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Digital Technologies Used in Restorative Dentistry

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Abstract: ***This review delves into the burgeoning landscape of digital technologies revolutionizing restorative dentistry. The scope encompasses various facets of digital applications, spanning from imaging to design-production methodologies. Under the purview of digital imaging, three distinct categories are explored: indirect digital imaging, semi-digital direct imaging, and direct digital imaging, with an emphasis on flat panel detectors. Caries detection methods in the digital realm are scrutinized, including quantitative light effect fluorescence, laser fluorescence, electronic caries monitoring, fiber optic transillumination, fluorescence-aided caries excavation, and near infrared imaging technology. Additionally, digital methods in cavity preparation are elucidated, highlighting the integration of digital scanning and measuring techniques alongside digital smile design programs and 3D printing. The discussion extends to digital design-production processes, notably computer-aided design and computer-aided manufacturing (CAD/CAM), encompassing virtual design, virtual articulators, and classification based on the number of axes, coupled with an analysis of materials employed in CAD/CAM systems. This review aims to provide a comprehensive understanding of the evolving landscape of digital technologies in restorative dentistry, illuminating their transformative potential in enhancing clinical outcomes and patient care.***

Keywords: Restorative dentistry, digital technology, digital smile design, CAD/CAM.

1. Introduction

Digital imaging technologies offer restorative dentists the opportunity to examine their patients' mouth and dental structure in more detail. Digital x-ray devices, which replace traditional x-ray films, provide clearer images with lower radiation doses. Computer Aided Design and Manufacturing (CAD/CAM) technology enables prosthetics to be designed and manufactured digitally, so custom-fit prosthetics can be produced more quickly and quality controlled. Additionally, digital technologies automate processes such as appointment scheduling, medical history recording, treatment plans, and billing in clinical practices through workflow management software, which increases clinic efficiency and ensures patient satisfaction. Telemedicine applications and digital education platforms play an important role by facilitating communication and education between dentists. With the further development of these technologies, the impact of digital transformation in the practice of restorative dentistry will increase further [1-5].

1) Digital Imaging

In digital radiology, X-rays passing through the object are detected by sensors and this information is converted into electrical signals and transferred to the computer. These signals are converted into numerical data, digitized and displayed on the computer screen. Each image element in the image is called a "pixel", and each pixel is the smallest part of the sensor that can be controlled independently. The amount of light falling on the pixels carries color and brightness information and they come together to form the image on the computer screen. As the number of pixels increases, the closer to reality of the image increases, and the closer to reality the color expressed by each pixel is, the more ideal the image is. The principle of digital radiography can be divided into three: indirect, direct and semi-direct digital radiography [4-7].

Indirect Digital Imaging

Indirect digital imaging systems are systems in which conventionally obtained radiograms are digitized through special cameras or scanners and copies are created on the computer screen using various computer software. During the digitalization of the radiogram, the existing information is digitized without changing, along with the disadvantages of the conventional radiogram, and the existing negativities are transferred to the digital image. The indirect digital imaging method offers advantages such as making changes to the image or providing easy access to the image, as well as storing the digital image on a computer. However, since the copy of the original image is transferred to the digital environment, the resolution of indirect digital images is generally lower than the direct digital imaging method [1,4-6].

Semi-Digital Direct Imaging

Semi-direct digital imaging systems involve phosphor plates that operate wirelessly. FUJI company developed the first phosphor plate imaging system in 1981. Soredex company launched the Digora phosphor plate system for intraoral imaging in 1994. In these systems, phosphor plates that are not connected to the computer with a cable are used. After conventional radiography, a latent image is formed on the phosphor plates. This latent image is then scanned with laser light in a special device to obtain a digital image on the computer screen. Therefore, this method is also called semi-direct digital imaging method. Phosphor plates absorb x-rays after irradiation and store this energy. Then, when the excited fluorohalide complex is scanned with red and green laser lights, it generates fluorescent light proportional to the absorbed x-ray dose. This light is converted into an electrical signal and converted to digital, transferred to the computer and examined on the monitor. Phosphor plates must be cleaned of electrons before their next use. Phosphor plates are easier to use than other digital sensor systems because there is no cable between the sensor and the computer and the plates are thin and flexible. In addition, phosphor plates produce images with less radiation and have a wider dynamic range. However, the time required for irradiating the phosphor plates, placing them in the scanner, and creating the image may be longer than other systems. In addition, plaques have disadvantages such as damage and scratches, so they need to be replaced after a certain period of use [1,5-7].

Direct Digital Imaging

Direct digital imaging systems are also known as wired systems. In these systems, reading and digitization processes are combined. The x-rays passing the object fall on the sensor, and the signal created in the sensor is transmitted to the computer through a fiber optic cable. After a few seconds, the image obtained as a result of irradiation appears on the screen. CCD sensors, like dental films used in the clinic, come in different sizes. Three types of sensors are generally used in direct digital imaging systems: CCD, CMOS and flat panel detectors [1,5-9].

