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Review Article

# Artificial Intelligence in Smart Dentistry: Clinical Applications, Operational Value, and the Future of Precision Oral Healthcare

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**Abstract:** Since the term artificial intelligence (AI) was first introduced in 1956, AI has evolved from a theoretical concept into a foundational pillar of high-performance dental medicine [1]. This article examines the current state of "Smart Dentistry," focusing on the integration of machine learning (ML) and deep learning (DL) algorithms across diagnostic imaging, precision treatment planning, predictive analytics, and administrative workflows. By synthesizing contemporary clinical evidence published between 2024 and 2026, this review highlights AI's emerging role as a clinical co-pilot enhancing diagnostic sensitivity, standardizing care delivery, reducing inter-observer variability, and improving practice efficiency and return on investment (ROI). Key challenges to adoption, including data bias, interpretability, regulatory oversight, and ethical liability, are discussed.Finally, the article outlines future directions centered on multimodal data integration, robotics, and personalized ("P4") dentistry, positioning AI as a transformative force in modern oral healthcare.

**Keywords:** Artificial Intelligence, Digital Dentistry, Computer-Aided Diagnosis, Deep Learning, CBCT Analysis, Predictive Analytics, Precision Dentistry.

**Abbreviation:** ML (Machine Learning), DL (Deep Learning), ROI (Return on Investment), P4 (Personalized, Preventive, Predictive, and Participatory care), CBCT (Cone-beam computed tomography), CNNs (Convolutional neural networks).

**Highlights / Key Points**

- Artificial intelligence rapidly transforming diagnostic accuracy, consistency, and efficiency across dental disciplines [2].
- Deep learning–based image analysis enhances detection of caries, periodontal disease, oral cancer, and periapical pathology [6,12].
- AI-supported diagnostics reduce inter-observer variability and improve early disease detection [3].
- Predictive analytics enable a shift from reactive treatment to proactive, preventive dental care [4].
- Responsible adoption of validated AI tools can improve clinical outcomes while preserving clinician-led decision-making [13].

## Introduction

In a recent scoping systematic review encompassing 109 studies, 53 distinct applications of artificial intelligence were identified across nearly all dental disciplines [3]. These applications included the processing of two-dimensional and three-dimensional imaging for the detection and assessment of dental caries, periodontal disease, oral cancer, oral and maxillofacial anomalies, cysts, tumors, and temporomandibular joint (TMJ) pathology [2]. AI has also demonstrated value in efficient archiving, longitudinal comparison, and analysis of radiographs, as well as in orthodontic treatment planning, restorative dentistry, prosthodontics, and esthetic dentistry [8].

Notably, the interpretation of cone-beam computed tomography (CBCT) scans has been shown to be significantly enhanced by computer vision and neural network architectures when compared with unaided human visual assessment [5]. As dentistry enters the upper echelons of modern healthcare delivery, the margin for diagnostic error continues to shrink while expectations for personalized, rapid, and evidence-based care continue to expand [5,15].

Artificial intelligence is no longer a peripheral innovation; it is increasingly becoming an indispensable ally in clinical decision-making [2]. From reading complex radiographic data sets to simulating long-term orthodontic outcomes, AI does not replace the clinician's expertise. Rather, it provides intelligence augmentation, enabling the translation of vast datasets into actionable, real-time clinical insights [15].

As frequently stated:

> "AI will not replace dentists—but dentists who use AI may replace those who do not."

## 1. Core AI Capabilities Transforming Dentistry

### I. Image Analysis and Interpretation

Convolutional neural networks (CNNs) and related DL architectures now demonstrate advanced capabilities in analyzing periapical, bitewing, panoramic, and CBCT images [6]. These systems can detect and quantify carious lesions, alveolar bone loss, and periapical pathology with high sensitivity, reducing diagnostic fatigue and improving consistency [7].

Early AI applications in dentistry focused on radiographic caries detection, digitally assisted periodontal charting, and patient risk assessment [4]. These systems laid the groundwork for current platforms capable of comprehensive diagnostic support. Contemporary commercial AI solutions many developed by innovative start-ups can simultaneously identify teeth, restorations, endodontically treated teeth, and implants, while detecting caries, calculus, periodontal disease, periapical lesions, anatomical variations, and other pathologies [8]. Increasingly, AI is also used for objective and reproducible bone-loss quantification, supporting diagnosis, monitoring, and treatment planning [2].

Clinical evidence supporting adoption continues to grow. Multiple studies demonstrate that AI systems perform reliably in the evaluation of dental radiographs, particularly in caries detection and periodontal bone-loss assessment [6]. In one recent study, a single AI platform outperformed clinical examination alone in detecting dental caries and periapical periodontitis among early-career dentists [3]. Importantly, diagnostic accuracy among experienced clinicians also improved with AI assistance, while inter-observer variability was significantly reduced [2].

These findings reinforce AI's role not as a replacement for clinical judgment, but as a powerful adjunct that enhances consistency, confidence, and quality of care.

