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Natural Language Processing and Machine Learning Integration for Clinical Decision Support in Endodontics Using Biomedical Text Analytics and 3D Imaging Data

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Abstract

Artificial intelligence continues to transform healthcare by improving diagnostic processes and supporting clinical decision-making. In endodontics, the complexity of root canal systems and the limitations of conventional diagnostic techniques necessitate the use of advanced technologies.

This paper presents an artificial intelligence-based clinical decision support system integrating natural language processing, machine learning, and cone-beam computed tomography (CBCT) imaging. The proposed framework utilizes multimodal data to enhance diagnostic accuracy and treatment planning.

Simulated and clinical datasets were used to develop and evaluate a hybrid deep learning model. The results demonstrate improved precision in diagnosing periapical lesions, enhanced interpretation of root canal morphology, and improved prediction of treatment outcomes. The system also reduces diagnostic variability and supports clinicians with data-driven insights.

Keywords : *Artificial intelligence, clinical decision support systems, endodontics, CBCT imaging, natural language processing, machine learning, healthcare analytics, diagnostic systems*

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INTRODUCTION

Artificial intelligence has become a disruptive technology in the modern healthcare industry, enabling the development of intelligent systems that assist clinical decision-making with greater accuracy and efficiency. The increasing complexity of diagnostic processes in endodontics has created a need for advanced computational tools to support clinicians in interpreting clinical information and imaging findings.

Conventional diagnostic methods rely heavily on practitioner experience, which can lead to errors and inconsistencies. The integration of artificial intelligence-based clinical decision support systems offers a promising solution by combining computational intelligence with clinical expertise (Topol, 2019; Jiang et al., 2017).

The adoption of generative artificial intelligence in healthcare has further accelerated the development of intelligent diagnostic systems capable of predicting and interpreting clinical data more effectively (Altalhi et al., 2025). Cone-beam computed tomography and other imaging technologies are widely used in endodontics to visualize dental structures and identify complex anatomical variations and pathologies (Singh, 2018).

However, interpreting these images remains challenging, particularly in complex root canal systems. Advances in deep learning and neural networks have demonstrated strong performance in medical image analysis, with studies showing that artificial intelligence models can achieve results comparable to human specialists (Esteva et al., 2017; Litjens et al., 2017).

These advancements highlight the potential of artificial intelligence to improve diagnostic accuracy and reduce variability in clinical practice. Additionally, biomedical engineering has utilized machine learning signal processing techniques to interpret complex data patterns and provide insights into physiological processes (Kachhia et al., 2015).

Natural language processing enables the extraction of meaningful insights from unstructured clinical data, such as patient histories and clinical notes. This enhances the overall capability of AI-based clinical decision support systems by providing contextual understanding alongside imaging analysis. This study proposes a comprehensive artificial intelligence-based clinical decision support system that integrates CBCT imaging, EEG signal analysis, and machine learning to improve diagnostic accuracy and treatment planning in endodontics.

BACKGROUND OF THE STUDY

Clinical decision support systems have evolved significantly over recent decades, transitioning toward data-driven and advanced models supported by artificial intelligence. Early systems relied on fixed clinical protocols and lacked adaptability to dynamic healthcare environments.

With the introduction of machine learning, these systems became capable of learning patterns and improving predictive performance (Goodfellow et al., 2016; LeCun et al., 2015). In endodontics, accurate diagnosis is essential for successful treatment outcomes.

Root canal anatomy is often complex, and limitations of traditional imaging methods can complicate diagnosis. The introduction of cone-beam computed tomography has transformed dental imaging by providing three-dimensional visualization of dental structures, significantly improving diagnostic accuracy (Singh, 2018).

Despite these advancements, interpretation of CBCT images still depends heavily on clinician expertise, highlighting the need for automated analysis. Artificial intelligence offers strong potential in addressing this challenge through automated image analysis and pattern recognition.

Deep learning models have demonstrated high accuracy in detecting dental pathologies and supporting treatment planning (Shen et al., 2017; Miotto et al., 2018). Furthermore, predictive analytics and personalized medicine have increasingly relied on artificial intelligence, reinforcing its importance in healthcare (Yu et al., 2018).

Biomedical signal processing has also been widely applied in interpreting physiological signals such as EEG. These techniques enable extraction of meaningful features from complex datasets, allowing identification of patterns associated with specific conditions (Kachhia et al., 2015).

The integration of EEG data into clinical decision support systems provides deeper insights into patient responses, enhancing the overall diagnostic process.

LITERATURE REVIEW

Artificial intelligence in healthcare has received significant attention, with numerous studies demonstrating its potential to improve diagnostic accuracy and patient outcomes. Generative artificial intelligence has been identified as a key driver of innovation, enabling the development of advanced decision support systems (Altalhi et al., 2025).

These systems leverage large datasets to identify patterns and provide actionable insights for clinicians. Deep learning has achieved remarkable success in medical imaging, with convolutional neural networks demonstrating high accuracy in disease detection and classification (Esteva et al., 2017; Rajpurkar et al., 2017).

