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The Utilization of Digital Tools for the Diagnostic Assessment and Therapeutic Management of Periodontalpathologies

Huiqi Wang[1, *]

[1]Southern Medical University,Guangzhou, China

*Corresponding author: huiqiwang@ldy.edu.rs

Abstract:

Digital technologies have a wide range of significance and far-reaching application potential in modern dentistry. They have become one of the key drivers of progress in dentistry. With the rapid development of computer technology, imaging technology and artificial intelligence, digital tools are completely reshaping the way dentistry is practiced. These tools not only improve the early diagnosis rate and diagnostic accuracy of various dental diseases, but also help dentists to tailor personalized treatment plans for different patients, which improves treatment outcomes and patient satisfaction. This article reviews the status of various digital technologies in the diagnosis and medical treatment of periodontal diseases, focusing on the specific applications of cone-beam computed tomography (CBCT), computer-aided design and manufacturing (CAD/CAM), three-dimensional printing technology, and the artificial intelligence technology. Meanwhile, a reasonable prediction and outlook of the future development trend and application prospects of these digital tools are provided at the end of the article.

Keywords: Periodontics, Digitalization, CAD\CAM, CBCT, Artificial Intelligence

1. Introduction

The historical development of periodontal disease can be traced back to the ancient civilisations of mankind, and the understanding of its causes and treatments has evolved over time. Initially, the causes of periodontal disease were unknown and treatment was mainly surgical, such as tooth extraction. In the 20th century, with the emphasis on oral health and the development of modern medicine, the causes, pathologies and treatments of periodontal disease were gradually studied.

At the beginning of the 20th century, the theoretical basis of periodontal disease was primarily the infection doctrine, which held that periodontal disease was primarily caused by oral bacterial infections. During this period, periodontal treatments were more limited and focused on mechanical removal of tartar and plaque and basic surgical procedures. With the development of microbiology, scientists gradually discovered the key role of plaque in periodontal disease and proposed that periodontal disease was caused by inflammation of the gums and periodontal tissues. The establishment of the plaque theory made it possible for prophylactic treatments such as regular tooth brushing and scaling to become effective preventive measures.

With the development of periodontology in the mid-20th century, periodontal disease was no longer seen as a problem confined to the oral cavity, but as closely related to systemic health. Extensive research has established a strong link between periodontal disease and various systemic conditions, including cardiovascular disease, diabetes mellitus, low birth weight, and chronic lung disease [1]. During this time, the concept of “periodontal medicine” has gradually emerged, emphasising that periodontal disease is not only a local oral health problem, but can also affect systemic health through inflammation and infection.

In the second half of the 20th century, the treatment of periodontal disease entered a new phase with the gradual development of non-surgical treatments, especially for early periodontal disease, where scaling of the gums and periodontal pockets gained popularity. With advances in biomaterials and technology, breakthroughs have also been made in periodontal regenerative therapy, making it possible to repair and regenerate periodontal tissues using bone graft materials and membrane techniques. These techniques have been remarkably effective in preserving affected teeth and restoring periodontal structures.

In the 21st century, with the advancement of technology, the diagnosis and treatment of periodontal disease has become more refined. Cone beam computed tomography (CBCT) and other high-precision imaging technologies are widely used in the diagnosis and treatment of periodontal diseases, making the diagnosis of periodontal diseases more accurate. CBCT can provide three-dimensional images of periodontal tissues, which can help clinicians assess the specific situation of alveolar bone loss and formulate a more personalized treatment plan. CAD/CAM and 3D printing technologies provide powerful tools for the diagnosis and treatment of periodontal disease, especially in the production of surgical guides and tissue regeneration and restorative systems. CAD/CAM and 3D printing technologies provide powerful tools for the diagnosis and treatment of periodontal diseases, especially in the production of surgical guides, tissue regeneration and restorations.AI technologies show great potential in the diagnosis and treatment of periodontal diseases. With enhanced capabilities in image analysis, personalized treatment design and disease prediction, AI will provide dentists with more accurate and efficient treatment tools. In addition, the application of digital technologies such as Digital Smile Design (DSD) has greatly improved the aesthetics of periodontal treatment [2].

Currently, the treatment of periodontal disease not only includes traditional mechanical removal and surgical means, but also combines modern technologies such as the use of biomaterials and digital image-guided therapy to provide patients with more personalized and precise treatment plans. This paper focuses on the application of CBCT, CAD\CAM technology, 3D printing technology, and artificial intelligence technology in dental diagnosis and treatment, and makes a reasonable prediction of the future development of related technologies.

