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The Digital Trio Revolutionizing Oral Restoration: A Review on Intraoral Scanning, 3D Printing, and Artificial Intelligence

Jiaxin Lin

Wuhan University, Wuhan, China
linjiaxin7288@163.com

Abstract. With the continuous development of the digitalization process in oral medicine, digital oral scanning, 3D printing and artificial intelligence technologies are gradually integrating and driving the transformation of the diagnostic model in oral restoration. This article, through systematic literature retrieval and analysis, integrates recent domestic and international research findings and clinical data on relevant digital technologies in the field of oral restoration, and explores the characteristics and applications of these three technologies in oral restoration. The results show that digital oral scanning can improve the accuracy of impression taking and clinical efficiency, 3D printing realizes the efficient personalized manufacturing of restorations, and AI technology can further optimize the design.

Keywords: Oral restoration, Digital intraoral scanning, 3D printing technology, AI technology

1. Introduction

With the continuous advancement of digital technology, digital intraoral scanning, 3D printing, and artificial intelligence (AI) have exhibited significant advantages in the field of dental restoration and are gradually realizing the integrated application of multiple technologies. However, most current research focuses on the verification of the "availability" of individual technologies, and there is a lack of systematic exploration of collaboration among different technologies, system integration methods, and the effect of intelligent optimization on the overall diagnosis and treatment process. This paper aims to study the characteristics, application models and the value of mutual collaboration of digital intraoral scanning, 3D printing and artificial intelligence in the field of dental restoration. The research methods include a systematic literature review (SLR) and clinical data analysis. The significance of this study lies in providing a theoretical basis and practical references for future digital dental restoration technologies, promoting the collaboration and integration of digital technologies in the field of dental restoration, enhancing the efficiency and precision of dental restoration, and improving patients' comfort during treatment.

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2. Digital scanning (oral scanning)

Currently, intraoral scanning technology, facial scanning technology, and cone beam computed tomography (CBCT) are three commonly used and rapidly developing technologies in restorative dentistry. Intraoral scanning technology uses a portable scanning probe to directly scan the surface morphology of teeth and surrounding soft tissues in the patient's mouth and obtain corresponding information [1].

2.1. Advantages

2.1.1. Technical aspects

Higher Precision and Ease of Operation Compared with traditional impressions, digital intraoral scanners have various advantages. Digital intraoral scanners can directly scan the teeth, dental arches, soft tissues, and other structures in the patient's mouth to obtain corresponding model data, which can be transmitted to software to generate digital models. The operation is simple and fast [2]. Moreover, in terms of technology, digital intraoral scanners have higher accuracy and repeatability. Traditional impression techniques have low precision and are prone to errors. Digital intraoral scanners use digital technology to directly scan and obtain information, thus effectively avoiding the deformation issues that may occur over time during the traditional impression process, as well as errors such as wear during the production of gypsum models [3].

2.1.2. Clinical efficiency

Shortening Model Acquisition TimeIn clinical practice, digital intraoral scanners do not have the cumbersome process of traditional impression taking, and can more efficiently obtain models, saving time for model collection [3]. Through the collection of model data from 70 patients in different groups, the results showed that the time taken for digital intraoral scanning was less than that for traditional impression taking ($P < 0.05$), indicating that this technology can effectively save time in the model collection step [4].

2.1.3. Economy and experience

Reducing Costs and Efficiency while Improving Patient ComfortIn addition, since digital intraoral scanners no longer rely on impression materials, they help save materials and reduce associated transportation and storage costs [3]. In the study of 70 patients, the frequency of impression retakes, medical waste emissions, and model wear for patients using digital intraoral scanners were all lower than those for patients using traditional impression techniques ($P < 0.05$) [4]. Secondly, the data from digital intraoral scanners are easier to store, transmit, and share, and can be directly observed and designed in software [3].

On the other hand, compared with taking impressions with materials in the mouth, digital intraoral scanning is more comfortable. In the above-mentioned study, the comfort scores of patients during impression taking with digital intraoral scanners were higher than those with traditional impression taking ($P < 0.05$), indicating that this technology can significantly improve the patient's medical experience [4].

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2.1.4. Added value

Optimizing restoration by combining digital colorimetry technologyIn addition, after digitally acquiring the patient's intraoral data, digital colorimetry technology can be used for color matching. This technology utilizes professional colorimetric instruments to accurately collect the color information of the patient's natural teeth, prepared teeth, and soft tissues, providing objective and reliable color references for clinicians and dental technicians. This approach can effectively reduce the subjective biases of doctors or technicians in traditional color matching methods, improve the accuracy and credibility of color matching results, make the restoration more closely resemble the color of the patient's natural teeth, and thereby enhance the aesthetics of the restoration and patient satisfaction [2].

2.2. Application

2.2.1. Pre-repair design

Digital intraoral scanning enables clinicians or technicians to draw aesthetic reference lines directly on a computer using relevant software, thus eliminating the need to draw on printed photos or physical models. This is more accurate and convenient [5]. At the same time, clinicians can also use the Digital Smile Design (DSD) tool to help patients visualize and intuitively understand the expected treatment outcome before treatment begins. It also allows them to make some personalized designs based on their individual needs, enhancing the predictability of treatment and patient satisfaction [6]. Compared to simple two-dimensional photos, the three-dimensional data model established digitally, combined with the aforementioned digital shade-matching technology, can make the final product more natural and aesthetically pleasing.