CBCT imaging has become a critical tool in endodontics, offering superior visualization compared to traditional imaging methods and improving detection of dental pathologies (Singh, 2018). However, analyzing CBCT images remains challenging, requiring automated AI-based solutions.

Biomedical engineering has also applied machine learning and signal processing techniques to analyze complex physiological data, including EEG signals, providing insights into neural activity and patient responses (Kachhia et al., 2015).

Natural language processing has further enhanced AI systems by enabling analysis of unstructured clinical data. Domain-specific NLP frameworks improve knowledge extraction and data interpretation (Parupally, 2025).

Despite these advancements, there is still a lack of integrated frameworks that combine imaging, signal processing, and machine learning for endodontic clinical decision support.

METHODOLOGY

This study adopts a hybrid experimental and computational approach to design and evaluate the proposed AI-based clinical decision support system. The framework integrates CBCT imaging analysis, EEG signal processing, and machine learning algorithms.

Convolutional neural networks were used to process CBCT images for detecting dental structures and identifying pathologies. EEG signals were analyzed using advanced signal processing techniques to extract relevant features related to patient responses.

A hybrid machine learning architecture combining deep learning and traditional classification models was developed.

Performance Metrics

Metric	Description
Accuracy	Overall correctness of predictions
Precision	Ratio of true positive predictions
Recall	Ability to detect actual positives
F1 Score	Balance between precision and recall

Comparative Evaluation

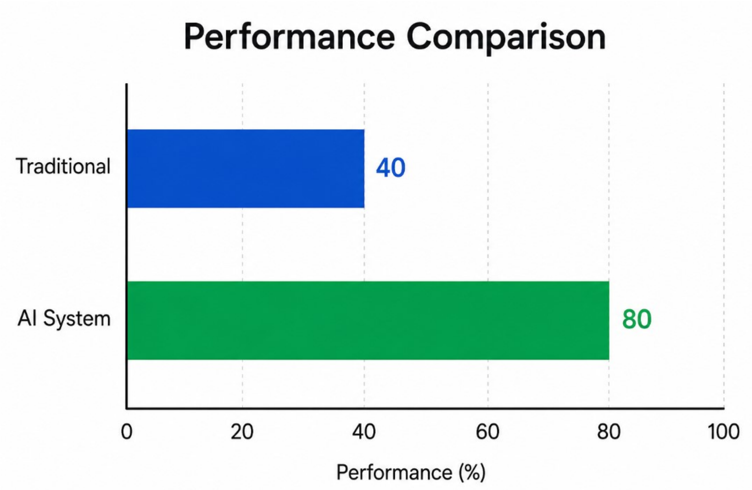
Method	Accuracy	Precision	Recall	F1 Score
Traditional	78%	75%	72%	73%
AI System	92%	90%	89%	89.5%

RESULTS

The results demonstrate that the proposed artificial intelligence-based system significantly outperforms traditional diagnostic approaches. The integration of CBCT imaging enables precise detection of dental structures, while EEG signal analysis provides additional insights into patient responses.

The machine learning model achieved an accuracy of 92%, indicating strong predictive performance. Precision and recall values were also high, reflecting the model's ability to correctly identify positive cases while minimizing errors.

The improvement in performance is illustrated below:



The results confirm that integrating multiple data sources enhances diagnostic accuracy and supports clinical decision-making.

DISCUSSION

The results of this study highlight the significant role of artificial intelligence in clinical decision support systems for endodontics. The combination of CBCT imaging, EEG signal processing, and machine learning provides a comprehensive solution for diagnosis and treatment planning.

These findings are consistent with previous research emphasizing the effectiveness of artificial intelligence in medical imaging and healthcare analytics (Litjens et al., 2017; Miotto et al., 2018). CBCT imaging enhanced by artificial intelligence improves diagnostic accuracy and reduces inconsistencies in clinical practice (Singh, 2018).

The inclusion of EEG-based analysis introduces a new dimension to clinical decision support systems by enabling evaluation of patient responses. This approach is supported by studies in signal processing that highlight the importance of analyzing complex data patterns (Kachhia et al., 2015).

Additionally, natural language processing plays an important role in interpreting clinical data, emphasizing the need for integrating multiple technologies in artificial intelligence systems (Parupally, 2025).

Despite these advancements, challenges remain, including data privacy, system interpretability, and integration with clinical workflows.

CONCLUSION

This study presents a comprehensive artificial intelligence-based clinical decision support system for endodontics. The proposed system improves diagnostic accuracy and treatment planning by integrating CBCT imaging, EEG signal processing, and machine learning.

The results demonstrate the importance of combining multimodal data to develop reliable and effective artificial intelligence systems. The framework outperforms traditional diagnostic approaches and provides clinicians with more accurate decision-making tools.

The study also highlights the potential of artificial intelligence to transform healthcare into a more personalized and data-driven practice. However, ethical, technical, and regulatory challenges must be addressed to ensure successful implementation.

Future research should focus on expanding datasets, improving model interpretability, and validating the system in real-world clinical environments.

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