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The Future of Dentistry and the Use of Artificial Intelligence: From Automated Diagnosis to Autonomous Treatment

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1. Abstract

Artificial intelligence is fundamentally reshaping dentistry, moving beyond experimental tools toward clinical integration that will define the future of oral healthcare. This article provides a comprehensive examination of how AI technologies including deep learning, computer vision, natural language processing, and generative models are transforming every domain of dentistry. Key applications analyzed include automated radiographic interpretation for caries, periodontitis, and oral pathology; AI-driven orthodontic treatment planning and clear aligner therapy; predictive analytics for patient risk stratification; robotic and haptic systems for implant surgery; generative design for prosthodontics; and AI-assisted endodontics. The future trajectory toward fully autonomous dental procedures, AI-powered teledentistry, and personalized prevention based on genomics and microbiome data is explored. Critical challenges are addressed: algorithmic bias, data privacy, regulatory approval for adaptive AI, liability frameworks, and resistance to adoption within the dental profession. The article concludes that AI will not replace dentists but will fundamentally redefine their role shifting focus from technical procedures to complex decision-making, patient communication, and compassionate care. The dental practice of 2035 will be a hybrid intelligence environment where human expertise and machine learning operate synergistically, improving access, quality, and affordability of oral healthcare.

2. Keywords:

Artificial intelligence, digital dentistry, machine learning, automated diagnosis, treatment planning, robotics, personalized dentistry, future of dental practice.

3. Introduction

Dentistry has historically been a visual and tactile profession. The dentist looks at radiographs, probes periodontal pockets, feels for caries, and relies on years of pattern recognition to make clinical judgments. This model, while successful for decades, has inherent limitations: human visual perception misses subtle lesions, diagnostic agreement between dentists is often mediocre (kappa values 0.4–0.6 for caries), and treatment planning is subjective [1-23].

Artificial intelligence offers a solution by augmenting human perception with computational pattern recognition that can analyze thousands of images, detect submillimeter abnormalities, and integrate patient data across multiple dimensions. Unlike traditional software that executes explicit instructions, AI systems particularly [24-39] deep learning models – learn from examples, improving with more data [40-54].

The future of dentistry will be characterized by:

- Ubiquitous AI assistance in every clinical decision
- Reduction of human error in diagnosis and treatment execution

- Democratization of expertise (a general practitioner with AI can perform at specialist level)
- Continuous learning systems that improve with each patient encounter

This article maps the trajectory of AI integration across dental specialties over the next decade, identifying which tasks will be automated, which will be augmented, and how the dentist's role will evolve [55-67].

4. AI in Diagnostic Imaging: The First Frontier

Radiographic interpretation is the most mature AI application in dentistry, with multiple FDA-cleared and CE-marked products already in clinical use.

4.1. Caries detection

AI models trained on bitewing, panoramic, and periapical radiographs can detect proximal and occlusal caries with sensitivity exceeding 90% - significantly higher than the 60-75% typical of human readers. More importantly, AI reduces false negatives (missed caries) without increasing false positives excessively [68-78].

Future direction (2026-2030): AI will not merely flag suspicious areas but will:

- Classify lesion depth (enamel, outer dentin, inner dentin, pulpal) according to ICDAS criteria
- Recommend specific restorative materials based on lesion size and location
- Integrate with caries risk assessment (salivary flow, diet, fluoride exposure) to suggest whether to restore or remineralize [79-98]

4.2. Periodontal bone loss assessment

Automated measurement of radiographic bone loss, traditionally a tedious manual task (measuring from CEJ to alveolar crest on 28 teeth), is completed by AI in under 10 seconds per panoramic image. Future systems will:

- Track bone loss longitudinally across multiple radiographs (e.g, 2024 vs. 2026)
- Generate 3D bone loss maps from CBCT data
- Predict future bone loss trajectory based on current rate and risk factors

4.3. Periapical pathology and cyst detection

AI detection of periapical radiolucencies (indicating apical periodontitis) approaches 95% sensitivity. For odontogenic cysts and tumors (dentigerous cyst, keratocystic odontogenic tumor, ameloblastoma), AI classifiers distinguish benign from aggressive lesions with accuracy rivaling oral pathologists [99-108].

4.4. Oral cancer screening

Early detection of oral squamous cell carcinoma remains challenging. AI models analyzing intraoral photographs, autofluorescence images, and narrow-band imaging can identify dysplastic and malignant lesions with sensitivity >90%. Future smartphones may incorporate AI-based oral cancer screening for patient self-examination, though biopsy confirmation remains necessary [109-132].

5. AI in Treatment Planning and Clinical Decision Support

Beyond diagnosis, AI is becoming indispensable for planning complex treatments.