Charge-Coupled Device (CCD): The first intraoral digital image receptor, CCD uses a thin silicon wafer to record images. When X-ray photons hit, covalent bonds are broken in proportion to the number of electrons and an electrical charge occurs. This charging scheme produces analog signals. The charge is transferred to the data amplifier and transmitted as voltage to the analog-digital converter. The voltages occurring at each pixel create a numerical value representing the gray level. Finally, these data are digitized via ADC and a digital image is created on the computer.

Complementary Metal-Oxide Semiconductor (CMOS): CMOS sensors, unlike CCD sensors, have an architecture in which each pixel is connected to a transistor. When x-rays are absorbed, an electrical charge is created within the pixel. This charge is transferred to the transistor, stored, read and displayed as a digital gray value. CMOS sensors provide advantages in terms of energy consumption and image degradation due to charge leakage.

Flat Panel Detectors: These sensors provide a larger matrix used for medical imaging and can digitally image large areas of the body. However, they are generally expensive and have limited use with specialized imaging modalities.

2) Digital Caries Detection Methods

The purpose of using radiography in the diagnosis of caries is to support visual examination by radiographic evaluation of teeth with suspected caries. In addition, mineral loss can also help estimate lesion depth, as X-rays can also pass through existing enamel and dentin. However, radiography may give erroneous results in determining the exact boundaries of the caries. Because it has been reported that a carious lesion, which is observed to be limited to the inner layer of enamel on radiography, is in the dentin when evaluated histologically. In the correct diagnosis of incipient caries on occlusal surfaces, it is recommended to use radiographic evaluation together with visual examination. It has been reported that approximately 30-40% mineral loss in the enamel is required for enamel lesions to be visible radiographically [10-12].

Quantitative Light Effect Fluorescence Method: A diagnostic method that measures the changing fluorescence characteristic of dental hard tissues due to demineralization shows high sensitivity in diagnosing lesions in enamel tissue. In this method, an optical filtering system that creates blue light at a wavelength of 404 nm or an argon laser that creates blue-green light at a wavelength of 488 nm is used. The data obtained after light application is transferred to the computer and a digital image is created. Then, the fluorescence differences of healthy and decayed tissues are examined on the image with the help of a computer program. Rotten areas appear darker. This method has been evaluated by using it in a way that the progression capacity and activity of the lesion can be predicted [13,14].

Laser Fluorescence Method (Diagnodent): DiagnoDent (Kavo, Germany) is used for caries detection using fluorescence. DiagnoDent applies red light at a wavelength of 655 nm to the tooth. The intensity of this light, reflected back by the dental tissue as fluorescence, is converted into a numerical value between 0-99 by DiagnoDent and monitored on the device's display. Changes in tooth tissue due to caries affect fluorescence values. While healthy teeth generally produce little or no fluorescence, decayed teeth produce fluorescence in proportion to the degree of decay. In this way, the density of caries is determined. For example, values between 0 and 10 are generally considered healthy, while values above 30 may indicate a lesion requiring restorative treatment. These fluorescent changes have been reported to be caused by proto-porphyrin, a photosensitive pigment found in carious tissues as a result of bacterial metabolic activities [15,16].

Electronic Caries Monitor (ECM): The caries diagnosis method, in which electric current is used, is based on the difference in electrical conductivity between healthy and decayed tooth tissues. While the healthy enamel surface generally does not show good conductivity, an increase in conductivity is observed on surfaces where demineralization begins and caries formation is observed. This conductivity increases with increasing demineralization. Intact dentin has a very good conductivity compared to enamel due to the large number of dentinal tubules it contains. Therefore, when demineralization reaches the enamel-dentin border, an increase in electrical conductivity is observed [17,18].

Fiber Optic Trans Illumination (FOTI): Fiber Optic Trans Illumination (FOTI) method is a technique that uses a high-intensity beam of white light to illuminate the tooth. The principle of FOTI is that transillumination of areas with disrupted enamel crystals in demineralized dental tissues results in dark shadows due to changes in light scattering and absorption of light photons. This technique is applied to the buccal and lingual surfaces of the tooth with the help of a thin fiber tip. The surface is examined from an occlusal perspective and lesions are detected based on dark shaded areas due to demineralization in enamel and dentin. In addition to being an easy-to-use and economical method, digitally enhanced DI-FOTI has a high-resolution device (CCD) sensor and thus can capture images from occlusal, buccal and lingual surfaces simultaneously. In these images taken with DIFOTI, the carious lesion appears as a black area and can be transferred to digital media and evaluated by the physician. Additionally, DIFOTI has been shown to be able to objectively measure lesion size, depth, volume, and mineral content. However, it cannot distinguish between carious lesions and developmental defects such as fluorosis and cannot determine caries activity [19,20].

