International Journal of Biology and Life Sciences
ISSN: 2957-9511 | Vol. 2, No. 1, 2023

Accurate Implantation and Long-term Stability with the Assistance of Computer-aided Design

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Abstract: With the constant development of radiation and computer technology, the field of implant dentistry is also experiencing a digital revolution, including digitalized data acquisition, computer-aided virtual planning, computer-guided implant surgery and restoration, etc. The digitalized clinical protocol promotes a more standardized and accurate dental implant treatment, which certainly will reduce the occurrence of complications for dental implant treatment, and achieve more predictable long-term stability in both function and aesthetics, This paper summarized the digital collection, digital smile design, computer-guided surgery planning, and implant supported prosthesis design in combined with the development status of digital technique, and the future trend.

Keywords: Dental implant; Computer-aided design; Digital technique; Digital smile design.

1. Introduction

With the rapid development and popularization of clinical technology of oral implants, implant repair complications have gradually become a crucial factor affecting the long-term stability of patients' implant repair treatment. Especially for inexperienced clinicians, "standardized and accurate" implant repair treatment is the key to reducing complications and ensuring long-term stability. Computer-aided virtual implant planning and design (computer-aided design and computer-aided manufacturing, CAD/CAM) enable doctors to use computers, graphics equipment and professional software to reconstruct the three-dimensional (3D) information of the soft and hard tissues in the mouth of patients and complete the design of virtual prostheses. Then, doctors can conduct "repair-oriented" 3D position planning of virtual implants, and finally realize the accurate transfer of virtual implant surgical planning to clinical actual surgical operations. It will help to achieve the expected precision and aesthetic effect of plant restoration, and further help to achieve the long-term stability of plant restoration. In order to achieve the goal of computer-aided precision planting, one of the key steps is to improve the precise preoperative planning and design of implant repair. The digitalization process includes digital information collection, aesthetic analysis and design, and implant surgery and restoration planning and design. This paper will describe the relevant concepts and clinical applications of each link of computer-aided implant planning and design.

2. Digital information collection

2.1. Concept of digital information collection

Digital information acquisition refers to the process of acquiring data such as jaw structure, dentition and mucosa morphology, facial soft tissue 3D image and mandibular motion state respectively through computer tomography, optical surface scanning, 3D stereo photography, mandibular motion tracking and other methods, for subsequent data fusion and CAD/CAM [2-4]. It includes body layer data acquisition technology, face data acquisition technology, digital facial body surface information acquisition technology, facial 3D dynamic information capture and calculation technology, and mandibular motion data acquisition technology.

2.2. Classification and characteristics of digital information acquisition system and its application in the oral implant

2.2.1. Digital impression system

Digital impression can reduce chair time to the greatest extent, and improve efficiency significantly. Moreover, it can reduce the time and economic cost of prosthesis production, improve the quality of oral treatment, provide a better patient experience, and promote production efficiency and economic efficiency. According to the 2018 ITI consensus, digital impression technology can be used as a conventional method for implant single crown restoration. However, the accuracy of the digital impression is still controversial for the implant repair of the large range of dentition defects or edentulous jaws. According to the research, although the accuracy of intraoral scanning can meet clinical needs, the accuracy of digital impression technology is not enough to replace the traditional impression, and its wide application still lacks sufficient evidence support [6, 7].

2.2.2. Facial 3D photogrammetric system

Modern digital stereo photogrammetry technology uses various energy sources, optical sensors and computers to carry out the 3D measurement, and its principle is based on the triangulation algorithm. According to the different methods of image collection, scanning technology can be classified into laser scanning technology and structured light projection technology.

1.2.2.1 Laser scanning

The basic laser scanner consists of a laser light source, an optical sensor (camera) and a scanning object (face). The transmitter optical irradiates the point or linear laser beam to the patient's face, and then collects the reflected laser through the camera that has a specific distance and angle from the laser source. The face, camera and laser source form a triangle. The distance between the laser source and the face is calculated based on the triangulation principle. In the process of rapid laser scanning of the face, linear repetition is continuously carried out, and finally 3D coordinates are formed [8, 9]. The advantages of this method are as follows. (1) It can quickly and accurately scan the face from multiple angles without being affected by ambient light. (2) The laser scanning equipment can be portable, which is convenient for use in an office with narrow space. (3) There is no need to process and merge the collected multi-view. The disadvantages of this method are as follows. (1) It cannot obtain the image immediately, the shooting time is long, and the motion artifact will significantly affect the accuracy. (2) Laser has a potential risk of eye injury. (3) It can only capture the surface morphology, and cannot observe the texture of soft tissue, which may cause errors [10-12] when the surface is fixed.

