**THE AI REVOLUTION IN CONSERVATIVE DENTISTRY AND ENDODONTICS: A NARRATIVE REVIEW**

**ABSTRACT**

**Background:** Artificial Intelligence (AI), introduced by John McCarthy in 1956, simulates human cognitive functions such as reasoning and decision-making. Its integration in dentistry, particularly in conservative dentistry and endodontics, has significantly advanced diagnostics, treatment planning, and patient care.

**Objective:** Thisreview explore the applications and clinical utility of AI in conservative dentistry and endodontics, highlighting its current impact and potential.

**Methods:** This narrative review synthesizes evidence from studies, AI model applications, and dental technologies. It categorizes AI by capability and functionality and explores its key subdomains—machine learning and deep learning. The clinical workflow and role of AI in various procedures are described.

**Results:** In conservative dentistry, AI is utilized for early caries detection, shade matching, caries risk prediction, restorative material selection, crown failure prediction, and finish line detection. Techniques like convolutional neural networks (CNNs), support vector machines (SVMs), and case-based reasoning systems demonstrate high diagnostic accuracy (up to 100%).In endodontics, AI aids in detecting periapical lesions and root fractures, determining working length, analyzing root morphology, supporting regenerative therapies, and predicting retreatment needs. CNNs applied to radiographic images have shown accuracy levels up to 97%, often exceeding human performance.

**Conclusion**:  
AI represents a transformative tool in conservative and endodontic dentistry, significantly enhancing diagnostic precision, predictive capability, and clinical workflow efficiency. However, limitations such as dependency on large datasets, lack of transparency in deep learning models, integration challenges, and ethical concerns must be addressed. Future advancements should focus on standardization, interdisciplinary collaboration, and clinician training to ensure AI serves as an effective adjunct to professional expertise.

**Keywords**: Artificial Intelligence, Machine Learning, Deep learning, Artificial neural network, Convolutional neural network.

**INTRODUCTION**

Artificial Intelligence (AI), a branch of applied computer science, was first introduced by Rajaraman and John McCarthy in 1956. It involves the development of systems that mimic human cognitive abilities such as reasoning, critical thinking, and decision-making using computational approaches(1). In dentistry, AI has demonstrated remarkable effectiveness by processing large volumes of data, recognizing complex patterns, and providing highly accurate predictions. This has significantly improved diagnostic accuracy, optimized treatment planning, and enhanced overall patient care(2). AI is now recognized as a powerful tool in performing advanced dental tasks, including the detection of caries, planning restorations, evaluating pulp health, and identifying periapical lesions with high precision and efficiency.

**HISTORY OF AI**

The origins of artificial intelligence trace back to 1763 with Thomas Bayes’ probability framework, followed by the concept of artificial neural networks introduced by McCulloch and Pitts in 1943. In 1950, Alan Turing laid foundational ideas in his paper on machine intelligence. Minsky and Edmonds built the first physical neural network (SNARC) in 1951 and by 1955, Newell and Simon developed the Logic Theorist, one of the earliest AI programs(3). Though AI has long been discussed in healthcare, its practical use in dentistry has significantly grown only in the past 10–15 years, fueled by advancements in digital tools like CAD/CAM, digital radiography, and electronic records.

**TYPES OF ARTIFICIAL INTELLIGENCE**

Based on Capability

1. Narrow AI (Weak AI):  
   Performs specific tasks (e.g., image recognition, disease prediction); cannot operate beyond its scope.
2. General AI:  
   Capable of performing any intellectual task like a human; uses "theory of mind" to understand human behavior (e.g., Fujitsu’s K supercomputer).
3. Superintelligent AI:  
   Surpasses human intelligence; can reason, solve problems, learn, and make independent decisions.

Based on Functionality

1. Reactive Machines:  
   Respond to specific inputs without memory (e.g., chess-playing AI).
2. Limited Memory:  
   Uses past data to make decisions (e.g., virtual assistants, self-driving cars).
3. Theory of Mind:  
   Understands human emotions and behavior (e.g., Sophia robot, though limited in emotional interpretation).
4. Self-aware AI:  
   Possesses human-like consciousness and emotional awareness (e.g., ChatGPT is a basic step toward this).