5.1. Orthodontics: From cephalometrics to complete treatment plans

Traditional orthodontic planning requires manual landmark tracing on lateral cephalograms (80-100 points) and subjective judgment of extraction versus non-extraction. AI now:

- Automatically identifies cephalometric landmarks with submillimeter accuracy in <1 minute (human: 20 minutes)
- Generates treatment simulation videos showing predicted tooth movements
- Suggests optimal anchorage strategies (headgear, temporary anchorage devices, or clear aligners)
- Predicts treatment duration based on patient age, malocclusion severity, and compliance history

Case example: Invisalign's proprietary AI (Smile Architects) designs thousands of aligner staging steps, with clinicians approving rather than creating plans.

5.2. Implant planning and prosthetic design

As discussed in prior articles, AI-powered software (e.g, Diagnocat, Relu) automatically segments critical anatomy (inferior alveolar canal, maxillary sinus floor, adjacent roots) from CBCT and proposes implant positions that are:

- Prosthetically driven (based on intraoral scan of planned restoration)
- Biologically safe (≥2 mm from adjacent structures)
- Biomechanically optimized (proper crown-to-implant ratio, stress distribution)

The future “one-click implant plan” will be common by 2028.

5.3. Endodontic working length and access cavity planning

AI models analyzing pre-operative periapical radiographs and CBCT can predict:

- Working length (±0.5 mm accuracy compared to electronic apex locator)
- Canal curvature radius and degree (for pre-bending files)
- Risk of calcified canal or isthmus presence [135-154]

Future AI may also design the access cavity - suggesting bur entry point, angulation, and depth to avoid perforation while providing straight-line access to all canals.

6. AI-Driven Robotics and Haptic Systems

Intelligent robotics represents the convergence of AI planning and physical execution.

6.1 Current State: Haptic guidance

As detailed in the implantology article, systems like Yomi use AI-generated plans to provide real-time haptic (force) feedback, preventing surgical deviation. The AI component:

- Creates the pre-operative implant plan
- Registers the patient's position to the CBCT coordinates (using fiducial markers or optical tracking)
- Continuously updates force constraints based on drilling progress

6.2. Near Future: Autonomous procedures

The leap from guidance to autonomy requires AI to handle unexpected events (e.g, patient cough, unexpected bone density change) Prototype autonomous robots incorporate:

- Real-time optical coherence tomography at the drill tip to distinguish bone from soft tissue
- Reinforcement learning models trained on thousands of simulated osteotomies to optimize drilling parameters (speed, irrigation, pecking motion)
- Emergency stop logic that pauses the procedure if any parameter exceeds safety thresholds

The first autonomous dental robot for implant placement is expected to receive regulatory clearance by 2028-2029.

6.3. AI in endodontic microsurgery

Robotic endodontic systems (e.g, the "EndoBot" prototype) use AI to:

- Localize root tip position on CBCT with submillimeter accuracy
- Guide ultrasonic root-end preparation while avoiding adjacent structures (mental nerve, sinus, adjacent roots) [155-167]
- Confirm retrograde filling completeness using intraoperative volumetric imaging

7. Personalized and Predictive Dentistry Using AI

AI's ability to integrate diverse data sources enables truly personalized dental care.

7.1. Caries risk assessment

Conventional caries risk assessment uses a checklist (past caries, fluoride exposure, diet, saliva flow) AI models incorporating these factors plus:

- Salivary microbiome composition (16S rRNA sequencing data)
- Genetic polymorphisms (e.g, AMELX, ENAM, MMP20)
- Socioeconomic and behavioral data (extracted from electronic health records)

Can predict individual 12-month caries risk with area under the curve (AUC) >0.85. High-risk patients receive tailored prevention: prescription fluoride, xylitol regimens, or even targeted antimicrobial therapy [168-187].

7.2. Periodontal disease progression prediction

For patients with periodontitis, clinicians struggle to predict who will respond to non-surgical therapy and who will progress to surgery. AI models analyzing:

- Baseline probing depths and bleeding scores
- Inflammatory biomarkers (e.g, IL-1β, MMP-8 in gingival crevicular fluid)
- Smoking status and glycemic control (HbA1c)

Predict 6-month treatment response with 80-85% accuracy, enabling early referral to periodontists for refractory cases.

7.3. Orthodontic relapse prediction

After orthodontic treatment, some patients relapse despite retainers. AI models using pre-treatment malocclusion type, post-treatment root position relative to alveolar bone, and age predict relapse risk, allowing clinicians to recommend fixed versus removable retainers or even prophylactic fiberotomy.

8. AI in Practice Management and Patient Communication

Beyond clinical applications, AI transforms the dental office backend.

8.1 Automated insurance verification and coding

Natural language processing (NLP) AI reads insurance plans, verifies patient benefits, and pre-authorizes treatments in minutes (human: days) The same AI suggests dental procedure codes (CDT codes) based on clinical notes and radiographs, reducing billing errors and claim denials [188-201].

