



## Digital frontiers in periodontal disease management

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### Abstract

Digital technology is transforming periodontology by enhancing diagnosis, treatment, and patient management. Periodontitis, a chronic inflammatory disease caused by biofilm, requires early and accurate detection, yet conventional methods such as probing and 2D radiography have limitations in precision and reproducibility. Digital innovations including digital radiography, intraoral scanners, cone-beam computed tomography, and artificial intelligence -driven platforms provide real-time, accurate data, improving early diagnosis, individualized treatment planning, and long-term monitoring. Salivary biosensors and wearable devices enable non-invasive, chairside, and remote monitoring of key biomarkers, supporting personalized care. Advanced treatment modalities such as 3D bioprinting, platelet-rich plasma/fibrin, and digitally guided regenerative protocols allow precise tissue reconstruction and accelerated healing. AI-integrated digital twins and T-Scan occlusal analysis optimize patient-specific interventions, while tele-periodontics and digital patient education platforms expand access and improve engagement. Digital Smile Design further facilitates aesthetic and functional treatment planning. Collectively, these digital solutions support minimally invasive, predictive, and patient-centered periodontal care. Integration of AI, biosensors, 3D bioprinting, and tele-dentistry represents a shift toward more precise, accessible, and outcome-driven periodontal management. This review highlights current applications, benefits, and future directions of digital periodontology, emphasizing its potential to redefine clinical practice and enhance oral healthcare outcomes.

**Keywords:** Artificial intelligence, CBCT, digital twin, 3D bioprinting, platelet-rich fibrin, salivary biosensors, tele-periodontics

### Introduction

With digital technology transforming clinical practice, dentistry has advanced significantly beyond its historical foundations. Periodontology, where precise diagnosis is critical, has particularly benefited from these innovations. Periodontitis, an inflammatory disease caused by biofilm accumulation, requires accurate and early evaluation for effective management. Conventional diagnostic methods, such as probing and two-dimensional radiography, often fall short in terms of precision, reproducibility, and early detection. Digital radiography, intraoral scanners, cone-beam computed tomography (CBCT), and artificial intelligence (AI)-driven diagnostic platforms now work together to give doctors real-time, accurate, and repeatable data. These technologies not only make diagnoses more accurate, but they also improve patient care, personalized treatment planning, and long-term monitoring. This review emphasizes the significance of digital solutions in enhancing periodontal health and revolutionizing modern periodontal care [1, 2].

### Digital diagnostics in periodontology

#### Salivary biomarker testing with digital biosensors

Salivary diagnostics has become a non-invasive, patient-friendly, and effective method for the early detection and monitoring of periodontal disease. Saliva contains a wide range of biomarkers, including enzymes, cytokines, antibodies, and microbial DNA, that reflect periodontal tissue damage and inflammation.

Digital biosensors often enhanced with nanomaterials and microfluidic technology enable rapid, sensitive, and real-

time detection of key biomarkers such as matrix metalloproteinase-8, interleukin-1 $\beta$ , and tumor necrosis factor- $\alpha$ , which are directly associated with periodontal breakdown and disease progression [3, 4].

Recent advancements have led to the development of smart biosensors that integrate wireless communication, microprocessors, and smartphone connectivity, thereby enabling chairside or even remote at-home monitoring. These point-of-care (POC) tools significantly strengthen periodontal diagnostics by supporting early disease detection, individualized treatment planning, and continuous disease monitoring [5].

#### Digital Imaging and Diagnostics

Digital imaging has revolutionized periodontal diagnostics by offering more accurate, efficient, and patient-friendly alternatives to conventional radiographic methods. Digital radiography, using solid-state detectors such as complementary metal-oxide semiconductors (CMOS) and charge-coupled devices (CCD), delivers high-quality images instantly while reducing radiation exposure. Indirect systems utilizing photostimulable phosphor plates provide reusable options with excellent image quality, further improving clinical efficiency [6]. Compared to traditional intraoral periapical and bitewing radiographs, digital imaging minimizes common issues such as projection errors, anatomical overlapping, and lack of three-dimensional visualization. However, the 2D nature of intraoral radiography still limits its diagnostic accuracy in detecting periodontal craters, furcation involvement, and infra-bony defects.