**WORKING OF AI**

AI operates using(1):

* Learning: Acquiring data and patterns
* Thinking: Reasoning and decision-making
* Self-correction: Refining performance over time

**KEY SUBDOMAINS**

1. Machine Learning (ML):  
   Uses data and algorithms to mimic human learning and improve accuracy.
   * Supervised Learning: Uses labeled data (e.g., medical diagnosis, fraud detection)
   * Unsupervised Learning: Uses unlabeled data to find hidden patterns (e.g., anomaly detection)
   * Semi-supervised Learning: Combines both methods (e.g., image/text classification)
   * Reinforcement Learning: Learns via trial and error based on feedback

Fig 1. ML Process

1. Deep Learning (DL):  
   A subset of ML that uses artificial neural networks to process data through multiple layers—mimicking the human brain.
   * ANNs: Solve complex problems
   * CNNs: Best for image and vision-related tasks
   * RNNs: Excel in handling sequential data like speech and text

**APPLICATIONS OF ARTIFICIAL INTELLIGENCE IN CONSERVATIVE DENTISTRY**

AI in Conservative Dentistry is applied for:

* Early caries detection
* In shade matching
* Predicting individual risk of developing dental caries
* Predicting crown failure
* In selection of restorative material
* Prediction of finish lines in crown

EARLY CARIES DETECTION

Identifying dental caries in their earliest phase enables intervention before more invasive treatment becomes necessary. Machine learning models can analyze dental radiographs, photographs , and 3D scans with greater consistency and accuracy than human evaluators, significantly reducing the subjectivity that often affects traditional diagnosis(4). Artificial intelligence algorithms used for dental caries detection include Convolutional Neural Networks, Support vector machines (SVMs) and Random Forest Algorithm(5). Identifying caries lesions in dental radiographs involves several key steps.

1. Image Acquisition
2. Pre-processing (Noise reduction, Contrast enhancement)
3. Segmentation
4. Feature Extraction
5. Classification
6. Post-processing
7. Validation

Existing artificial intelligence technologies for dental caries diagnosis include Pearl, Overjet and Denti. AI.

IN SHADE MATCHING

Traditional shade matching—using visual comparison with shade guides—has always been vulnerable to inconsistent lighting, observer bias, and guide wear(6). AI has shown remarkable potential in dental shade matching, with peak accuracies nearing 99–100%(7). Thanathornwong et Al developed a clinical decision support system to help general practitioners predicting color change after in-office tooth whitening in patients(8). However, to translate these techniques into clinical practice, standardized imaging protocols, diverse real-world trials, and evaluation of usability and cost-effectiveness are needed.

PREDICTING INDIVIDUAL RISK OF DEVELOPING DENTAL CARIES

Dental caries has multifactorial etiology, with key contributing factors including a cariogenic diet, bacterial activity, vulnerable tooth structure, and the duration of exposure. Ogwo et al, developed a machine learning model to predict future caries in young adults by incorporating key life-course risk factors such as sociodemographic, dietary, fluoride exposure, behavioral habits, and dental history. The model demonstrated strong predictive ability for cavitated caries, and with further validation, it holds potential to support dentists and policymakers in implementing early oral health interventions(9).

PREDICTING CROWN FAILURE

Enhancing the longevity of CAD/CAM composite resin (CR) crowns is a highly important goal. Yamaguchi et al. demonstrated that AI, specifically CNN analysis of 3D-to-2D die images, can reliably predict debonding in CAD/CAM composite resin crowns with near-perfect accuracy. This innovation offers promising support for improving restoration longevity(10).

IN SELECTION OF RESTORATIVE MATERIAL

The durability of dental restorations largely depends on the type of material chosen, but it is also influenced by factors such as the cavity's features, the patient's habits, and the clinician's skill. Aliaga et al. designed a case-based reasoning (CBR) system to assist clinicians in selecting between amalgam and composite resin for posterior restorations, while also forecasting the expected durability of the restoration. The system effectively guides material choice and predicts lifespan, enhancing clinical decision-making(11).

PREDICTION OF FINISH LINES IN CROWN

The condition of periodontal tissues directly affects the marginal adaptation of restorations, with inflammation influenced by the position and shape of the margin line. Zhang B. et al developed a deep-learning approach to automate the extraction of the finishing (margin) line in 3D tooth preparation models—an essential step in restorative dentistry thus replacing laborious manual tracing. This approach successfully automated the margin line identification process with high accuracy (~97.4%), efficiently replacing manual extraction(12). This can serve as a model for future AI-driven tools in digital dentistry supporting integration with CAD/CAM systems for more efficient prosthetic fabrication.

**APPLICATIONS OF ARTIFICIAL INTELLIGENCE IN ENDODONTICS**

* Detection of periapical lesions
* Detection of root fractures
* Determination of working length
* Determination and analysis the morphology of root and root canal system
* Prediction of the need for retreatment
* Role in regenerative endodontics

DETECTION OF PERIAPICAL LESIONS

Early detection of periapical lesions can enhance treatment success, halt disease spread to adjacent tissues, and minimize the risk of complications. Dentists’ accuracy in identifying periapical radiolucencies on both 2D and 3D dental images has been reported to vary significantly, ranging approximately from 53 % to 90 % (13). AI has been successfully applied to periapical radiographs, panoramic radiographs, and CBCT scans for periapical lesion detection(14). A systematic review by Naik et al. shows AI, particularly CNNs, generally outperform human clinicians in detecting periapical lesions on dental radiographs with accuracy levels ranging between 70%- 97%(15). Kazimierczak et al. evaluated the diagnostic accuracy of the AI software Diagnocat for detecting periapical lesions and found that it performed well with CBCT (sensitivity ~78%, specificity >98%) but showed low sensitivity (~33%) with OPG, highlighting the need for clinician oversight with 2D imaging(16).

