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Artificial Intelligence in oral medicine and radiology: A review

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Abstract

Background: Artificial intelligence (AI) has evolved from theoretical concepts into an important component of contemporary dental science. Advances in machine learning, deep learning, artificial neural networks, and convolutional neural networks have enabled automated analysis of complex clinical and imaging data.

Aim: To review the current applications and clinical potential of AI in oral medicine, oral and maxillofacial radiology, pathology, and oral oncology.

Materials and Methods: A targeted literature review of 32 foundational references was undertaken, encompassing publications from the conceptual development of AI in 1955 through clinical applications up to 2021. Evidence was categorized into maxillofacial radiodiagnosis, diagnostic oral pathology, and oral oncology, with emphasis on algorithms, diagnostic targets, and comparison with human clinical performance.

Results: AI demonstrated promising diagnostic performance in automated tooth detection and numbering, dental caries identification, periodontal bone assessment, biopsy pre-screening, tissue spectral analysis, oral lesion classification, cervical lymph-node metastasis detection, and survival prognostication. In several applications, AI achieved diagnostic accuracy comparable to or exceeding experienced clinicians.

Conclusion: AI can augment clinical decision-making and improve diagnostic efficiency in dentistry. However, algorithmic transparency, data standardization, patient privacy, ethical governance, and multicentre validation remain essential for safe and evidence-based clinical integration.

Keywords: Artificial Intelligence, Machine Learning, Deep Learning, Oral Medicine, Oral and Maxillofacial Radiology, Oral Oncology, Diagnostic Imaging

Introduction

The idea of Artificial Intelligence (AI) was first formally mapped out in 1955 during the planning phases of the Dartmouth Summer Research Project. John McCarthy and his colleagues famously suggested that human learning and cognitive thinking could be broken down mathematically and recreated using machines [2] For several decades, the field went through dramatic highs and lows as early developers hit walls with limited computer processing speeds and memory. However, the medical world has recently seen an explosion of automated systems powered by modern GPU processing chips, digital diagnostic networks, and deep neural layer networks [9, 14].

In modern healthcare and cancer management, AI software has evolved from basic rule-based programming into deep learning models capable of picking up hidden visual patterns that easily bypass human eyes [24]. Because radiology and anatomical pathology rely so heavily on digital imaging, they naturally became the early testing grounds for these advanced tools [10, 24]. Stomatological specialties are currently mirroring these medical advancements, using machine learning to boost diagnostic accuracy, lower human error rates, and handle time-consuming clinical charting work [20]. Today, AI in dental medicine has moved past theoretical concepts and is actively setting new standards for clinical speed and accuracy [17,21].

Review of literature

Foundational Principles and Technical Infrastructures

To safely apply these tools in clinical practice, it helps to understand the underlying technology. Machine learning is a broad concept where algorithms review existing training data to find patterns and make predictions without being specifically hard-coded for every scenario. A key part of this discipline involves Artificial Neural Networks (ANNs)—mathematical systems modelled loosely after human neurons that pass data across input, hidden, and output processing layers [26].

Deep learning (DL) takes this a step further by stacking multiple hidden layers to independently pick out abstract features from complex data. Convolutional Neural Networks (CNNs) are a specialized type of deep learning engineered specifically to analyse structural grid patterns, like digital image pixels [3, 30]. CNNs use mathematical matrices to automatically isolate borders, textures, and specific anatomical shapes, making them the gold standard for reviewing maxillofacial radiographs and digital biopsies [3].

AI in Oral and Maxillofacial Radiology (OMFR)

Maxillofacial imaging produces highly structured digital images that are well-suited for neural network processing [22]. Current research shows that AI platforms maintain high diagnostic accuracy across intraoral periapical radiographs, panoramic films, and Cone Beam Computed Tomography (CBCT) scans [3].

1. Automated Tooth Detection and Numbering

Manual charting during initial patient intake is tedious and highly vulnerable to simple clerical mistakes. Implementing deep learning object-detection networks allows software to automatically isolate, track, and number individual teeth on digital periapical views [25]. These models help streamline the initial intake process by building digital records automatically.

2. Detection of Dental Caries

Spotting early or proximal dental caries remains a constant challenge due to overlapping tooth anatomy and minor variations in enamel mineral levels. Early efforts focused on using basic computerized caries detectors to help clinicians spot problem areas on digital intraoral films [12]. *Devito et al*. upgraded this approach by utilizing a multilayer perceptron neural network that significantly lowered inter-operator variance and improved diagnostic accuracy [26]. Modern CNN models are even more precise, identifying early demineralization zones that junior clinicians might easily miss [30]. Additionally, optical and biochemical setups like the Calcivis platform allow for real-time tracking of active enamel decay, helping providers step in with non-invasive therapies earlier [11].

AI in Oral Oncology: Screenings, Diagnostics, and Prognostication

Oral squamous cell carcinoma (OSCC) is notorious for its poor survival numbers, mostly because it is caught far too late. AI provides useful diagnostic support across early screening, diagnostic differentiation, and survival forecasting [18, 19].

1. Surface Lesion Discrimination and Deep Classification

Telling the difference between early oral potentially malignant disorders (OPMDs) and basic benign inflammation takes years of specialized clinical experience. *Welikala et al.* trained a deep learning network to automatically identify and classify lesions from everyday clinical camera photographs, offering a reliable option for low-cost community health screenings [5]. To improve how software reads fine details, Chan *et al*. created a texture-map-based branch-collaborative network that proved highly accurate at identifying early malignant changes from standard clinical snapshots [7].

