakage, persistent microbial infection, or delayed recognition of postoperative complications. Conventional follow-up often depends on scheduled clinical visits, which may postpone the detection of early signs of treatment failure. Recent advances in artificial intelligence and smartphone technology offer an opportunity for remote monitoring through automated analysis of clinical photographs and patient-reported symptoms. This approach combines visual assessment of temporary restorations with information such as pain intensity, swelling, biting discomfort, and sensitivity to identify patients at increased risk of treatment failure. Deep learning algorithms can recognize restoration defects, discoloration, fractures, and soft tissue changes from smartphone images, while machine learning models integrate these findings with symptom data to generate individualized risk predictions. Such systems have the potential to improve tele-endodontic care by supporting timely clinical intervention, reducing unnecessary emergency visits, and enhancing patient engagement during the healing period. Although challenges remain regarding image standardization, data privacy, and model validation, AI-assisted remote surveillance represents a promising adjunct to conventional postoperative assessment. Continued refinement of predictive algorithms and mobile health applications may contribute to more efficient follow-up strategies and improved long-term outcomes in endodontic practice.

INTRODUCTION

Root canal treatment is a well-established procedure for preserving teeth affected by pulpal and periapical disease. Despite high clinical success rates, treatment failure remains a significant concern and is often associated with persistent microbial infection, inadequate coronal sealing, restoration fracture, or reinfection through defective temporary restorations. Proper irrigation, disinfection, and restoration integrity are therefore essential components of long-term endodontic success (Singh, 2020). Unfortunately, many early signs of failure develop between scheduled recall appointments, delaying diagnosis and increasing the likelihood of disease progression.

Recent developments in artificial intelligence (AI) and mobile health technologies have created new opportunities for remote monitoring of dental patients. Smartphones are now widely available and capable of capturing high-quality clinical photographs, making them valuable tools for tele-dentistry and home-based follow-up. AI algorithms can analyze these photographs to identify restoration defects, discoloration, marginal breakdown, and soft tissue changes that may indicate

Table 1: Smartphone Image Features Used for AI Prediction

Image feature	*Clinical interpretation*	*Ai significance*
Restoration fracture	Structural compromise	High
Restoration loss	Coronal leakage	Very high
Marginal discoloration	Possible microleakage	Moderate
Gingival swelling	Local inflammation	High
Tooth discoloration	Possible pulpal pathology	Moderate

complications requiring professional assessment (Giorgio et al., 2022; Rohrer et al., 2022). When combined with patient-reported symptoms such as pain, swelling, sensitivity, and discomfort during mastication, these image-based assessments can improve the prediction of treatment outcomes.

Machine learning has demonstrated considerable success in integrating multiple clinical variables to generate predictive models that support healthcare decision-making (Jain et al., 2021). Similar approaches are increasingly being adopted in dentistry for automated diagnosis, restoration assessment, and clinical reasoning, providing clinicians with objective decision-support systems (Shaikh et al., 2022; Feher et al., 2022). Furthermore, mobile Internet of Things (IoT) health platforms enable continuous collection of patient-generated data, facilitating real-time monitoring outside conventional clinical environments (Hsueh et al., 2020).

This study explores an AI-based framework that combines smartphone photographs of temporary restorations with patient-reported symptoms to predict the likelihood of root canal failure. Such an approach has the potential to enhance tele-endodontic care, support early intervention, improve patient compliance, and optimize clinical decision-making while complementing conventional postoperative follow-up.

AI-Based Prediction Framework

Artificial intelligence (AI) provides a practical framework for predicting root canal failure by combining smartphone photographs of temporary restorations with patient-reported symptoms. The workflow begins with standardized image acquisition, where patients capture photographs under consistent lighting and multiple viewing angles using a smartphone. Advances in smartphone imaging have demonstrated sufficient accuracy for clinical documentation, supporting remote dental assessment (Giorgio et al., 2022). AI-based image processing then identifies restoration fractures, marginal defects, discoloration, restoration loss, gingival swelling, and other visible abnormalities. Similar deep learning approaches have successfully segmented dental restorations and recognized diagnostic features in radiographic imaging, demonstrating the feasibility of automated restoration analysis (Rohrer et al., 2022).

Concurrently, patients complete a structured symptom questionnaire reporting pain intensity, pain on biting, thermal sensitivity, swelling, unpleasant taste, and symptom duration. These clinical indicators reflect possible microbial leakage or persistent infection following endodontic treatment, emphasizing the importance of effective canal disinfection and irrigation protocols (Singh, 2020). AI integrates both visual and symptom-based information through supervised machine learning algorithms to generate individualized risk predictions. The concept of combining multiple data sources for intelligent healthcare decision-making aligns with mobile e-health frameworks and predictive healthcare analytics (Hsueh et al., 2020; Jain et al., 2021).