2.2.2. Implant restoration

During the implant process, using digital intraoral scanning, along with facial scanners, mandibular movement analyzers, and CBCT, to create a virtual dynamic model of the patient can improve the predictability and accuracy of the entire treatment process [7]. After obtaining an accurate intraoral model of the implant position and other soft and hard tissues through digital intraoral scanning, simulating the patient's occlusion and movement using the virtual model can increase the success rate of implant restoration.

2.2.3. Edentulous occlusion

Given that edentulous patients have lost their dentition, leaving only soft tissues in the oral cavity, traditional impression techniques require dentists to have high technical proficiency. Considering the usually complex intraoral conditions of these patients, digital intraoral scanning can accurately capture the soft tissue information in the oral cavity, effectively avoiding the errors that may occur with traditional impression taking.

3. 3D printing technology

3D printing technology, also known as additive manufacturing (AM), is based on the digital model of computer-aided design (CAD). It not only reduces material waste and enhances design flexibility but also achieves high control over the manufacturing process through computer control [8]. This

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technology works by slicing the collected data file vertically into thin layers and printing them layer by layer, with each layer printed on top of the previous one until the final form of the restoration is produced.

3.1. Features

By using a variety of materials, 3D printing technology can precisely reproduce the three-dimensional structure of complex natural teeth and ensure the standardization and consistency of the manufactured restorations [9].

In oral restoration, 3D printing technology has higher accuracy and flexibility. Compared with traditional restoration methods, 3D printing technology can directly print and manufacture restorations based on digital models, while traditional restoration requires a more complex and cumbersome mold-making and processing process. Therefore, using 3D printing can reduce errors and uncertainties in the manufacturing process. In addition, 3D printing technology can also provide personalized solutions for different patients based on their different anatomical characteristics [10].

3.2. Application

3.2.1. Dental restoration

3D printing technology can accurately generate corresponding 3D models based on patients' CT scans or intraoral scans, and make fine optimizations and adjustments to their crown restorations. Professor Liu Jian and others selected 72 patients with single-tooth dental defects as the research subjects. The conventional group was restored using traditional silicone rubber impression and gypsum model, while the observation group was restored using 3D printing and intraoral scanner technology. The results showed that the satisfaction rate of the observation group with tooth restoration reached 97.22%, which was significantly higher than that of the conventional group (77.78%), with statistical significance (x^2 = 4.571, P = 0.032). At the same time, in the post-restoration assessment, the quality of life scores of the observation group in the dimensions of social function, material life, psychological function, and physical function were significantly higher than those of the conventional group, with statistically significant differences ($P < 0.001$). Additionally, the anxiety and depression scores of the observation group after restoration were lower than those of the conventional group, with statistical significance ($P < 0.001$) [11].

3.2.2. Complete denture

Generally, the intraoral conditions of edentulous patients are relatively complex. Traditional impression and model-making methods not only require high technical skills from dentists but also involve a long and complicated process. However, by obtaining corresponding information through digital intraoral scanning technology and using computer-aided design and 3D printing technology, the efficiency can be significantly improved, and personalized trays can be quickly fabricated, greatly simplifying the manufacturing process [12].

3.2.3. Implant restoration

Improving and enhancing the effective osseointegration between implants and surrounding bone tissue can increase the success rate of implant restoration. Studies have shown that 3D printing can improve the surface characteristics of implants. The micro/nano hierarchical structures constructed

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on the surface can significantly increase their roughness and hydrophilicity, while accelerating the deposition and mineralization of hydroxyapatite, thereby enhancing the adhesion, differentiation, and matrix mineralization of bone marrow mesenchymal stem cells (BMSCs). Most importantly, this structure can promote new bone formation and rapid [13]. Application of AI in digital technology

The application of artificial intelligence (AI) technology in the field of prosthodontics has developed rapidly. Through predictive analysis, it can effectively improve the efficiency of diagnosis and treatment, enhance diagnostic accuracy, develop personalized treatment plans, and optimize long-term patient care. Therefore, AI technology has been widely integrated into the optimization of diagnostic tools, the formulation of treatment plans, and various key links in the care process [14]. At the same time, in clinical operations, the application of AI technology can effectively simplify work processes and reduce human errors, thereby promoting the realization of precision medicine.

In prosthodontics, the assistance of AI's intelligent design function can significantly improve the production efficiency of prostheses. This technology can automatically generate crown and bridge design schemes that meet biomechanical standards through precise analysis algorithms. Meanwhile, with 3D printing technology, it can effectively ensure the accuracy of prostheses. Additionally, in implantology, AI technology also plays a significant auxiliary role in preoperative planning and implant positioning. By analyzing CBCT images and using intelligent algorithms to determine the optimal implant site, AI can improve surgical accuracy and reduce the risk of complications [15].

4. Conclusion

With the continuous advancement of digital oral scanning, 3D printing, and artificial intelligence (AI) technologies, oral restoration is gradually entering a new era of precision, efficiency, and personalization. Digital oral scanning technology can obtain real-time and accurate three-dimensional data of the oral cavity, improving the patient's medical experience while laying a solid foundation for the subsequent design of restorations. AI can assist doctors in intelligent diagnosis, treatment planning and prognosis prediction by analyzing massive amounts of data, thereby increasing the success rate of treatment. 3D printing technology enables the rapid customization and production of restorations (such as crowns and implant guides), shortening the treatment course and reducing costs. The combination of the three will create an efficient intelligent diagnosis and treatment closed loop: from precise data acquisition and intelligent analysis to efficient manufacturing. This will make oral restoration more precise, efficient and personalized, while improving the success rate of treatment and patient experience, and promoting the transformation of oral healthcare from "standardization" to "precise and personalized customization".

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