2. Risk Profiling and Metastasized Staging

Predictive computer models excel at processing multi-variable patient files. Sharma and Om utilized probabilistic and general regression neural networks to build risk-stratification models, calculating oral cancer vulnerability by cross-referencing patient lifestyle habits with early clinical markers [16]. For oncological staging, *Ariji et al.* used deep learning systems to analyse contrast-enhanced computed tomography (CT) scans for cervical lymph node involvement [31]. The software matched or exceeded the accuracy of veteran radiologists, helping prevent hidden metastases from being overlooked [31].

3. Multi-Modal Survival Prognostication

Standard TNM staging criteria can sometimes fall short when attempting to forecast individual patient outcomes. *Kim et al.* built a deep learning survival model for oral cancer patients by combining standard clinical metrics, microscopic pathology notes, and genomic biomarker data [32]. This multi-modal deep learning system accurately forecast individual survival timelines and drug treatment responses, making true personalized medicine a reality for oral surgeons [32].

Methods

To map out the current clinical value and practical performance of AI across oral medicine, pathology, and radiology, we conducted a targeted literature review of the 32 provided foundational references.

Search and Selection Strategy

The analysed material includes peer-reviewed papers, clinical trials, healthcare white papers, and early engineering models published from the initial concept years (1955) through recent clinical applications (2021). The collected data was organized into three distinct clinical categories:

1. Maxillofacial radio diagnostics (caries, bone levels, and anatomy tracking)
2. Diagnostic oral pathology and optical tissue spectroscopy
3. Clinical oral oncology (lesion screening, tumour staging, and survival modelling)

Inclusion and Extraction Matrices

Every study was evaluated based on its clinical setup, the type of data used (radiographs, whole slide scans, camera photos, or spectral charts), the exact algorithmic framework deployed (CNN, ANN, PCA, or regression systems), and the final diagnostic targets. The performance metrics of these automated models were directly compared against human clinical standards. Review articles and clinician surveys were compiled separately to track practical deployment barriers, real-world workflow integration, and the ethical realities of healthcare computing.

Results

A comprehensive look at the pooled data indicates that modern artificial intelligence models can regularly achieve diagnostic accuracy that rivals or surpasses human dental specialists across multiple disciplines.

Radio diagnostic Efficiency

Deep learning algorithms demonstrated exceptional performance when handling routine image-based dental diagnostic tasks:

- **Anatomical Mapping:** Object-detection frameworks successfully automated the tedious process of locating and numbering teeth on routine periapical films [25].
- **Caries Identification:** Multi-layer networks and specialized CNNs demonstrated significantly higher

sensitivity in detecting early, hidden proximal decay compared to conventional visual checkups [26,30].

- **Periodontal Bone Assessment:** Deep neural systems matched the diagnostic capabilities of veteran clinicians when calculating bone loss lines on panoramic views, while simultaneously providing data-backed long-term tooth survival projections [28,29].

Pathological and Spectral Accuracy
In laboratory pathology setups, computerized workflows clearly optimized the processing of large, complex tissue samples:

- **Biopsy Pre-Screening:** Whole Slide Imaging (WSI) algorithms scanned massive high-resolution digital slide fields quickly, flagging atypical cellular zones to reduce diagnostic processing times [8].

- **Spectral Analysis:** Applying PCA and K-means nearest neighbour calculations to tissue fluorescence readings yielded highly reliable tissue classifications, proving that non-invasive optical biopsies are a viable future tool [15].

Oncological Screening and Prognostication
AI models delivered strong clinical value across all stages of oral oncology management:

- **Lesion Identification:** Advanced branch-collaborative networks and deep learning systems effectively separated early-stage malignant conditions from benign oral inflammation using standard camera photographs [5, 7].

- **Metastasis Tracking:** CNN evaluation of contrast-enhanced CT scans successfully identified cervical lymph node involvement with high accuracy, reducing staging errors [31].

- **Survival Modelling:** Multi-modal deep learning systems that combined physical clinical data with pathology findings and genomic profiles outperformed traditional TNM models in individual patient survival tracking [32].

Conclusion
Artificial intelligence has transitioned from its foundational theoretical roots into an indispensable pillar of modern dental science [2]. By significantly enhancing the detection of early dental caries, automating periodontal charting, mapping advanced morphometric variations, and facilitating the early detection and prognostic modelling of oral malignancies, intelligent systems are successfully augmenting the capabilities of the dental workforce.[5,13,28,30]
These technologies do not signal the displacement of the dental practitioner: instead, they introduce a collaborative clinical paradigm where machine analytical precision enhances human clinical intuition. [23]
However, to successfully integrate AI into daily dental practice, the profession must address ongoing challenges related to the transparency of "black box" algorithms, data standardization across multi-brand imaging platforms, and strict patient privacy protocols. [10] The dental academic community must take a proactive role by introducing comprehensive AI literacy into postgraduate curricula, establishing standardized multi-centre validation trials, and formulating clear ethical guidelines. Ultimately, the systematic, ethically grounded adoption of these intelligent frameworks will define the next gold standard of evidence-based patient care in oral medicine, radiology, and pathology. [14, 21]

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