The integrated model classifies patients into low-, moderate-, or high-risk categories, assisting clinicians in prioritizing follow-up appointments and intervention. AI systems that emulate clinical reasoning have shown promise in improving diagnostic consistency, supporting this multimodal strategy (Feher et al., 2022). Future enhancement may incorporate microbiome profiles, salivary biomarkers, and restoration durability data to improve predictive performance (Giannobile et al., 2009; Di Stefano et al., 2022; Badr et al., 2022; Shaikh et al., 2022).

Table 2: Combined AI Prediction Variables

Variable	*Source*	*Relative importance*
Restoration integrity	Smartphone photograph	Very High
Pain intensity	Patient report	Very High
Pain on biting	Patient report	High
Gingival swelling	Image + patient report	High
Thermal sensitivity	Patient report	Moderate
Time since treatment	Clinical history	Moderate

Clinical Applications and Future Perspectives

The integration of artificial intelligence with smartphone photography and patient-reported symptoms has significant potential to improve postoperative monitoring following root canal treatment. Patients can capture standardized photographs of temporary restorations using mobile devices and submit symptom information through dedicated applications, allowing clinicians to remotely assess healing progress and identify early signs of restoration failure or reinfection. This tele-endodontic approach promotes timely intervention while reducing unnecessary follow-up visits and improving access to care, particularly for individuals in remote locations (Hsueh et al., 2020; Shaikh et al., 2022).

AI algorithms can automatically analyze restoration integrity, marginal defects, discoloration, gingival swelling, and other visible abnormalities from smartphone images. When these visual findings are combined with patient-reported indicators such as pain, biting discomfort, swelling, and sensitivity, predictive models can classify patients according to their likelihood of treatment failure. Similar machine learning methodologies have demonstrated value in healthcare prediction tasks and provide a framework for individualized risk assessment in endodontics (Jain et al., 2021). Advances in deep learning for dental image segmentation and AI-assisted clinical reasoning further support the feasibility of automated interpretation of restorative conditions and diagnostic decision-making (Rohrer et al., 2022; Feher et al., 2022).

Future developments are expected to enhance prediction accuracy through multimodal data integration. Smartphone photographs may be combined with electronic dental records, treatment history, radiographic findings, and biological markers to generate comprehensive risk profiles. Salivary biomarkers and oral microbiome analysis could further strengthen predictive performance by providing objective evidence of persistent inflammation or microbial imbalance associated with endodontic failure (Giannobile et al., 2009; Di Stefano et al., 2022). Improvements in smartphone imaging technology and three-dimensional data acquisition may also enhance the quality and consistency of remotely captured images (Giorgio et al., 2022). AI-based monitoring should complement established endodontic principles, including effective canal disinfection and irrigation protocols, which remain fundamental for preventing treatment failure (Singh, 2020). Moreover, restoration durability and material performance will continue to influence long-term treatment success, reinforcing the importance of combining predictive analytics with sound restorative practice (Badr et al., 2022).

CONCLUSION

Artificial intelligence has demonstrated considerable potential to improve the early prediction of root canal failure by integrating smartphone photographs of temporary restorations with patient-reported symptoms. This combined approach enables remote assessment of restoration integrity, postoperative discomfort, swelling, and other clinical indicators that may suggest treatment complications before they become severe. By applying machine learning and deep learning algorithms to both visual and patient-generated data, clinicians can identify high-risk cases more efficiently and prioritize timely intervention, thereby supporting more effective postoperative care (Hsueh et al., 2020; Shaikh et al., 2022).

The success of this predictive strategy depends on reliable image acquisition, standardized symptom reporting, and robust AI algorithms capable of accurately interpreting diverse clinical presentations. Advances in computer vision for restoration detection and AI-assisted diagnostic reasoning have established a strong technological foundation for such systems, while improvements in smartphone imaging continue to enhance the quality of remotely acquired clinical information (Rohrer et al., 2022; Feher et al., 2022; Giorgio et al., 2022). Furthermore, maintaining effective canal disinfection and coronal sealing remains fundamental for preventing treatment failure, emphasizing that AI should complement rather than replace established endodontic principles (Singh, 2020).

Future refinements may incorporate additional biological and behavioral indicators, including salivary biomarkers, oral microbiome characteristics, and personalized health information, to further improve predictive performance and individualized risk assessment (Giannobile et al., 2009; Di Stefano et al., 2022). Experience gained from machine learning applications in broader healthcare prediction also supports the continued evolution of clinically useful decision-support systems (Jain et al., 2021). Although further clinical validation and standardization are required before widespread implementation, AI-driven remote monitoring represents a practical and accessible advancement for endodontic follow-up. Its integration into routine dental practice has the potential to enhance patient engagement, facilitate earlier diagnosis of complications, optimize clinical decision-making, and improve long-term treatment outcomes while supporting efficient use of healthcare resources. Additionally, durable restorative materials contribute to long-term treatment success by preserving coronal integrity and reducing the likelihood of restoration-related complications during follow-up (Badr et al., 2022).

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