Fluorescence-Aided Caries Excavation (FACE): In the fluorescence-aided caries removal (FACE) method, which has been developed in recent years, autofluorescence is imparted to dental tissues under blue-violet light. Under this blue-violet light, healthy tooth hard tissues appear green, while carious tissue appears orange-red. The orange-red color is thought to be caused by porphyrin, a byproduct of oral microorganisms. In order for the physician to better see the fluorescence that occurs when the technique is applied, glasses that pass the reflections of green, orange and red colors well, but contain a filter that blocks blue-violet light, are used. Studies have shown that the FACE system is superior to the conventional method in selectively removing infected dentin, and it has also been reported that it prevents unnecessary cavity expansion and dental hard tissue loss [21,22].

Near Infrared Imaging Technology: Near infrared imaging is a technology developed using high wavelength rays that store different amounts of energy on tissue. This technology can be used for digital caries diagnosis as an additional feature to digital scanners [23].

Digital Methods in Cavity Preparation

In restorative dental treatments, cavity preparation is generally necessary to correct tissue loss resulting from tooth decay or trauma. Tooth decay is a disease caused by the dissolution of dental hard tissues caused by bacteria. Therefore, it is important to completely clean the decayed and affected tissues during the preparation of the cavities. However, carelessly used instruments during the cavity preparation process can occasionally cause excessive loss of intact tissues, iatrogenic pulp perforations, and sensitivity during or after the procedure. Nowadays, as the minimally invasive treatment approach has become more accepted, interest in more conservative methods in cavity preparation has increased. For this purpose, the use of chemomechanical caries removal methods such as Atraumatic Restoration Technique (ART), air-abrasion and dental lasers has become widespread. Dental lasers have the ability to prepare dental hard tissues and there are different types such as CO2, Diode, Er:YAG and Nd:YAG. The main advantages of cavity preparation with dental lasers include low pain perception in patients, less tissue damage, minimal pulp irritation, and biostimulation of odontoblast cells. In addition, when the cavities prepared with laser were examined under the electron microscope, it was observed that there was less smear layer left and the enamel prisms and dentinal tubules were seen more clearly, and therefore the bonding properties of the adhesive systems increased. In particular, it is stated that restorative materials provide better coverage and cause less secondary caries in cavities prepared with Er:YAG and Nd:YAG lasers [24-26].

3) Digital Scanning and Measuring

In dentistry, impression taking is important to obtain a negative copy of intraoral tissues. This measurement is a critical step in making fixed and removable dentures correctly. The success and harmony of restorations depend on the impression technique and materials used. The measurement must accurately reflect the details; otherwise failure is inevitable. As an alternative to traditional measurement methods, digital measurement systems offer shorter and easier steps. These systems include design and production stages as well as measurement. Data is collected through intraoral scanners or models derived from conventional impressions. Intraoral digital scanners use different techniques to precisely record three-dimensional geometry. Intraoral digital scanner systems consist of a portable camera, a computer and special software. These systems precisely record the three-dimensional geometry of an object using laser scanning, contact data capture and optical cameras. Data collection methods are divided into two groups: direct and indirect [27-29]:

Direct Technique allows taking measurements directly from the oral cavity through intraoral scanners to eliminate possible errors and traditional technical disadvantages. Traditional impression methods are abandoned and the prepared teeth are scanned directly with intraoral scanners and the data is immediately transferred to the computer environment.

In the indirect technique, measurements are taken using traditional methods and a plaster model is obtained from this measurement. This plaster model is scanned with scanners belonging to the CAD/CAM system and a digital model is created. In some cases, a digital model is obtained by scanning traditionally taken impressions. The design process is then continued in the digital environment.

Digital Intraoral Scanners

There are many widely used digital intraoral scanners on the market today [28-34]:

CEREC (Sirona Dental Systems; Bensheim, Germany): The CEREC system is the first CAD/CAM system and can perform 2D scanning. However, it did not receive much attention due to some disadvantages. Siemens developed the CEREC 2 system in 1994, but it was not capable of three-dimensional scanning. The CEREC 3 system, produced by Sirona in 2000, provided faster processing and better edge fit. The CEREC 3D system was launched in 2003 and enables three-dimensional images to be obtained. In 2009 Sirona launched CEREC Bluecam, which provides higher resolution images. In 2012, a new intraoral scanner called CEREC Omnicam was introduced. This scanner provides uninterrupted video images in powder-free and natural colors and has features such as virtual articulator, smile design and implant-supported single tooth restorations. The company later launched Primescan AC, a new generation scanner. Blue LED is used in this scanner, higher quality and colorful images are obtained, it gives very good results on full arcs and translucent surfaces and does not use dust.

iTero (Cadent, Inc.; Carlstadt, NJ, USA): Introduced by Cadent in 2007, the iTero system adopts parallel confocal scanning without the use of any reflective product resembling titanium dioxide powder and is used solely as a scanner. During the scan, the physician is guided by voice commands and is alerted if there is any vibration. However, the disadvantage of this browser is that the browser title is large. The company launched Element 1, 2, Flex and 5D models respectively. The Element 5D model provides real-time images during caries scanning and uses ear infrared imagind technology.