DETECTION OF ROOT FRACTURES

Vertical root fractures (VRFs) are uncommon complications observed in endodontically treated teeth. Research indicates their occurrence ranges from 3.7% to 30.8% in such cases(17). Fukuda et al. utilized an AI model to identify vertical root fractures on panoramic radiographs, achieving a sensitivity of 75% and a positive predictive value of 93%(18). Oszari et Al developed a transfer learning tool which aids in automatic detection of VRF on intraoral periapical raidograph and found that it had significant potential in enhancing diagnostic accuracy(19). Enhancing AI for diagnosing vertical root fractures can help prevent unnecessary treatment of teeth that cannot be restored and avoid the extraction of healthy teeth due to misdiagnosis.

DETERMINATION OF WORKING LENGTH

Accurate determination of working length is a vital step in root canal therapy, as it directly impacts treatment success. It ensures thorough debridement of the canal system and prevents overextension of obturation materials into the periapical region, thereby promoting optimal healing and reducing the risk of post-treatment complications(20). Several techniques are commonly used to locate the apical foramen and determine working length, including radiographic methods, the paper point technique, digital tactile feedback, electronic apex locators and CBCT(21). Radiographic readings can be affected by several factors, risking misdiagnosis. Hence, computer-based methods are essential for more reliable working length determination. Saghiri et al. reported high accuracy of AI models in locating the apical foramen and determining working length (up to 96%), though limited by the use of extracted teeth and cadavers(22). Qiao et al. also showed superior accuracy of an AI model over the dual-frequency impedance method (85%), but the small sample size suggests the need for further validation(23).

ROLE OF AI IN REGENERATIVE ENDODONTICS

Stem cells are effective in cell therapy due to their abilities for self-renewal and differentiation into various tissues. AI has been utilized to design stem cell-based therapies and optimize scaffold structures for dental tissue regeneration.

* **Stem Cell Differentiation:** AI can analyze gene expression data to predict optimal conditions for differentiating mesenchymal stem cells into odontoblast-like cells.
* **Scaffold Design:** AI-generated scaffold designs with tailored porosity, strength, and biocompatibility enhance cell adhesion and tissue regeneration
* **Predictive Modeling:** AI helps predict treatment outcomes based on patient-specific factors like age, health, and genetics, paving the way for more personalized and effective regenerative dental care (24).

PREDICTION OF THE NEED FOR RETREATMENT

Endodontic retreatment is complex due to its unpredictable nature and the multiple factors contributing to the failure of the initial treatment(25). Deep learning models, particularly convolutional neural networks (CNNs), are highly effective in analyzing imaging data to identify missed canals, fractures, or periapical lesions—key factors in retreatment planning. Campo et al. developed a case-based reasoning model to predict the outcomes of non-surgical root canal retreatment by assessing associated risks and benefits. The algorithm offered recommendations on whether retreatment was advisable, using data on recall, performance metrics, and statistical probabilities(26).

DETERMINATION AND ANALYSIS THE MORPHOLOGY OF ROOT AND ROOT CANAL SYSTEM

Variations in root canal anatomy pose a significant challenge in the identification and management of endodontic cases. Missed or untreated canal portions account for up to 42% of treatment failures, ultimately affecting the success of the procedure(27). Hiraiwa et al. evaluated a deep learning system for analyzing panoramic radiographs and found it to be highly accurate in differentiating between single and multiple roots in the distal roots of mandibular first molars(28). With CBCT data, AI can reconstruct and analyze 3D root structures, aiding in better diagnosis and treatment planning. AI can assist in classifying root canal configurations (e.g., Vertucci types) for educational or diagnostic purposes.

**CONCLUSION**

Despite its expanding role in dentistry, artificial intelligence (AI) in conservative dentistry and endodontics faces key limitations. A major challenge is the reliance on large, high-quality annotated datasets, which are often limited especially in endodontics impacting model accuracy and generalizability(29). The "black-box" nature of deep learning models like convolutional neural networks (CNNs) also limits interpretability, making clinical validation difficult (30). Additionally, integration with existing digital systems remains costly and technically complex, and concerns over data privacy, consent, and liability persist. Its successful integration into clinical practice depends on overcoming these limitations. Ultimately, AI should be viewed as a complementary tool,one that augments, rather than replaces, the expertise and judgment of dental professionals.

Disclaimer (Artificial intelligence)

Author(s) hereby declare that NO generative AI technologies such as Large Language Models (ChatGPT, COPILOT, etc.) and text-to-image generators have been used during the writing or editing of this manuscript.

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