1.2.2.2 Structure light scanning

The structure light scanning includes moire measurement, passive stereo photography and hybrid stereo photography. Moire profilometry is a special structure light measurement, which means that the light is projected onto the grating near the face to produce a twisted light band, and then the camera is adopted to capture the twisted light band to generate a 3D face image. It can capture subtle distorted light to achieve higher-resolution scanning, thus making it possible to obtain clinical images in real-time. However, the required hardware equipment is complex and expensive, which has a high requirement for the experience of operators. The speed of image acquisition is slower than that of other structured light technologies and is vulnerable to motion artifacts [13, 14]. Passive stereo photogrammetry refers to the instantaneous capture of multiple high-resolution two-dimensional photos by two or more cameras, and then the synthesis of 3D images by special calculation methods, without the need to project laser or structured light. The system has a short scanning time, simple hardware equipment and a high degree of automation. Its disadvantage is that it requires subsequent processing and calculation. Hybrid stereo photography includes active stereo photography and passive stereo photography. By projecting white or blue light, which is safer than the laser, onto the face, a twisted light band stripe that is suitable for the natural curvature of the face contour is generated. Then, the camera captures the twisted light stripe to obtain the 3D surface data of the face, and in the process, several high-definition 2D photos are taken at the same time. Finally, the 3D surface data is mapped to the 2D photo to generate the 3D stereo color image. Its principle is also triangle spacing measurement. The advantage of this system is that the quality and accuracy of 3D surface images are the highest. The disadvantages are high hardware cost and large floor area.

1.2.2.3 Facial four-dimensional (4D) stereo photogrammetry system

4D stereo photogrammetry refers to the technology of accurately recording the movement track of facial muscles by tracking the real-time position of facial marker points to accurately construct the dynamic 3D shape of the face [17, 18], mainly including 3dMD dynamic 4D system and DI4DTM __ 4D capture system. 3dMD dynamic 4D can continuously capture 60 frames/second of 3D surface images in 10 minutes; DI4DTM (passive stereo photogrammetry system) system uses a digital camera to capture high-resolution (2048x2048 pixels) photos during facial movement at a speed of 60 pieces/second, and finally generates a 3D video sequence of dynamically changing surfaces.

1.2.2.4 Mandibular motion tracking system

According to the observation site, it can be divided into incisor motion recording and condyle motion recording. Incisor motion recording is a kind of recording instrument with magneto-electric conversion mode, which is to use the movement information of the mandibular incisor area to reflect the movement state of the entire mandible. It can observe the movement track of the mandibular central incisor from the sagittal plane, coronal plane and horizontal plane. It will not interfere with the maxillary teeth, nor restrict the mandibular movement, and can be connected with the computer, electromyograph and muscle relaxation instrument synchronously. However, the incisor motion record cannot reflect the respective motion characteristics of the two condyles. In the study of lateral mandibular movement and the asymmetry of the shape or function of bilateral joints and muscles, it is essential to use a condyle recorder to record the movement tracks of the left and right condyles, including a mechanical recorder and an electronic face bow recorder. The mechanical recorder records the movement track of the mandible through the tracing board fixed in front of both ears and the tracing pen fixed on the face bow splint of the mandibular dentition. The disadvantage of this device is that it can only record the final result of the condyle movement, and the mechanical contact between the tracing pen and the tracing board limits the 3D movement of the condyle. The principle of the electronic face bow recorder is similar to that of the mechanical recorder. The mechanical tracing pen and tracing board are replaced by piezoelectric induction devices. The condylar movement is no longer restricted by the tracing pen and the tracing board, and can display the 3D space track of the condylar movement and the temporal characteristics of the condylar movement.

3. Aesthetic analysis design

3.1. Concept of aesthetic analysis design

Digital smile design (DSD) is a digital aesthetic analysis and design method. It uses professional digital design software such as Keynote and Photoshop to integrate the collected clinical data of patients before surgery, carry out aesthetic analysis and design of teeth and smiles, and conduct a quantifiable digital simulation of the results of aesthetic restoration treatment to obtain intuitive digital restoration effects. In recent years, some computer software programs of DSD have been introduced into clinical practice and research. They are multi-purpose conceptual tools that can strengthen diagnosis vision, improve communication and improve the predictability of treatment by carefully analyzing the facial and dental features of patients [24, 25].

3.2. Application of aesthetic analysis and design in the oral implant

The arrival of the digital era has added new connotations to aesthetic planting. Digital data collection, digital aesthetic analysis, digital implant surgery, and digital implant repair run through the whole process of planting in a digital aesthetic area to realize the planting concept guided by aesthetic restoration. Doctors can conduct digital preoperative diagnosis, evaluation and information acquisition of aesthetic areas through aesthetic analysis and design. After that, they can use the virtual tooth arrangement or virtual digital wax design in the software to determine the ideal position of the prosthesis, and guide the accurate 3D position virtual planning of the implant in the aesthetic area according to the virtual prosthesis. Meanwhile, they can also use this as a reference to complete virtual bone incremental design, digital impression making, CAD/CAM personalized cutting and other technologies. Besides, the implementation of precision implant surgery can be guaranteed with the assistance of a computer-assisted static guide plate or dynamic navigation technology. Through the precise design and implementation of each link, the expectable aesthetic effect and long-term stability of implant repair can be achieved.