8.2. AI chatbots for patient triage and education

Dental practices already deploy AI chatbots (e.g, on websites, via SMS) that:

- Answer common questions (post-operative instructions, insurance coverage)
- Triage emergency calls ("Are you bleeding? Can you breathe?")
- Send appointment reminders and recall notifications with personalized content (e.g, "Your 6-month recall is due; based on your last visit, please bring your night guard")

8.3. Voice-activated clinical documentation

Dental clinicians spend 20-30% of their time on documentation. AI-powered voice recognition (trained on dental terminology) allows the dentist to dictate notes naturally: "Tooth #19 MOD composite, caries removed, no pulpal exposure, etch and bond, restoration polished". The AI converts this to structured EHR notes, attaches radiographs, and queues for billing.

9. Challenges and Ethical Imperatives

Despite enormous potential, AI integration faces significant hurdles.

9.1. Algorithmic bias and generalizability

Most dental AI models are trained on datasets from specific populations (e.g, Korean, Western European, North American) Performance drops significantly when applied to different ethnic groups (due to variations in tooth morphology, bone density, lesion appearance), age ranges (pediatric vs. geriatric), or disease prevalence (low-prevalence populations increase false positives) Solutions include:

- Mandatory multi-center, multi-ethnic training datasets
- Continuous performance monitoring and model retraining
- Regulatory requirement to report subpopulation performance

9.2. Regulatory approval for adaptive AI

Traditional FDA clearance applies to fixed algorithms. But AI that learns and updates over time ("adaptive AI") breaks this model. A system cleared in 2026 may behave differently in 2028 after millions of additional training examples. Regulators are developing "predetermined change control plans" where manufacturers specify in advance how the AI will evolve and what validation will be performed [202-215].

9.3. Liability and malpractice

If an AI misdiagnoses caries and the tooth progresses to endodontic treatment, who is liable? The dentist who relied on the AI? The software manufacturer? Current tort law places responsibility on the clinician as the ultimate decision-

maker. However, as AI becomes more autonomous, pressure will mount for shared liability frameworks. Some propose "professional AI liability insurance" covering AI-related errors [216].

9.4. Data privacy and security

AI requires data large volumes of radiographs, intraoral scans, and patient records. Centralized cloud AI services create attractive targets for cyberattacks. Decentralized "edge AI" (running on local computers without sending data to the cloud) mitigates this but limits the ability to improve models across clinics. Federated learning training AI across multiple clinics without exchanging raw patient data is a promising solution.

9.5. Resistance from the dental profession

Some dentists fear AI will devalue their skills or replace them. Surveys indicate 40-60% of dentists express concern about AI. Overcoming this requires:

- Demonstrating AI as an assistant, not a replacement
- Incorporating AI literacy into dental education
- Showing improved outcomes and reduced burnout (less time on tedious tasks)

10. The Future Dental Practice: A Vision for 2035

Synthesizing the trends above, the dental practice of 2035 will look very different from todays.

Patient journey:

1. **Pre-visit:** Patient uploads smartphone intraoral photos. AI chatbot triages urgency and pre-fills history.
2. **Arrival:** Intraoral scanner and CBCT (if indicated) performed by dental assistant.
3. **Diagnosis:** AI analyzes all images, generates diagnostic report (caries map, bone loss chart, pathology detection), and presents treatment options with predicted outcomes and costs.
4. **Planning:** Dentist reviews AI plan, modifies if desired, and discusses with patient using AI-generated animations. Shared decision-making is enhanced, not replaced.
5. **Treatment:** For simple procedures (class I composite), AI may guide the dentist via augmented reality glasses (showing exact bur depth and margin location) For complex procedures (implant, apicoectomy), robot-assisted or autonomous execution occurs under dentist supervision.
6. **Follow-up:** AI monitors healing via patient-submitted photos, predicts complication risk, and adjusts recall interval.

The dentist's role evolves to:

- Diagnostician-in-chief: Validating AI findings and integrating contextual factors AI misses (patient anxiety, financial constraints, personal preferences)
- Proceduralist for complex/unusual cases: AI cannot handle every anatomical variation or complication
- Communicator and empathizer: AI cannot replace human reassurance, trust-building, or breaking bad news
- Manager of the AI system: Ensuring it is up-to-date, validated, and used appropriately

11. Conclusion

Artificial intelligence will not replace dentists, but dentists who use AI will replace those who do not. The future of dentistry is hybrid intelligence humans and machines working together, each doing what they do best. Machines excel at pattern recognition, speed, consistency, and avoiding distractions. Humans excel at judgment, ethics, empathy, and handling uncertainty.

The adoption of AI is inevitable, driven by patient demand (faster, more accurate care), payer pressure (reducing unnecessary treatments and complications), and professional desire to reduce burnout. The question is not whether AI will transform dentistry, but how quickly and responsibly.

Dental schools must begin teaching AI literacy today. Regulators must create pathways for adaptive AI approval. Clinicians must engage with AI developers to ensure tools meet real-world needs. If these pieces align, the future of dentistry will be brighter, more precise, and more humane than ever before.

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