Advancements like digital subtraction radiography (DSR) allow clinicians to detect even minute changes in bone lesions over time, enhancing longitudinal follow-up [7]. Meanwhile, cone-beam computed tomography (CBCT) has emerged as a gold standard for comprehensive three-dimensional evaluation. CBCT provides superior visualization of periodontal structures, bone defects, and furcation involvement, facilitating precise diagnosis, treatment planning, and interdisciplinary collaboration [8, 9].

### **Artificial Intelligence and Risk Assessment in Periodontology**

Artificial intelligence and machine learning are transforming periodontal diagnostics by providing rapid, objective, and highly reproducible results. Deep learning models, particularly convolutional neural networks (CNNs), have demonstrated superior accuracy in detecting alveolar bone loss, furcation involvement, and periodontal defects on radiographs and CBCT compared to conventional methods. Beyond diagnostics, AI-driven platforms integrate clinical parameters, systemic conditions, and microbiological data to generate individualized periodontal risk scores, supporting preventive and precision-based interventions. Tools such as the Periodontal Risk Calculator exemplify this trend, enabling clinicians to stratify patients into different risk categories and tailor therapy accordingly [10].

### **Digital Treatment Planning and Surgical Interventions 3D Bioprinting**

Three-dimensional (3D) bioprinting has opened new horizons in regenerative periodontology by enabling the precise fabrication of multiphasic scaffolds that closely mimic the structural and functional architecture of periodontal tissues, including bone–ligament–cementum interactions. Using CAD/CAM-based designs, drug-loaded, bioresorbable scaffolds can be positioned with high accuracy, supporting the simultaneous regeneration of alveolar bone, periodontal ligament, and cementum. The incorporation of stem cells, growth factors, and bioactive molecules further enhances cellular integration and accelerates wound healing. This technology not only optimizes implant placement but also reduces inflammation, promotes osteogenesis, preserves the alveolar ridge, and lowers donor site morbidity. In addition, 3D bioprinting allows dose-specific drug delivery, real-time customization during surgery, and creation of simulation models for patient education and surgeon training, making it an indispensable tool in precision periodontal therapy [11, 12].

### **Platelet-Rich Plasma and Platelet-Rich Fibrin in Periodontal Regeneration**

Autologous platelet concentrates have emerged as valuable adjuncts in periodontal regeneration by harnessing the body's intrinsic healing capacity. Platelet-rich plasma, a first-generation concentrate, is rich in growth factors such as platelet-derived growth factor, transforming growth factor- $\beta$ , and insulin-like growth factor-I, which stimulate angiogenesis, cell proliferation, and bone formation. However, limitations related to preparation complexity and risk of cross-infection prompted the development of platelet-rich fibrin, a second-generation concentrate [13].

PRF provides a biocompatible fibrin matrix that gradually releases bioactive molecules, promoting sustained healing of both hard and soft tissues. It has demonstrated benefits in

periodontal defect correction, sinus augmentation, implantology, pulp revascularization, and maxillofacial reconstruction. Its ease of preparation, cost-effectiveness, and ability to enhance angiogenesis and reduce inflammation make PRF a powerful adjunct to digitally guided regenerative protocols.

### **Digital Twin Technology**

The concept of the digital twin a virtual replica of the patient has begun to influence periodontal care. By integrating CBCT data, intraoral scans, and AI-driven predictive models, a digital twin allows simulation of disease progression, treatment responses, and long-term outcomes. Such models facilitate patient-specific planning, continuous monitoring, and interdisciplinary collaboration, moving periodontology toward proactive and predictive healthcare [14].