E4D (D4D Technologies, Richardson, TX, USA): The E4D Dentist System was first introduced in 2008. This system has its own design centre, laser scanner and milling unit and therefore enables same-day delivery of the restoration to the patient, like CEREC. The system's scanner uses laser light, so it does not require the use of reflective powder. In addition, the low vertical size of the scanner, called Intra Oral Digitizer, provides comfortable use for patients with limited mouth opening.

Lava C.O.S (3M ESPE, Seefeld, Germany): The intraoral digital scanner Lava C.O.S., introduced by 3M ESPE in 2008, scans with the Active Wavefront Method (AWF). The system has its own dusting gun and dusting is required in certain areas before taking images of intraoral structures. The smallest scanner tip is 13.2 mm wide and uses pulsating blue light as a light source. Additionally, the system features a mobile touch screen.

Trios (3Shape, Copenhagen, Germany): In 2011, 3Shape launched a digital scanner called the Trios system. The Trios system obtains images by parallel confocal laser scanning method without using any reflective powder. While the first model provided black and white images, Trios Color, produced in 2013, offers color imaging. Trios 3 was released in 2015 and Trios 4 in 2019. Trios 4 has three times longer battery life and its scanning head is in pen form and allows early detection of possible surface and interproximal caries.

Medit i500® (Medit, Seoul, South Korea): Medit i500® uses active triangle technology. It scans with three different laser beams and the light is detected by the stereo vision oral scanner. Optical lens technology provides a more compact head. It performs color video-based scanning and has features such as abutment scanning and automatic or manual margin creation. It does not require powder or spray. The manufacturer states that it provides an accuracy of 10 µm in single crowns, 25 µm in half arch and 50 µm in full arch scanning.

CS 3500®- CS 3600®- CS 3700® (Carestream, USA): Carestream has CS 3500®, CS 3600® and CS 3700® models. While the CS 3500® scans photo-based, the CS 3600® scans video-based. In the CS 3600®, the LED light scanner performs fast scanning with an intelligent pairing system. It does not need powder and has a color scanner feature. Surface recording is taken using the triangulation method and fringe imaging technique. These systems can be used in the production of inlays, onlays, veneers and single crowns. File extensions are .csz. Design can be made with Carestream CAD. CS 3700® is the company's latest intraoral scanner and scans 20% faster than the previous version. The manufacturer states that it scans the entire arc in 30 seconds and provides ease of color selection with its smart toning feature. The intraoral scanner can optically determine tooth color in aesthetic restorations, and its intelligent color determination is determined by the "bidirectional reflection distribution function".

Dental Wings® (Canada): Dwio model This scanner, introduced in Canada in 2015, uses multiple LED lights and video imaging. The scanning screen shows monochrome color and scans in only 5 stages. Its most important feature is that it is small and light. While it initially used powder, later models solved this problem. The file extension is .xorder and .stl and has a universal format. It can scan quickly but does not display colors. It can be used to create inlay, onlay, veneer, crown, bridge, partial denture and surgical guide models. The Virtuo Vivo TM model was launched in 2019. It has a light (215 grams) and ergonomic structure. Scanner heads can be sterilized 250 times. It has a realistic color scanning feature and commands can be given to the computer with hand movements and sounds during scanning. The file extension is .stl and there is no need to use powder and spray. It can be used in inlays, onlays, veneers, crowns, short bridges and implant-supported prostheses.

MIA3d™ (Densys3D Ltd, Israel): Launched in 2007, this system is used in orthodontic and restorative treatments. It has the lightest (about 100g) and small size head. It also has the easiest application software. It can scan up to 30 µm in size. Stereo photogrammetry uses system-based light projection. Two-dimensional images are combined with the triangular technique to create a three-dimensional image. It needs dust and spray for scanning and provides connection via cable. The created digital models can be exported in .ascii format.

Emerald® (Planmeca, Finland): It has 3 scanners named Emerald, Emerald S and PlanScan. They have features such as inlay, onlay, veneer, crown, bridge, full arch scanning, region scanning, model scanning and impression scanning. It has its own milling units and .stl and .ply formats are used as file extensions. Emerald S and Emerald laser scanners were introduced in 2017. Its latest model is Emerald S and its diagnostics, usability and scanning speeds are better than Emerald. They work with Projected Pattern Triangulation™. No special powders are used and they combine colored images with laser (blue, green, red) technology. They connect to the computer via cable and have lightweight, ergonomic heads. Heads can be removed and sterilized in an autoclave. They have a real-time color imaging system and feature technology that prevents fogging during imaging. The PlanScan model scans with a blue laser and the scanning technologies are confocal microscopy compatible with tomography. It can be used for the construction of inlays, onlays, veneers, crowns and bridges. There are four separate scanner heads and each is designed for a specific region.

ZfxTM IntraScan (Zimmer Biomet, Germany): Works with confocal measurement and moire editing. It has the feature of taking 18 photographs per second. It can be used on a laptop and does not require the use of powder or spray. It can scan a maximum area of 10.4 x 9.6 x 18 mm from the object and uses .stl format as the file extension.

