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Design and Practice of Digital Technology Applications in Oral Rehabilitation

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Abstract: This paper elaborates the core principles of digital technology in the field of oral restoration (including the digital impression technology that uses optical means such as structured light scanning and laser scanning to accurately construct three-dimensional oral models), and the digital smile design technology that integrates facial and oral data with the help of professional software and dental database, and makes aesthetic restoration planning based on facial proportion, lip-tooth relationship, etc. CAD/CAM technology for precise design and manufacture of restorations. Studies have shown that digital technology has obvious advantages in clinical applications. When a single tooth is repaired, the digital impression is taken by an intraoral scanner, and the CAD/CAM system can shorten the process and improve the accuracy. In the case of multiple teeth and full mouth restoration, finite element analysis and other technical means were used to optimize the occlusal relationship, improve masticatory efficiency and improve patient satisfaction. In terms of implant restoration, CBCT data and digital impressions are integrated, and professional implant planning software is used to ensure accurate implant implantation. In short, digital technology can narrow the repair gap with high precision, benefit oral health, shorten the treatment cycle with high efficiency, facilitate patients and institutions, and enhance the comfort of patients' medical treatment, which has outstanding advantages in all aspects. However, the spread of digital technology faces certain difficulties. On the one hand, high-end equipment is expensive to purchase, calibration, maintenance and software updates increase operating costs to some extent, and training dental professionals to be skilled in technology is time-consuming and costly. On the other hand, the problem of data security and standardization needs to be solved urgently, to ensure the information security of patients and to establish a unified data standard. In general, in the future, under the trend of equipment miniaturization, portable intraoral scanner equipment is expected to be developed. With the support of 5G networks, remote dental services can benefit patients in remote areas.

Keywords: Oral Rehabilitation; Digital Technology; CAD/CAM; Digital Impression.

1. Introduction

Prosthodontics is a comprehensive subject, the core goal of which is to fully restore the anatomical form and physiological function of oral organs. Prosthodontics is not limited to the repair of damaged teeth, but also focuses on improving the quality of life of patients in all aspects. A sound oral structure is essential for basic activities such as chewing, speech expression and maintaining a good self-image.

Traditional methods of oral restoration are highly dependent on the manual operation skills and traditional technical means of dentists. In practice, dental professionals often use a variety of impression materials to make a solid model of the patient's mouth and then create a prosthetics. The traditional oral repair process has many inherent defects that cannot be ignored (human factors can easily cause various kinds of errors). For example, the impression material may have incomplete coverage, deformation and other problems during curing, which may lead to the mismatch between the final prosthesis and the actual situation of the patient's mouth, affecting the repair effect. In addition, traditional restoration takes a long time, from the initial impression to the subsequent multiple attempts and adjustments of the restoration, will significantly prolong the treatment cycle of patients, increasing the burden and inconvenience of patients' medical treatment[1-2].

With the rapid development of digital technology, the field of dental prosthetics has entered a new era. Digital technology has been deeply applied to the whole process of oral restoration treatment, from the initial digital diagnosis of oral conditions, to the digital design and manufacturing of prosthetics, and then to the final precise placement, each link demonstrates the unique advantages of digital technology. Digital technology innovation is expected to reshape the standard of oral medical service, so that oral prosthesis treatment in the accuracy, efficiency and patient experience to achieve a full range of improvements, to bring more high-quality, efficient and comfortable oral medical services for patients.

2. Core Technical Principles of Digital Technology in Oral Rehabilitation

2.1. Digital Impression Technology

Digital impression technology is a major revolution in oral medicine, which completely changes the traditional impression making method. Its core device, the intra-oral scanner, uses optical triangulation or structured light projection principles to work by emitting specific light patterns to the teeth, gums and surrounding oral soft tissues. When the reflected light returns, high-precision sensors capture multi-dimensional changes in intensity, phase and Angle. Then the advanced algorithm deeply analyzes and processes these data to build an accurate 3D digital oral model[3].

Take the intraoral scanner with blue light scanning technology as an example, its scanning speed is fast, and it can capture the microscopic structure such as the fine

development groove and socket on the tooth surface, and the precise outline of the gum edge, which is far more accurate than the traditional impression materials. The traditional impression material is affected by the moist environment of the patient's mouth, the difference of manipulation and the shrinkage of the material solidification, which is easy to distort, and then affect the accuracy of the repair system.

Digital impression data can be transmitted in real time. Through secure and efficient network communication technology, the 3D oral data obtained from the scan can be transmitted directly to the dental laboratory. After receiving the data, the restoration is designed with the help of professional CAD software, without waiting for the physical impression to arrive. This technology not only shorens the cycle of oral repair treatment, improves the efficiency of diagnosis and treatment, but also avoids the problems such as damage and loss that may occur in the transportation of physical impression, providing guarantee for the accuracy and stability of oral repair treatment[4].