4. Surgical auxiliary planning and design

4.1. Concept of surgical auxiliary planning and design

CAD is a technology that uses computers, graphics equipment and professional software to assist designers in design. It can reconstruct the oral soft and hard tissues of patients through interactive software and virtual simulation technology, and provide clinicians with visual 3D structure information of the jaw. In addition, it can complete the anatomy and parameter design of future prostheses, thus helping to determine the virtual planning of restoration-oriented implants [27-29]. The use of surgical assistant planning and design software for the virtual planning of predictable implants has the following advantages. (1) It avoids damaging important anatomical structures such as the mandibular nerve canal and maxillary sinus, avoids adjacent teeth and improves the safety of operation. (2) The improved preoperative plan enables more accurate implant implantation. (3) It has realized the implantation of the ideal 3D position of the implant guided by repair. (4) It can achieve minimally invasive surgery, reduce postoperative discomfort, swelling and pain of patients, improve doctors' work efficiency, improve patients' acceptance and satisfaction, and reduce surgical risks. (5) In some special cases, the existing bone conditions can be used to place the implants to minimize or avoid additional bone increment surgery, reducing the surgical incision, operation time and the number of visits.

4.2. Surgical auxiliary planning and design

In oral implant surgery, oral implant planning software is usually employed for pre-implantation virtual design. Most of them are third-party software systems, including tool kits such as jaw measurement, jaw 3D reconstruction, nerve/blood vessel recognition, virtual implant placement, surgical analysis, simulated treatment, prosthetic setting, and various implant systems, prosthetic morphology, and surgical accessory databases.

After the acquisition of digital information data, the image is output as DICOM format data compatible with the planning and design software, and uploaded to the built-in implant planning software or the third-party implant planning software to obtain the virtual images of the cross-section, curved section and multi-plane reconstruction of the jaw, and carry out 3D virtual reconstruction. The reconstructed 3D layer contains axial, coronal and sagittal images. Different layers display different anatomical structures of the jaw, which enables doctors to more intuitively understand the anatomical shape of the jaw, measure the height and width of the bone in the edentulous area, and realize the design, preoperative analysis and simulated treatment of the 3D position of the virtual implant. Finally, the guide plate for implant surgery is made by 3D printing technology to guide the operation of implant surgery, and then the ideal restore-oriented planting site and long-term stability of implant repair are obtained.

5. Implant restoration design

With the progress of computer graphics technology and optical scanning technology, the design of implant-supported upper restoration is more mature. Implant restoration design can be used for digital virtual design of implant upper abutment, crown bridge, bracket, rod clamp and other types of restoration through the following functions: setting of placement path, drawing of gingival line, abutment design, anatomical form design, bridge design, cutting back function, bracket design, rod clamp design and virtual gingival design [30, 31]. Generally, most implant repair design software and conventional crown and bridge repair software are integrated with each other, the design types are gradually diversified, and the auxiliary tools are increasingly enriched. For example, the virtual bed-jig frame function is used to adjust the occlusion of the implant upper prosthesis. The digital aesthetic design of the anterior tooth area is conducted combined with facial scanning, and preoperative temporary dentures are designed by linking the guide plate design software of digital implant surgery.

For implant restoration design, digital design can include the design of personalized abutment, screw retention crown and implant restoration support. In order to meet the personalized characteristics of different patients, such as gingival conditions, gingival profile, implant angle and axial condition, and patient aesthetic requirements, the personalized abutment is more and more widely used in the upper part of implant restoration. Generally, personalized abutments can be made by grinding, casting and CAD/CAM. Compared with other methods, CAD/CAM technology has the advantages of speed, efficiency and high accuracy, and gradually replaces other methods to become a more commonly used personalized abutment manufacturing technology. Among functions of implanting restoration design software, in addition to personalized abutment design, screw retention crown is also a common digital implant restoration method. Besides, according to the different conditions of vertical repair space, soft tissue defect and periodontal status, for implant upper prosthesis, patients with edentulous jaws can choose various types of digital solutions such as injection molding and filling after the artificial teeth are arranged on the titanium bracket, direct ceramic decoration on the zirconia bracket, single crown restoration after the titanium bracket is cut back, and titanium rod clamp overdenture restoration, while the design standards of different restoration schemes vary greatly [32, 33].

6. Summary and prospect

In clinical practice, stomatologists should fully understand and try to avoid possible deviations and complications, take preventive measures, correctly select the indications, and strictly plan the surgical plan with the assistance of digital scanning data and virtual design software platform to obtain accurate planting oriented by repair. In the future, computer-assisted digital medicine, whether from preoperative examination, diagnosis, design, or intraoperative operation, as well as the later superstructure fabrication and repair, patient management, and implant peripheral maintenance, will carry out digitalization and informatization throughout the whole process of diagnosis and treatment, achieve true digital precision planting, and help the long-term stability of implant repair.

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