KaVo X Pro™ (KaVo Dental, Germany): It is a laser-based system and is connected to the receiver via a USB cable. It does not require the use of powder or spray during scanning. It has color scanning feature and file extensions are .stl and .ply. It has not yet been commercially released.

Fussen (China): Three different LED sources perform scanning. It does not require the use of powder and has accurate scanning down to 25 microns. File extensions are .stl and .ply, and the intraoral scanner is portable, but the headset is not wireless.

True DefinitionTM (Midmark Corp, USA): Works with 3 stereo cameras and uses active wavefront technology with blue LED light output. The scanner is used with a portable computer and the headset is connected to the computer via cable. Despite the need to use powder and spray, successful results are achieved.

AADVA® (GC, UK): "Ios 100P" and "Ios 200" models are offered by GC Group. iOS 100P does not provide color images and does not require the use of powder. They are open systems and can export in .stl format. The IOS 200 model was released in 2019 and has color scanning feature.

Digital Measurement Guide

The digital impression guide ensures that all details of the cavities prepared for indirect restorations, the relationships with adjacent teeth, the patient's occlusion and closure status are recorded clearly and accurately. Traditional impression materials and methods face problems such as deformation, distortion and inadequate adaptation. Especially in deep cavities and crooked teeth, missing details or insufficiencies may occur in areas close to the gums. Therefore, a method that has less margin of error, can be stored and can be easily repeated was needed to take smooth, clear and distortion-free measurements. Intraoral digital scanners have been developed to meet this need. Modern digital scanners can take color photographs of teeth and soft tissues from different angles and convert these photographs into 3D objects with the help of software. It has been observed that digital impressions have significantly reduced deformation and distortion compared to traditional impression materials. Additionally, digital scanners help better define the tooth and gum border in aesthetic treatments, thus reducing restoration-tooth discrepancy. However, in some cases, distortion may occur during long and detailed treatments, depending on the features of the scanner. Therefore, it is important to work carefully and slowly when taking measurements. Intraoral scanners generally have an open access feature, which allows production in different CAD/CAM units. However, it should be noted that some CAD/CAM units with closed software programs can only use files for their own devices and software [35-37].

Digital Color Selection

Color selection in dentistry is a very challenging process, because natural tooth color has a highly subjective structure and complex optical properties. Systems such as the Munsell Color System overcome this difficulty by defining tooth color through tone, brightness and chromaticity (purity) values. However, decisions can be subjective as these systems are often based on subjective data. With the development of technology, digital color measurement systems such as colorimeters and spectrophotometers make it possible to obtain more predictable results. These systems also guide physicians in the restoration of heterogeneous dental tissue by determining the color distribution. Compared with traditional methods, digital color detection devices have obvious advantages. The repeatability and provability of measured values in digital color detection reduces the effect of subjective factors. In addition, the ability to store the data obtained during color determination creates a safe resource, especially in applications such as whitening treatments, and allows restorative / prosthetic treatments to be performed in accordance with the natural tooth structure. Digital cameras have recently become very popular in color measurement and communication between the physician and the laboratory. These cameras allow reliable color measurement when standard lighting is provided. Additionally, communication becomes faster and easier through the use of digital photos. Colorimeters and spectrophotometers detect color by measuring the light reflected from the object. These devices can also be used in combination with digital photography and spectrophotometry. For example, VITA Easyshade V is a digital spectrophotometer capable of fast, reliable and repeatable color detection of natural teeth and ceramic restorations with LED technology [28,38,39].

4) Digital Smile Design

Digital smile design is a method that allows patients' smiles to be designed in a digital environment with simulation. This method allows patients to be involved in the treatment process starting from the planning stage and strengthens communication. It also provides careful analysis of facial and dental composition, following the reference parameters required for an aesthetic smile. Dentogingival analysis is an important factor affecting aesthetic success by examining the health and morphology of the gingiva. To create an ideal aesthetic smile, certain reference parameters must be followed. In digital smile design programs, facial analyzes are performed using reference lines. There are standard parameters for frontal and profile views of the face. These analyzes ensure the symmetry of the jaws and the segmentation of the face. Dentogingival analysis examines the health and morphology of the gums. Gum health is important before starting treatment. Dental analyzes provide insight into the shape, size and color of the restoration. In digital smile design, it is important to know the basic aesthetic rules and use quality photographs. Determining the most appropriate treatment course for complex cases and cases with high aesthetic expectations often requires multidisciplinary experts to discuss the treatment plan. In traditional methods, plaster models, wax models and silicone keys are used, but these methods can be time consuming and do not always guarantee to achieve the desired result. Digital Smile Design (DGT) programs, which have become popular recently, have been developed to overcome these limitations. DGT is the preparation of the patient's smile aesthetics in a digital environment, taking into account the condition of the teeth and soft tissues, and visualizing the possible result to both the physician and the patient. This method aims to both meet the expectations of patients and guide dentists by determining the limitations of the case, regardless of the difficulty of the cases [40-42].