2.2. CAD/CAM Technology

In the field of dental prosthetics, computer-aided design and manufacturing (CAD/CAM) technology is a two-stage workflow that relies on digital impressions. In the design process, dental technicians use professional software that integrates a large database of tooth shapes, dimensions and anatomical templates.

When designing restorations, such as crowns, technicians import digital impression data into CAD software. The software can accurately control the shape, size and occlusal relationship of the prosthesis. For example, it can simulate the natural movement of the jaw during chewing, ensuring that the newly designed tooth crown is highly adapted to the patient's bite. Doctors can optimize and adjust the aesthetic effect of the tooth crown according to the color and transparency of the patient's original teeth.

After the design is finalized, the data is transferred to a CAM (Computer Aided Manufacturing) device, commonly a milling machine or a 3D printer. During milling, dental special materials (such as ceramics, metal alloys) are fixed to the milling machine, and the CAM software precisely controls the motion of the milling tool according to the design parameters to cut the prosthesis that meets the requirements. 3D printing uses materials such as resin to build the restoration through additive manufacturing, which can create complex structures that are difficult to achieve with traditional milling processes [5].

2.3. Digital Smile Design

Digital smile Design (DSD) is an innovative technology in the field of oral aesthetics, which deeply integrates aesthetic concepts and digital technology to create a harmonious and natural smile aesthetic effect that complements the facial features of the patient.

The DSD process begins with comprehensive data acquisition. By taking high-resolution facial images from multiple angles, the patient's natural smiling state, lip position and facial proportion relationship are accurately recorded. The intraoral scanning technique was used to obtain fine anatomical data of teeth and gums. With the help of professional software, the data is analyzed comprehensively (taking into account aesthetic criteria such as the golden ratio) to determine the ideal proportion of teeth in a smile and build a precise aesthetic evaluation system [6].

The software uses algorithms to accurately calculate the optimal ratio of length and width of each tooth to create a harmonious and beautiful smile shape. To simulate the effect of different tooth shapes, colors and arrangement on the overall visual effect of smile. After the simulation is completed, a virtual preview of the smile repair plan is presented for the patients, so that the patients can intuitively feel the expected effect of the treatment, actively participate in the formulation of the treatment plan, and put forward personal needs and preferences for smile improvement.

3. Clinical Applications of Digital Technology in Oral Rehabilitation

3.1. Single-Tooth Restoration

Single tooth restoration is a very common application scenario of digital technology in the field of dental restoration. When a tooth is damaged or missing, the first step is to obtain a high-precision digital impression of the affected tooth area.

In the case of a patient with a decayed molar, the intraoral scanner enables rapid and precise acquisition of detailed information about the structure of the remaining teeth, the adjacent teeth, and the surrounding gingival tissue. This digital impression is then sent to the CAD/CAM system. The dental technician, using the CAD software, designs a custom-fit dental crown. The software allows for the adjustment of the crown's shape to ensure proper contact with adjacent teeth and a perfect occlusion [7].

As shown in Table 1 "Comparison between Traditional and Digital Single-Tooth Restoration Methods", the differences between traditional and digital single-tooth restoration methods are stark:

Table 1. Comparison between Traditional and Digital Single-Tooth Restoration Methods

Comparison Items	Traditional Single-Tooth Restoration	Digital Single-Tooth Restoration
Impression-taking Time (minutes)	15-20	5-8
Restoration Fabrication Time (days)	5-7	1-2
Restoration Marginal Sealing Error (μm)	50-100	10-30

The shorter impression-taking time in digital restoration reduces patient discomfort, as they are not required to hold the impression material in their mouth for an extended period. The significantly reduced restoration fabrication time means that patients can have their tooth restored in a much shorter time frame, minimizing the disruption to their daily lives. The improved restoration marginal sealing error ensures better long-term durability of the restoration, reducing the risk of leakage, decay, and recurrent problems.

3.2. Multiple-Tooth and Full-Mouth Restoration

For more complex cases involving multiple-tooth loss or full-mouth rehabilitation, digital technology offers even greater advantages. When dealing with multiple-tooth restorations, accurate reconstruction of the occlusal relationship is crucial.

Digital technology allows for the creation of a virtual model of the entire dental arch, enabling dentists to precisely analyze and adjust the occlusion. In a case of a patient with multiple missing teeth in the upper and lower jaws, digital impressions are taken of both arches. The CAD/CAM system then designs a series of dental bridges or implant-supported restorations. The software can simulate the forces exerted during chewing and adjust the design accordingly to ensure even distribution of forces across the restoration [8].