### II. Oral Cancer Detection

Artificial intelligence has emerged as a particularly impactful tool in the detection, grading, and prognostic assessment of oral cancer one of the most critical challenges in dental diagnostics [12]. AI research has focused on differentiating malignant from non-malignant tissues, improving early detection, and supporting risk stratification [12].

A systematic review of 19 studies published between 2000, and January 2023 demonstrated that AI systems significantly outperformed conventional clinical approaches without AI support [12]. Reported sensitivity ranged from 97.76% to 99.26%, specifically from 92% to 99.42%, and overall diagnostic accuracy from 89.47% to 100%. A separate review of 17 studies further confirmed AI's ability to enhance early detection [12]. Deep learning models demonstrated sensitivity values between 79% and 98.75% and specificity between 82% and 100%. Machine learning approaches showed sensitivity ranging from 94% to 100% and specificity from 16% to 100%. Diagnostic accuracy ranged from 81% to 99.7% for DL and 43.5% to 100% for ML models, reflecting variability related to dataset quality and algorithm design.

Collectively, these findings underscore AI's growing role as a transformative adjunct in oral cancer screening, with the potential to significantly improve patient outcomes through earlier, more consistent detection.

### III. Endodontics

In endodontics, AI research has focused on the assessment of pulpal disease, periapical pathology, and vertical root fractures, as well as the determination of root canal morphology, pulpal cavity and lesion segmentation, working length estimation, force analysis during instrumentation, and evaluation of treatment failure [9].

A review of 24 studies comparing radiographic assessment with and without AI assistance found AI systems to be effective; however, substantial heterogeneity and risk of bias were observed [9]. A 2022 scoping review of 12 studies primarily focused on periapical pathology and vertical root fractures reported diagnostic accuracies exceeding 90%, with most studies utilizing DL applied to conventional radiographs [9].

In one high-quality investigation, DL-based apical lesion segmentation applied to more than 450 panoramic radiographs achieved a sensitivity of 0.92 and a precision of 0.84 [7]. The authors concluded that AI analysis of panoramic imaging may meaningfully support periapical lesion evaluation.

**IV. Implantology**

In implant dentistry, AI has been studied for diagnostic support, outcome prediction, and implant design optimization [11]. A 2024 systematic review and meta-analysis of 22 studies investigating AI-based implant identification on conventional radiographs reported an overall accuracy of approximately 93% [10]. Further high-quality studies focusing on commonly used implant systems were recommended.

A systematic review of 17 studies in 2023 found that seven studies predicting osseointegration or implant success achieved accuracies between 62% and 80% [11]. Another seven studies reported implant-type recognition accuracies between 94% and 98% [10]. The remaining studies explored AI-guided implant design modifications including porosity, length, and diameter highlighting AI's potential to evaluate the implant–bone interface and propose design optimization [11].

### 2. Predictive Analytics for Proactive Care

Machine learning models increasingly enable risk prediction for periodontal breakdown, implant failure, and disease progression by analyzing longitudinal patient data [4]. This capability represents a shift from reactive intervention to proactive, preventive care aligning dentistry with broader trends in precision medicine [15].

### 3. Administrative and Patient-Facing Applications

While clinical applications remain central, AI-enhanced administrative systems are already widely deployed [13]. Voice-activated AI allows hands-free retrieval of radiographs and patient records during procedures, improving efficiency and reducing cross-contamination risk. AI-integrated practice management software supports automated treatment validation, claims submission, payment processing, and revenue-cycle optimization [13].

As administrative automation expands, dental teams are increasingly freed to focus on patient care, clinical judgment, and human interaction—elements that remain irreplaceable [15].

## Discussion

### The Clinical Reality of AI Integration

#### Interpretability and the "Black Box" Challenge

Deep learning models often lack transparency, raising concerns regarding trust and accountability [2]. Explainable AI (XAI) systems that visually highlight decision-driving features are increasingly necessary for clinical acceptance [13].

#### Data Quality and Generalizability

AI performance can vary based on imaging hardware, software, and population demographics [3]. Validation across diverse datasets is essential to avoid bias and ensure equitable care [2].

#### Ethics, Liability, and Standard of Care

Current frameworks emphasize that clinicians remain the primary duty bearers [13,14]. However, as AI becomes embedded in routine workflows, failure to use validated AI tools may eventually be viewed as a deviation from the evolving standard of care [13].

#### Enhancing the Patient–Clinician Relationship

Contrary to concerns about dehumanization, AI may strengthen patient relationships by reducing administrative burden and improving visual communication and education [15].

#### Future Directions

Key anticipated developments include:

- Multimodal data integration and creation of patient "digital twins" [15].
- Real-time intraoperative AI guidance during surgical procedures [11].
- AI-driven education, simulation, and ergonomic optimization [13].
- Robotics-AI convergence for precision-guided interventions [14].

## Conclusion

Artificial intelligence is positioned to become an indispensable ally in modern dentistry amplifying, not replacing, the clinician's expertise. By adopting validated tools, ensuring responsible integration, and maintaining patient trust, dental professionals can transform AI from a technological novelty into a driver of better, safer, and more efficient care. As AI capabilities continue to expand, their role as a complementary force alongside clinical judgment will be central to the future of high-performance, precision-based dental practice.

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