2. Application and prospects of CBCT in the diagnosis and treatment of periodontal diseases

The application of CBCT technology in the diagnosis and treatment of periodontal disease has received much attention in recent years and has shown great potential especially in the diagnosis and treatment planning of periodontal disease. CBCT affords clinicians high-definition, 3D visualizations, enabling more precise risk evaluation and the formulation of either preventative or strategically incremental (involving soft tissue and/or bone) periodontal treatment plans tailored to individual patients [3]. Amparo Ramis-Alario et al. showed that in 70% of cases, CBCT provided clinically relevant information that was not available from conventional 2D imaging [4].This section summarizes the current status and future perspectives of CBCT technology in the management of periodontal disease.

2.1 Imaging studies of the amount of bone loss in the oral cavity

At present, CBCT technology is a widely utilized diagnostic tool in the assessment of periodontal diseases, particularly in the evaluation of alveolar bone levels and three-dimensional observation of periodontal lesions in complex cases. Conventional two-dimensional radiographs frequently lack the requisite resolution to accurately depict the intricate details of the bone structure. In contrast, CBCT employs a three-dimensional imaging technology that enables the clear visualization of periodontal tissue structures. Furthermore, CBCT has proven to be an accurate and dependable imaging modality for assessing the extent of bone loss within the oral cavity. M. Ruetters and colleagues conducted a clinical and imaging investigation where they utilized CBCT to examine the vertical bone loss at 260 sites across 10 cadavers. The study’s results indicated that Cone Beam Computed Tomography (CBCT) serves as an efficacious technique for identifying and delineating vertical, buccal, and oral

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bone loss. Moreover, CBCT possesses the capability to refine treatment strategies and to forecast the biological constraints of the alveolar membrane within the context of orthodontic interventions [5].

2.2 High-precision surgical guide production

In a study by Pandey et al., it was demonstrated that the utilization of CBCT in the diagnosis of complex periodontal lesions can facilitate the acquisition of more comprehensive imaging data, thereby enabling physicians to formulate treatment plans with greater accuracy. In the context of surgical planning, CBCT technology can facilitate the creation of precise surgical guides for dental implants and periodontal surgery by integrating imaging data with computer-aided design (CAD) [6]. Komuro et al. observed in a study that the utilisation of three-dimensional images generated by CBCT can accurately assess the position of the implant. When combined with a digitised model, this data can be used to generate highly accurate surgical guides, thereby enhancing the surgical success rate [7]. This technique enables the planning of complex periodontal surgeries, particularly those involving implants and bone regeneration, with a greater degree of precision, thereby reducing the risks and potential errors associated with surgical procedures.

2.3 Progress monitoring of CBCT in the treatment of periodontal disease

Furthermore, CBCT is a valuable tool for monitoring the treatment progress of periodontal diseases. The regular acquisition of CBCT images enables physicians to monitor the integration of bone grafts or periodontal regenerative materials in real time, facilitating prompt adjustments to the treatment plan [8]. This is crucial for the long-term management of periodontal patients, particularly in cases necessitating multiple surgeries or bone grafting treatments, where the imaging data furnished by CBCT can markedly enhance outcomes. Despite the growing prevalence of CBCT technology in periodontal practice, there remain a number of challenges and opportunities for its future development. Firstly, while the radiation dose of CBCT technology is relatively low, caution should be exercised with regard to long-term and frequent use. Furthermore, the resolution of CBCT image data is susceptible to fluctuations depending on the equipment and operating techniques employed. This can potentially result in instances of suboptimal image quality or data inconsistencies, thereby necessitating heightened precision in diagnosis[7] (Table.1).

Table.1 Overview of referenced articles

Reference	Theory	result	Conclusion	Keyword
[3]	CBCT measurements of the vertical dimension of the buccal and lingual bones	CBCT measurements were accurate and reliable, with a median buccal bone loss of 3.8 mm and a median difference of -0.2 mm from clinical measurements	CBCT is very accurate in detecting and characterizing buccal and lingual bone loss and is suitable for combined orthodontic and periodontal treatment	Cone beam CT, buccal lateral bone, orthodontics, periodontics
[5]	Evaluation of diagnostic imaging methods for bifurcation lesions	CBCT was 82.4-84% accurate for FI detection, exceeding IO and OPG, but neither met the gold standard	CBCT is an effective tool for detecting F but still needs to be combined with other methods to improve accuracy	Bifurcation lesions, cone-beam CT, diagnostic methods, systematic evaluation
[6]	3D technology in orthodontic treatment	CBCT and Intraoral Scanner Improve Accuracy of Orthodontic Treatment and Reduce Errors in Traditional Model Measurements	Digital scanning technology significantly improves results in orthodontic treatment and reduces errors associated with manual measurements	Intraoral Scanner, CBCT, Orthodontics, 1D Scanning
[7]	Comparison of scanning methods in digital dental implant technology	CBCT measurements were smaller than actual values, with shrinkage ranging from 1.8% to 6.9%, whereas intraoral and model scans showed less shrinkage	Attention needs to be paid to the accuracy of data matching between different scanning modalities to avoid clinical errors	Digital dental implants, model scanning, intraoral scanning, cone beam CT