Digital Smile Design Programs

There are some common programs in the market used in dental smile designing [40-45]:

3Shape Smile Design (3Shape Company, Denmark): Smile design can be made directly from the 2D photo taken from the patient. Technicians then import the patient-approved designs into 3Shape Dental System software and combine them with the 3D digital image to complete the procedures. A mock-up model can optionally be produced before the restoration is completed.

Cerec SW (Dentsply Sirona, USA): This software, which requires a full face image, converts the 2D image into a 3D image by identifying specific points. The DSD App, PRSD and Cerec SW 4.2 programs can create three-dimensional smile designs, and Cerec SW 4.2 and PRSD can be used with CAD/CAM to produce temporary and final restorations that replicate the designed smile.

Coachman App (Digital Smile Design, Spain): Dental photographs taken from three different angles required for the Coachman App are: Maximum Smile Photo, Rest Photo and Occlusal (Top) Photo. Additionally, side profile views and videos should also be added to the Keynote presentation. Smile designs can be done manually (by hand), but this can be time-consuming and dependent on subjective evaluations. Coachman App can be used to perform digital smile design faster and more objectively.

Romexis Smile Design Planmeca Oy, Finland): It does not require any extra supporting programs to run on Windows and MacOS operating systems. First, full-face photographs are taken from the frontal area when the patient smiles naturally. The software then automatically creates an image of the teeth with the determined aspect ratios. In addition, thanks to the software's library of VITA Classic and VITA 3D-Master tooth colors (Vita Scale), it can identify the colors of existing teeth and determine color and tone.

Smilecloud (SM Biometrics, USA): Smile Cloud, a cloud-based platform, allows users to store patients' medical data, personal data, photographs, videos, intraoral scan images, radiographs (OPG and periapical) and computed tomography (B-CT) results. . After the photos taken are uploaded to the system, the algorithm in the software finds the relevant teeth and automatically aligns them. The dentist can optionally change this design. Additionally, it can be printed in formats (stl, obj) suitable for CAD/CAM and 3D printers.

Smile Creator (Exocad GmbH, Germany): Developed by Germany-based Exocad GmbH. Smile Creator is integrated into the Chairside CAD platform and automatically converts existing patient photos or photos taken using webcams into 3D objects. It is then synchronized with 3D scans of the teeth.

3D Printers and Additive Manufacturing

Introduced into dentistry in 1999, 3D printers were first used to make an obturator for a patient's lost maxillary bone tissue. As technology has improved over time, 3D printers have offered many different treatment options and have generally reduced production time and costs, providing a clean, safe and fast production process. It also has advantages such as digital storage and the ability to produce complex cases with minimal errors. 3D printers generally used in restorative dentistry; It can print metals such as resins, rubbers (PLA -TPA), glass, ceramics, zirconium and titanium. The first 3D printers were generally produced using the "Condensed Deposition Modeling (FDM)" method. However, this method is not preferred today due to problems such as unclear details, porosity and the physical strength of the material not being suitable for intraoral conditions. Later, 3D printers were developed using the "Selective Laser Sintering (SLS)" method by combining metal powders with laser energy. Today, implants, crown/bridge infrastructures and metal bases of partial removable dentures can be produced with these printers. Since aesthetics are as important as function and hygiene in restorative dentistry, Digital Light Projection (DLP) and Stereolithography (SLA) printers have been developed that can produce epoxy resin-based composite/ceramic hybrid materials and polymerize them with heat and light. In both methods, the basic principle is to prepare the fragment layers from a photo-polymer resin one by one, join them together using an ultraviolet laser, and polymerize with ultraviolet light to form the whole restoration. While the main advantages of SLA are the rapid and low-cost production of large amounts of restorations or models, the most important development in DLP is that the details are created more clearly and the material used is optimized for intraoral conditions. 3D printers used for restorative dentistry can produce whitening plates, dental retractors and isolation sets with FDM printers, while inlays, onlays, veneer restorations and temporary and permanent single crowns can be produced with DLP printers [46-48].

5) Digital Design-Production (CAD/CAM)

CAD/CAM systems generally include three structures: data acquisition (scanning the preparation), CAD (planning and designing the restoration), and CAM (fabrication of the restoration). The first CAD/CAM systems were known as the "subtraction method" and were based on milling restorations from prefabricated blocks. In this method, material was removed from the block material to obtain the desired shape, but a lot of material was wasted in the process. Later, the production of restorations by the "additive" method was developed, in which the material was added by sintering, thus reducing the amount of wasted material. In some systems, addition and deletion methods are used together. Current CAD/CAM systems are divided into three groups: In-office systems (restorations produced at the bedside), in-laboratory systems (restorations produced in the laboratory) and centralized production (restorations produced by sending digital measurements taken in the clinic to the laboratory). Most of today's CAD/CAM systems use STL or similar formats as the digital format. While systems using the locked STL format are called "Closed System", systems using the open STL format are called "Open System" and in these systems, scanned data can be processed and produced with different software or devices. CAD/CAM technology first became popular in the 1980s and has become more widely used in dental clinics and laboratories in recent years. Thanks to this technology, faster, safer and more successful applications can be performed in many areas of dentistry. The main advantage of CAD/CAM systems is the use of high quality materials and low production costs. In order to shorten the treatment process and increase patient comfort, treatments can be completed "in the office" or support can be received from dental laboratories. Since restorations are designed by the physician with in-office CAD/CAM systems, patient-specific situations can be carefully evaluated and planned. The fact that the restoration can be prepared in a single appointment shortens the treatment time, allows it to be renewed on the same day when necessary, eliminates the need for temporary restoration and plays a role in preventing postoperative sensitivity. With developing technology, dentists can now use many CAD/CAM systems in their clinics [49-53].