### **Digital Monitoring and Maintenance T Scan system in Periodontics**

Occlusal trauma, although not a primary etiological factor for periodontitis, can exacerbate disease progression and compromise regenerative outcomes. Traditional tools like articulation paper and waxes lack the ability to measure occlusal force, timing, and sequence of contacts. The T-Scan system introduces a computerized solution using ultra-thin pressure sensors that record bite duration, contact sequence, and relative force intensity. Its advanced software provides dynamic, color-coded visualizations of occlusal contacts, enabling accurate identification of premature contacts and imbalances. The latest version, T-Scan III (7.0), has been shown to guide precise occlusal adjustments, thereby improving periodontal stability and healing [15]. This system strengthens personalized treatment planning and enhances long-term outcomes in periodontal therapy.

### **Tele-periodontics**

Tele-periodontics, a subspecialty of tele dentistry, leverages telecommunications to extend periodontal care to remote and underserved populations. By integrating digital radiography, intraoral cameras, and tele probes, it enables remote diagnosis, consultation, monitoring, and treatment planning. Through real-time videoconferencing and store-and-forward systems, general practitioners can collaborate with periodontists for expert input, thereby improving early detection and reducing delays in treatment. Tele-periodontics also enhances continuing education via tele-training and facilitates postoperative monitoring, making high-quality periodontal care more accessible and cost-efficient [16]. While challenges such as infrastructure limitations and data security remain, its potential to improve equity in periodontal care is significant.

### **Digital Patient Education & Communication Digital Smile Design**

Digital Smile Design (DSD) represents a paradigm shift in aesthetic and functional dentistry, merging software-based analysis, digital imaging, and patient-centered planning. By assessing dento gingival, dental, and facial parameters, DSD enables clinicians to simulate outcomes with remarkable precision even before initiating treatment [17]. This enhances patient-clinician communication, builds trust, and improves acceptance by allowing patients to visualize predicted results. Clinically, DSD supports more accurate diagnosis,

individualized treatment planning, and documentation for medico-legal purposes. Reviews, such as that by Cervino *et al.*, have highlighted its role in optimizing aesthetic and functional outcomes, while simultaneously strengthening patient satisfaction and engagement <sup>[18]</sup>.

### Wearable Biosensors and Cloud-Based Periodontal Care

Wearable devices and smartphone-integrated biosensors are enabling continuous monitoring of salivary or gingival crevicular biomarkers linked to periodontal inflammation. These innovations hold promise for early detection of exacerbations, remote disease tracking, and improved patient compliance. Cloud-based platforms further enhance continuity of care by securely storing and sharing digital periodontal charts, radiographs, and biosensor data across practices. This not only facilitates multi-centre research and epidemiological studies but also supports global collaboration in periodontal care <sup>[19]</sup>.

### Future Perspectives

The future of digital periodontology lies in greater integration of artificial intelligence, machine learning, and wearable biosensors. AI algorithms are expected to enable early detection, risk prediction, and personalized treatment planning, while saliva-based biosensors integrated with smartphones and wearables may allow continuous home-based disease monitoring <sup>[20]</sup>. Emerging 3D bioprinting technologies hold the promise of patient-specific tissue regeneration, potentially achieving complete periodontal restoration. Tele-periodontics is anticipated to expand into global collaborative networks, improving access and professional education across resource-limited regions. Collectively, these innovations point toward a future where periodontal care is proactive, predictive, personalized, and patient-centered.

### Conclusion

Digital technologies have ushered in a transformative era in periodontology, bridging gaps between accurate diagnosis, individualized therapy, and long-term monitoring. From biosensor-based salivary diagnostics and advanced imaging techniques to 3D bioprinting, platelet concentrates, T-Scan systems, tele-periodontics, and Digital Smile Design, these tools enhance precision, efficiency, and patient engagement. By fostering minimally invasive interventions, improved predictability, and sustainable outcomes, digital solutions are redefining periodontal practice. As integration advances, periodontology will become increasingly accessible, personalized, and outcome-driven, setting new standards of excellence in oral healthcare.

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