2.4 Future prospects for CBCT

It is anticipated that CBCT technology will be integrated with artificial intelligence (AI) to enhance the automation of image analysis. The application of AI algorithms to CBCT images enables the automatic identification of areas affected by periodontal lesions, facilitating the delivery of precise diagnostic recommendations and reducing the workload of physicians. The advent of 3D printing technology has enabled the integration of CBCT image data with 3D printing, thereby facilitating the creation of more personalized surgical guides and restorations for periodontal surgeries. This approach has the potential to enhance the precision and efficacy of treatment.

3. Application and Prospect of CAD\CAM and 3D Printing Technology in Periodontal Disease Diagnosis and Treatment

The advent of computer-aided design and computer-aided manufacturing (CAD/CAM) technology has led to significant advancements in the field of dentistry. CAD/CAM technology is currently employed in a multitude of diagnostic and treatment operations, particularly in the context of periodontal disease management. The technology's potential for enhancing efficiency and precision in dental procedures is immense. It can be stated that CAD and CAM provide a seamless connection from design to manufacturing, with 3D printing representing a pivotal link in this chain. As an additive manufacturing technology, it enables the rapid and personalized production of items from digital models [8]. The integration of these three elements enhances the efficiency of the design, validation, and production processes, reduces time and cost, and facilitates the manufacturing of complex and customized products related to dentistry (Fig.1).

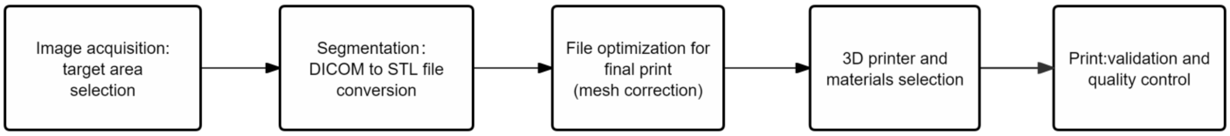

Fig.1 3D Printing Process

3.1 Application of digital impressions and surgical guides

In periodontal surgery, the conventional method of taking dental impressions is frequently time-consuming and laborious, and is susceptible to inaccuracies due to a number of factors. A digital impression system enables rapid acquisition of high-resolution 3D images of teeth and periodontal structures within the oral cavity. The data obtained can be used by dentists and researchers to design customized surgical guides that can be manufactured with high precision through 3D printing technology. This significantly reduces the risk of surgical errors and postoperative complications. In the article by Eva Anadioti et al., the researchers evaluated the retention and stability of 3DP CRDPs by two experienced prosthodontists at one week, five months, 12 months, and 18 months after denture implantation using the Modified Kapur Index (MKI). Both groups demonstrated a notable enhancement in denture retention and stability in comparison to the initial denture ($p < 0.05$). Additionally, the findings indicated that the 3D approach led to heightened satisfaction across all outcome surveys [9]. The advantages of enhanced precision are also evident in the capacity to more effectively reconcile aesthetic and functional considerations during the design and restoration of smiles.

3.2 Periodontal tissue regeneration and restoration

The application of the three-in-periodontal-tissue-regeneration concept is primarily reflected in the capacity to provide personalized tissue regeneration scaffold design and manufacturing. By employing CAD/CAM technology, medical professionals are able to customize biomaterial scaffolds to align with the specific requirements of periodontal tissues, utilizing the patient's oral data to precisely control the shape, size, and various parameters of the scaffolds. In comparison to traditional scaffolds, 3D-printed bioscaffolds present novel solutions for tissue regeneration. Such scaffolds can be coupled with stem cells or growth factors to facilitate the regeneration of hard and soft tissues [10]. An additional example is the capacity to customize the shape and pore structure of scaffolds when utilizing bone grafting materials produced via 3D printing technology to enhance cell attachment and growth conditions, which subsequently accelerates the tissue healing process.