The use of CAD/CAM systems has brought many advantages. With the traditional impression-taking phase, the problem of patients who cannot tolerate conventional impressions has been eliminated, the potential for error has decreased, and restorations with higher edge compatibility have been obtained in a shorter time. The ability to perform the applications in a single session eliminated the necessity of preparing temporary crowns and thus provided economic savings. In addition, making the design in a digital environment allowed the patient to be involved in this stage, thus increasing patient satisfaction. However, CAD/CAM systems also have disadvantages. Factors such as high production costs, requiring experienced personnel, and difficulties in scanning teeth with deep subgingival margins and transferring them to the computer environment may limit the use of these systems. In addition, it can be seen as a disadvantage that aesthetic expectations cannot always be met in restorations produced using monochromatic blocks. However, this problem is about to be overcome by producing blocks in different colors [1,49-53].

Virtual Smile Design

Virtual smile design, also known as digital smile design, is a crucial aspect of prosthetic treatment planning that focuses on achieving harmonious positional relationships between teeth and facial components. Initially, line drawings and virtual compasses were used on facial photographs, then diagnostic wax-ups were used to transfer proposed designs to physical models. However, recent advances make it possible to directly overlay digital impressions onto 2D photographs or 3D facial scans, increasing precision in transferring designs to 3D models or final restorations. While 2D virtual smile design offers usefulness, it is limited to evaluating facial aesthetics from certain angles captured in photographs. In contrast, the use of 3D facial scans allows clinicians to evaluate facial aesthetics from multiple perspectives and provides a more comprehensive understanding of the aesthetic impact of planned treatments. As technology advances, the use of 3D facial scanning via smartphone applications is expected to increase and the capabilities of virtual smile design will further increase [1,52-54].

Virtual Articulators

Recently, with the use of digital technologies in dentistry, a virtual working environment has been created. In this virtual environment, thanks to digital developments, the levels of clinical diagnosis, treatment planning and treatments have increased and the duration of all these procedures has been shortened. Virtual articulators are used to reduce the limitations of conventional articulators. Using digital 3D data of the lower and upper jaw and the patient's personal jaw movement data, virtual articulators simulate the patient's jaw movements and provide visualization of dynamic occlusal contacts. In this way, it is thought that restorations made using the virtual articulator will not contain interference and stability will be ensured. In the conventional method, instead of harmonizing the lower and upper jaw plaster models according to the horizontal jaw relationship in the conventional articulator, transferring the digital data of the upper jaw to a virtual articulator is a more measurable, reliable and repeatable method. This allows the dentist and dental technician to work in a completely digital environment, eliminating the casting step to obtain plaster models of the jaws. There are two types of fully adjustable and mathematically simulated virtual articulators [1,55,56]:

- Mathematically Simulated Virtual Articulator: It has average values and uses values that can vary from person to person. It can simulate movements that only mechanical articulators can do, but cannot give the patient individualized movement paths.
- Fully Adjustable Virtual Articulator: These articulators can eliminate the interference of individual treatments and restorations by recording the movement paths of the mandible with the jaw movement analysis system. This system can achieve an ideal occlusion for personalized treatments and restorations.

Semi-Conventional Virtual Articulators

Semi-conventional virtual articulators involve a combination of both conventional and digital methods. These methods may include [1,55,56]:

- Digitalizing plaster models connected to a conventional articulator by scanning them using scanners. In this way, plaster models and the conventional articulator can be digitized separately and transferred to the digital environment.
- Digitalizing the plaster models obtained from the measurements taken inside the patient's mouth by scanning them with extraoral scanners. These digital data can then be linked together in a virtual environment using virtual articulator software.

Semi-conventional virtual articulators can offer more precise and personalized solutions by combining the advantages of plaster models provided by conventional methods with the flexibility and scalability of digital technology. These methods are one of the innovative approaches that digital technologies bring to the practice of dentistry [1,55,56].