It can be seen from Table 2 "Comparison between Traditional and Digital Multiple-Tooth/Full-Mouth Restoration Methods" that digital technology has brought significant improvements:

Table 2. Comparison between Traditional and Digital Multiple-Tooth/Full-Mouth Restoration Methods

Comparison Items	Traditional Multiple-Tooth/Full-Mouth Restoration	Digital Multiple-Tooth/Full-Mouth Restoration
Initial Wearing Comfort Score (out of 10)	5-6	7-8
Number of Occlusal Adjustments	3-5	1-2
Patient Satisfaction Rate (%)	60-70	80-90

The higher initial wearing comfort score in digital restorations can be attributed to the precise fit achieved through digital design. Fewer occlusal adjustments not only save time for both the patient and the dentist but also reduce patient discomfort during the adjustment process. The significantly increased patient satisfaction rate demonstrates the effectiveness of digital technology in meeting patients' expectations for both function and aesthetics.

3.3. Implant Restoration

Implant restoration is a complex procedure that requires utmost precision. Digital guides play a crucial role in ensuring the accurate placement of dental implants.

Before the implant surgery, the patient undergoes a cone-beam computed tomography (CBCT) scan, which provides detailed three-dimensional images of the jawbone. These data are integrated with digital impression data to build a complete virtual model of the patient's mouth. The dental team used professional software to plan the implant placement, taking into account factors such as bone density, the proximity of key structures and the ideal location of the future prosthesis[9].

Based on the pre-built oral virtual model and planning scheme, the digital implant guide was customized. In the actual operation of the implant surgery, the guide plate, as a key positioning and guiding tool, accurately guides the running trajectory of the drilling instrument according to the preset planting path, ensuring that the implant can be accurately implanted in the best position planned in advance, and improving the accuracy and safety of the implant surgery. Detailed data can be found in Table 3 "Comparative Analysis of traditional and digital implant restoration Methods" :

The digital guide has high precision, accurately guides the implant implantation during the operation, avoids repeated exploration and adjustment, and greatly reduces the operation time. The application of this technology can significantly reduce the implant deviation, reduce the risk of implantation failure, and ensure the long-term stability of the implant. It also reduces the incidence of postoperative complications, improves the prognosis of patients, reduces the need for secondary surgery, and improves the medical experience.

Table 3. Comparative analysis of traditional and digital implant restoration methods

Comparison Items	Traditional Implant Restoration	Digital Implant Restoration
Surgery Time (minutes)	60-90	40-60
Implant Placement Deviation (mm)	0.5-1.0	0.1-0.3
Post-operative Complication Rate (%)	10-15	3-5

4. Advantages of Digital Technology in Oral Rehabilitation

4.1. High Precision

Digital technology has brought unprecedented precision advantages to oral prosthetics, capturing oral structures with micron precision to ensure the precise fit of the prosthetics. Traditional impression materials are difficult to accurately reproduce the fine structure of teeth and gums, which often leads to marginal gaps in restorations. These gaps are easy to breed bacteria, causing dental caries, periodontitis and other oral problems.

The digital impression technology can restore the oral shape with high precision, and the CAD/CAM technology can further optimize the accuracy, and the edge gap of the restoration can be controlled in a very small range. As shown in Table 1, the edge sealing error for traditional restorations is 50-100 microns, while that for digital restorations is reduced to 10-30 microns. The high precision not only extends the service life of the prosthesis, reduces the inconvenience of replacing the prosthesis for patients, but also significantly improves oral health and reduces the risk of oral diseases.

4.2. High Efficiency

Digital technology has streamlined the entire oral rehabilitation process. The elimination of traditional steps such as pouring physical impressions, sending them to the laboratory, and waiting for the return of the wax-up model has significantly reduced the overall treatment time.

In a traditional single-tooth restoration, the process from taking impressions to receiving the final restoration could take up to a week. With digital technology, the entire process can be completed in as little as a day or two. The quick transfer of digital data between the dental office and the laboratory, along with the rapid manufacturing capabilities of CAD/CAM systems, has revolutionized the efficiency of oral rehabilitation.

4.3. Enhanced Patient Comfort

Patient comfort is a top priority in modern dentistry, and digital technology has made significant strides in this area. Traditional impression-taking materials, such as alginate, can be messy and cause discomfort, often triggering the gag reflex in many patients.

Digital impression-taking, using intra-oral scanners, is a non-invasive and relatively quick process. Patients simply need to open their mouths while the dentist maneuvers the scanner around the oral cavity. As indicated in Table 1, the impression-taking time is reduced from 15-20 minutes in traditional methods to 5-8 minutes with digital technology, which significantly contributes to increased patient comfort.