3.3 Personalization of restorations and dentures

In the advanced stages of periodontal disease, a significant proportion of patients are at risk of tooth loss. CAD/CAM technology enables the fabrication of highly precise, personalized restorations based on a rapid mouth scan, while also matching these restorations to the patient's actual oral condition. This technology enables the surgeon to design and fabricate an array of dental prostheses, including dentures, crowns, and bridges, tailored to the specific needs of each patient. In comparison to conventional restorative techniques, the utilisation of 3D-printed restorations has

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been demonstrated to markedly diminish material wastage whilst simultaneously facilitating superior marginal fit and strength [11]. This not only serves to enhance patient comfort but also extends the service life of the restorations and improves aesthetics.

3.4 Prospects for future development of CAD/CAM technology

3.4.1 Integration of digital diagnosis and treatment processes

With the maturity of CAD/CAM technology and 3D printing technology in the dental field, the future development trend will be to combine them with other digital diagnosis and treatment tools to form a complete digital workflow. For example, by combining with 3D scanning technology, 3D printing technology and artificial intelligence, the entire digital operation from diagnosis to treatment can be realized. This will dramatically shorten the diagnosis and treatment time, and reduce surgical errors [12].

3.4.2 Application of new materials

With the advancement of material science, emerging technologies such as 4D printing are expected to play a greater role in the treatment of periodontal diseases.4D printing materials are able to self-regulate under external stimuli (e.g., temperature or humidity), which makes dynamic repair of periodontal tissues possible [9]. This smart material may be used in the future for periodontal regenerative scaffolds that are able to adjust in real time to the growth needs and growth status of the tissue, thus improving the treatment outcome.

3.4.3 Advancement of personalized precision medicine

In the future, personalized periodontal treatment will rely on breakthrough CAD/CAM technology advances. By integrating a patient's periodontal data, medical history information, and biological characteristics, dentists will be able to utilize CAD/CAM technology to provide a customized treatment plan for each patient. This will not only enhance short-term treatment outcomes, but also significantly improve long-term patient health [11, 12].

4. Exploring the Application and Future Potential of Artificial Intelligence Technology in the Diagnosis and Management of Periodontal Disease

The advent of artificial intelligence (AI) has precipitated a surge in its utilisation within the medical domain, particularly in the context of periodontal disease diagnosis and treatment. In dentistry, AI models have been specifically designed to assist in the diagnosis of oral diseases ranging from common caries problems to more complex periodontal diseases and oral cancers.AI models can aid in diagnosis, treatment planning, and patient management in endodontic treatment. Combined with modern tools like CBCT, AI can be an invaluable aid to clinicians [13]. Periodontal disease is a prevalent chronic inflammatory condition that primarily affects the tissues that support the teeth, including the gingiva and alveolar bone. In severe cases, it can result in the loosening or even loss of the affected teeth [14]. This section presents a review of the current status and future prospects of the application of AI technology in the diagnosis and treatment of periodontal diseases.

4.1 Application of Artificial Intelligence in Periodontal Diseases

The application of AI technology in periodontal disease diagnosis primarily concentrates on image analysis, particularly the automated analysis of image data through deep learning algorithms to enhance diagnostic efficiency and accuracy. AI technology has demonstrated considerable potential in the early diagnosis of periodontal disease. The conventional diagnosis of periodontal disease relies on the physician's expertise and image examination, whereas AI can analyze a vast array of clinical data in the database, including X-rays, CT images, and so forth, to augment the accuracy of diagnosis. For instance, Ozden et al. used artificial neural networks (ANN), decision trees (DT), and support vector machines (SVM) to classify periodontal illnesses in 150 patients. They found that SVM and DT performed better in diagnostic support than artificial neural networks [15].

4.1.1 Radiographic Diagnosis:

It has been demonstrated that convolutional neural networks (CNN) can facilitate the identification of periodontal bone loss to a considerable extent. For instance, Kurt-Bayrakdar et al.'s AI system, which is built upon the U-Net architecture, exhibits proficiency in the identification of comprehensive alveolar bone loss, horizontal and vertical bone loss, as well as bifurcation defects. Notably, the system achieved an area under the curve (AUC) score of 0.951 for the detection of total alveolar bone loss, signifying a substantial level of diagnostic precision [14]. Additionally, research has highlighted the AI system's exceptional precision in identifying periodontal pathological alterations, implying its potential as an invaluable asset for assessing disease severity and devising treatment strategies.

4.1.2 Detection of periapical inflammation:

In the detection of apical periapical (AP) inflammation, artificial intelligence (AI) demonstrated high accuracy and sensitivity. For instance, the AI system utilising the YOLOv3 deep learning architecture demonstrated high detection accuracy in the mandible; however, it exhibited suboptimal performance in the maxilla, particularly in cases of uncertain foci with expanded periodontal space. This indicates the potential for a limitation in the performance of AI in specific anatomical regions [16].