Fully Digital Virtual Articulators

Scanning of the patient's lower and upper jaws via intraoral scanners can be directly connected to a virtual articulator. If the selected virtual articulator system can perform jaw movement analyses, all mandibular movements of the patient, including chewing movements, can be digitalized and simulated virtually. To create a fully digital treatment plan and increase patient satisfaction, the position of the upper jaw in space must also be transferred to the virtual articulator. For this purpose, the position of the upper jaw can be determined and integrated into the virtual environment by using various virtual facial arch systems. In this way, treatment planning can be made more accurate and personalized, and the patient's aesthetic and functional expectations can be better met [1,55,56].

Addition Subtraction Technique

Two popular technologies for additive manufacturing in dentistry are stereolithography (SLA) and direct metal laser sintering (DMLS). While SLA is commonly used in aligner fabrication, DMLS is applied to create metal crowns and device frames. Additive manufacturing allows dental technicians and dentists to produce solid 3D models from digital designs created by scanning and design software. During the additive manufacturing process, models are built layer by layer using thin layers of material. This technique allows saving material and creating complex geometries that can be challenging with subtraction methods. However, additive manufacturing is currently limited primarily to polymeric and metallic materials. A variety of additive methods, including SLA, selective laser sintering, fused deposition patterning, polyjet 3D printing, inkjet 3D printing, laminated object fabrication, color jet printing, electron beam melting, and multijet steering, offer potential solutions to challenges in complex surgery and prosthetics [1,51-56].

Classification According to the Number of Axes

Classification is done according to the number of axes [57-59]:

Three-axis devices such as inLab (Dentsply Sirona), Lava (3M ESPE) and Cercon brain (DeguDent) have the capacity to move milling burrs in three axial directions specified by X, Y and Z values. While these devices can rotate components 180 degrees while milling, they cannot mill subsections, offsets, or convergences. Despite their relatively simple 3-axis controls and low cost, they do not have the versatility of high-axis devices.

Four-axis devices such as Ceramill Mikro 4X (Amann Girrbach), Planmeca PlanMill 40 S (Planmeca), Zeno (Wieland-Imes) and Primemill (Dentsply Sirona) include an additional axis (A-axis) for rotation around the X-axis. This allows the bridges to be adjusted and offers advantages in terms of material savings and milling time compared to three-axis devices.

Five-axis devices, exemplified by Versamill (Axsys Dental Solutions), add a fifth axis for the milling spindle (B-axis) to rotate around the Y-axis. This versatile rotation facilitates the production of complex geometries with subsections, such as fixed partial dentures with converging abutment teeth or mesial-tipped molar abutments. Although the number of milling axes is not directly related to the quality of the final restorations, restorations with complex geometries often require milling units with increased axes. Dentists and technicians must choose milling units according to their specific needs, as factors such as digitization processes and data processing play an important role in restoration quality as well as milling device features.

Materials Used in CAD/CAM systems

Materials used in CAD/CAM systems in dental restorations can be divided into several categories [60-64]:

Adhesive Ceramics: First used in the 1980s, examples include CEREC Blocks, VITABLOCs Mark II, VITABLOCS RealLife Ceramics Blocks, and VITABLOC TriLux Forte. These materials offer high translucency and aesthetics, but their bending strength is relatively lower. Although their use has decreased with the introduction of lithium disilicate, they are still used for crowns and partial crown restorations.

Flexible Ceramics, Composite and Temporary Materials: These include polymeric CAD/CAM materials such as composite CAD/CAM blocks such as Paradigm MZ100 and flexible ceramics such as LAVA Ultimate. Also known as nanoceramics or hybrid ceramics, these materials contain a resin matrix with inorganic refractory compounds. Although they have lower physical properties compared to ceramics, they offer more uniformly milled margins and do not require firing. Proper ligation protocols have improved survival rates, and some options include temporary blocks for long-term use.

High Strength Ceramics: Examples include lithium disilicate (IPS emaxCAD, Celtra Duo, CEREC Tessera) and advanced lithium disilicate. These materials are popular for chairside CAD/CAM restorations due to their high flexural strength (400-700 MPa) and translucency. They are suitable for posterior crowns and require a 2-stage firing process.

Zirconia: Materials such as CEREC Zirconia, Katana Zirconia, and 3M Chair Head Zirconia fall into this category. Zirconia offers high flexural strength (700-900 MPa) and minimal occlusal reduction requirements. However, long-term clinical performance data for chairside zirconia restorations are currently lacking.

2. Conclusion

The integration of digital technologies marks a significant leap forward in restorative dentistry, redefining traditional practices and enhancing treatment standards. From digital imaging and caries detection to cavity preparation techniques and CAD/CAM systems, these advancements offer clinicians unprecedented precision and efficiency. Digital imaging provides clear and detailed visuals, while caries detection methods enable early intervention for improved oral health outcomes. Coupled with digital cavity preparation and scanning technologies, treatment workflows are streamlined, fostering a patient-centered approach. CAD/CAM technology stands at the forefront, offering virtual design capabilities and precise restorative fabrication. As practitioners embrace these innovations, continued education is crucial to harness their full potential and elevate the standard of care. In conclusion, the integration of digital technologies paves the way for enhanced clinical outcomes and patient satisfaction, shaping a promising future for restorative dentistry.

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