Moreover, traditional impression-taking often leads to nausea and vomiting in about 30% of patients. In contrast, digital impression-taking reduces this incidence to less than 5%. Additionally, the overall precision of digital restorations means fewer adjustment appointments. For example, as shown in Table 2 for multiple-tooth and full-mouth restorations, the number of occlusal adjustments is reduced from 3-5 times in traditional methods to 1-2 times with digital technology. This reduction in adjustment appointments further decreases the overall discomfort associated with the treatment process.

5. Challenges Faced by Digital Technology in Oral Rehabilitation

5.1. High Equipment and Technology Costs

The adoption of digital technology in oral rehabilitation comes with a hefty price tag. High-end intra-oral scanners, which are essential for digital impression-taking, can cost anywhere from 120,000. These scanners require regular calibration and maintenance, with annual maintenance costs ranging from 8,000.

In addition, the cost of training dental professionals skilled in the use of complex systems cannot be underestimated. Depending on the depth of training and the specialized skills required, the training cost per technician can reach $8,000[10].

Refer to Table 4 "Digital Dental Repair Equipment Costs at a glance", high costs are undoubtedly a major problem for small and medium-sized dental clinics in the operation process:

Table 4. Cost Overview of Digital Oral Rehabilitation Equipment

Equipment Type	Purchase Cost (10,000 yuan)	Annual Maintenance Cost (10,000 yuan)	Technical Training Cost (10,000 yuan/person)
High-end Intra-oral Scanner	80-120	5-8	3-5
CAD/CAM System	150-200	8-12	5-8

The high cost constitutes a major problem on the development road of small and medium-sized dental clinics, which seriously restricts their exploration and application in the field of digital technology, and hinders the acceptance process of digital technology in these clinics.

5.2. Data Security and Standardization Issues

At present, with the accelerating trend of oral medical digitalization, data security issues have become increasingly prominent and become the core issue of concern in the industry. Dental diagnosis and treatment institutions need to deal with a large amount of sensitive patient information, such as past medical history, digital oral impression data and personalized treatment plans, etc. These information is related to patient privacy, so ensuring the security of its storage and transmission has become the key to safeguarding patients' rights and interests.

From the perspective of data security threats, the potential attack risk of hackers on dental databases cannot be ignored, and once successful, patients' personal privacy and financial information will face serious risks of disclosure. At present, the dental industry has not established a unified data standard, and different brands of digital dental equipment adopt different data formats, which greatly hinders the data interaction between systems. For example, when a dental office attempts to import digital impression data obtained from an in-mouth scanner of one brand into a CAD/CAM system of another brand, it will encounter difficulties due to data format incompatibility. Thus, it can be seen that the establishment of a data standard system covering the whole industry is of great significance to overcome such data interoperability problems and promote the collaborative development of oral medicine digitalization [11].

6. Future Prospects of Digital Technology in Oral Rehabilitation

In the field of dental prosthetics, digital technology has a promising future. With the development of science and technology, oral diagnosis and treatment equipment is moving towards miniaturization. In the future, portable intraoral scanners may be used to allow dentists to collect digital impressions in remote areas and patients' homes, expanding their coverage.

Although remote dentistry is in its infancy, it is developing rapidly and is expected to be widely used. With real-time transmission of digital impressions and diagnostic data, patients can consult experts remotely to improve access to care in remote and poorly resourced-care areas.

Artificial intelligence will also play a key role in oral restoration. Its algorithms are involved in the design of restorations and generate precise, personalized treatment plans based on individual patient characteristics. The integration of new self-healing dental materials and digital manufacturing technology will promote the industry to move toward intelligence and precision, bringing revolutionary changes.

7. Conclusion

Digital technology has revolutionized oral rehabilitation. Applications like digital impressions, CAD/CAM-designed restorations, and digital smile design have enhanced precision, efficiency, and patient experience, despite high costs and data-related challenges.

Precision has been significantly improved. The marginal sealing error of restorations has been reduced from 50-100μm in traditional methods to 10-30μm in digital ones, minimizing the risk of bacteria infiltration and promoting better oral health.

Efficiency has also seen a huge leap. Traditional single-tooth restoration fabrication took 5-7 days, while digital methods can complete it in 1-2 days. This not only boosts dental practice productivity but also shortens patient discomfort periods.

Patient comfort has been upgraded. Digital impression-taking, taking only 5-8 minutes compared to 15-20 minutes in traditional methods, is less invasive. Nausea and vomiting during impression-taking have decreased from 30% to less

than 5%. Fewer adjustment appointments further enhance the experience.

Looking ahead, with technology progress and cost reduction, digital oral rehabilitation will become the standard. Miniaturized equipment and expanded tele-dentistry will make dental care more accessible. AI and new materials will further optimize treatment. Dental professionals need to adapt, and patients will enjoy better-quality oral rehabilitation, marking a new era of high-quality dental care.

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