4.1.3 Detection of gingivitis:

Additionally, artificial intelligence has been employed for the automated detection of gingivitis through the analysis of intraoral photographs, thereby facilitating the generation of automated plaque control recommendations. The sensitivity of the AI system in detecting gingivitis has been demonstrated to be 0.92, while its specificity is 0.94. These values are comparable to those observed in human dentists [17]. Seven investigations documented the application of AI for diagnosing gingivitis through intraoral imagery, exhibiting a diagnostic accuracy that spans between 74% and 78.2% [18].Such a system could be utilized to monitor the efficacy of patients' plaque control and provide them with continuous professional counsel, thereby enhancing their oral health outcomes.

4.1.4 Periodontal grading and bone loss assessment:

Bone resorption due to progressive dentoalveolar disorders, triggered by invasive oral or periodontal microbiota, orthodontic interventions, traumatic injuries, or systemic/local pathological states, ranks as one of the most formidable oral and maxillofacial conditions to address, as it results in inflammation that disturbs bone homeostasis [19].In their study, Alotaibi and colleagues demonstrated the application of convolutional neural network (CNN) algorithms for the assessment of periodontal bone loss severity. The VGG-16 model enabled the system to detect and classify different degrees of alveolar bone loss. Despite achieving a classification accuracy of 73%, the system performed poorly in a multiclassification model, highlighting the challenges of AI in subdividing periodontal grading [20] (Table.2).

Table.2 Application of different algorithms

Areas of application	Models/Algorithms	Sample size	Diagnostic performance indicators	Reference
Periodontal Bone Loss Detection	U-Net	1121 images	AUC:0.951 (total alveolar bone loss) Sensitivity:1 Specificity:0.995	[14]
Periapical Infection Detection	YOLOv3	306 images	Correct mandibular recognition rate: 84.5% Correct maxillary recognition rate: 28%	[16]
Gingivitis Detection	DeepLabv3+	567 images	Sensitivity: 0.92 Specificity: 0.94 .	[17]
Grading and Evaluation of Alveolar Bone Loss	VGG-16	1724 images	Accuracy: 73% (normal/pathologic) Accuracy of severity grading: 59%	[20]

4.2 Prospects for Future Development

The application of artificial intelligence (AI) technology in the context of periodontal diseases is a promising avenue of research. Future research may be improved in the following ways:

4.2.1 Dataset optimization:

Large-scale, high-quality datasets will help improve the generalization ability and diagnostic accuracy of AI algorithms. Future AI systems will need to integrate multiple sources of data, including clinical data, imaging data, etc., to build more comprehensive periodontal health assessment models [20].

4.2.2 Personalized treatment planning:

An intelligent diagnosis and treatment planning system that incorporates AI has the potential to develop personalized treatment plans based on individual periodontal conditions, thereby optimizing treatment outcomes and patient experience [12]. The integration of patients' oral health data allows for the support of long-term periodontal disease management, which significantly improves patients' quality of life.

4.2.3 Real-time monitoring and remote diagnosis and treatment:

It is anticipated that the real-time monitoring functionality of AI will facilitate remote monitoring and management of periodontal health in the future, thereby offering patients convenient and cost-effective treatment options [15].

5. Summary

It is evident that the implementation of CBCT technology in the diagnosis and treatment of periodontal diseases offers a promising avenue for advancement. From diagnosis to treatment planning, CBCT provides a powerful tool for

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medical practitioners, offering three-dimensional images and precise diagnostic data. As technology continues to evolve, the integration of CBCT in periodontal treatment is poised to become more pervasive and sophisticated, offering enhanced support for more accurate diagnosis and treatment of periodontal diseases.

The application of CAD/CAM technology and 3D printing technology demonstrates considerable potential for use in the diagnosis and treatment of periodontal diseases. In addition to enhancing the precision of surgical procedures and reducing the required treatment time, these technologies play a pivotal role in the development of bespoke restorations and periodontal tissue regeneration. As technology continues to evolve, these innovations will offer new and improved solutions for periodontal disease treatment, accelerating the digital transformation of the entire dental field.

The implementation of AI in the diagnosis and treatment of periodontal disease is already demonstrating tangible outcomes, particularly in the domains of image diagnosis, disease grading, and treatment planning. As technology continues to advance, AI will offer substantial assistance in the early diagnosis and personalized treatment of periodontal diseases, significantly enhancing clinical work efficiency and patient health management.

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