ORIGINAL RESEARCH PAPER

Dentistry

SYSTEMATIC LITERATURE REVIEW OF THE DIGITAL DENTISTRY

KEY WORDS: Digital Dentistry, Intraoral Scanner, CAD, CAM, Virtual Reality,

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ABSTRACT

In recent years, with the advancement of technology, dental diagnostic and treatment applications have become more efficient and cost-effective. Digital diagnostic and treatment methods that shorten the processes have started to be used. New methods and technical equipment continue to be developed. Digital imaging systems, robotic surgery applications, intra- and extraoral scanning systems, CAD-CAM systems, 3D printing, 3D modeling and analysis methods, digital orthodontics, digital cephalometry, invisalign endodontic biomicroscopes, apex locators and endodontic rotary systems have been used in recent years. The improvement of digital restorative production systems has allowed dentists to choose restorative materials different from traditional ones, to produce restorations within the clinic and also to reduce laboratory workflows. The first step of dental digital systems was digital cameras. With the development of intraoral and laboratory scanner cameras, digital imaging systems moved to another phase. This was followed by computer-aided diagnosis, treatment planning, digital design and production, and the construction of restorations. With the discovery of artificial intelligence, a new chapter in digital dentistry was opened. Success in digital dentistry depends on the precision and accuracy of digital devices and the knowledge and skills of dental personnel using digital devices and methods. This study aims to present current approaches to digital dentistry.

INTRODUCTION

The progress in information technologies and the related digital transformation has advanced rapidly in the field of health in a short time. Digital transformation has initiated changes in management and clinical processes within healthcare. Artificial intelligence applications accompanying this digital transformation have swiftly adapted to the health sector, manifesting in various applications across administrative and clinical procedures. The restructuring of service processes in healthcare by artificial intelligence contributes to a reduction in both administrative and clinical costs. In clinical processes, it accelerates tasks such as diagnosis and treatment, aiming to enhance service quality by minimizing human errors.

Digital dentistry relies on the utilization of optical and computer-based devices incorporating digital components in dental treatment. Dentistry remains influenced by developments initiated with the integration of technology and computers into our lives. In this context, traditional methods employed in the diagnosis and treatment process have largely given way to digital methods. Digital systems have replaced silicone or alginate impressions with digital 3-dimensional (3D) impressions captured with specialized cameras. Moreover, porcelain teeth crafted by technicians have been supplanted by ceramic teeth produced through CAD/CAM systems and 3D printers. In implant treatments, digital dentistry is evident through navigated implant methods.

Dentistry has undergone rapid digitalization in recent years, transforming various aspects of the field. Imaging and diagnostic methods, impressions, orthodontic treatments, prosthetic restorations production, surgical planning, robotic surgery, smile designs, and numerous other dental applications can now be effortlessly and swiftly conducted using digital methods. Traditional dental practices are gradually being replaced by these digital technologies. These advancements empower dentists to deliver cost-effective and error-free treatments in a shorter timeframe, enhancing comfort and satisfaction for patients. Digital technology also contributes to making treatment outcomes more predictable.

Similar to other fields of medicine, modern dentistry has embraced digital transformation, resulting in reduced costs and increased benefits [1,2]. According to the World Health Organization, over 60% of school-age children and nearly 100% of adults globally experience dental problems. About 20% of adults aged 35-45 face severe periodontal issues with the potential need for tooth extraction. In the elderly population aged 65-74, the total edentulism rate is approximately 30%[2]. Improvements in global quality of life contribute to longer lifespans and an expanding elderly population, consequently escalating the demand for dental treatments, as observed in all medical fields [3].

Digital technologies have found widespread use in various dental areas. This study aims to provide current information on the digital technology employed in dentistry, with a particular emphasis on digital dentistry systems and workflow considerations. The study elaborates on the working principles of contemporary digital dentistry systems, along with the devices and materials utilized in these processes.

Digital Transformation In Dental Education

In the past, dental education was confined to phantom heads and artificial teeth simulating various dental practices and treatment scenarios. Presently, virtual three-dimensional simulators are readily available. This virtual environment comprises a visual screen projecting a mouth or even the entire patient's head. These displays can be incorporated into specialized glasses to enhance the perception of reality, and haptic input devices enable users to receive feedback in terms of tactile sensations.

Research indicates that students trained with virtual reality (VR) simulators learn at an accelerated pace, execute more procedures in a shorter timeframe, attain proficiency levels equivalent to traditional laboratory training, and seek more assessments via computer, thereby streamlining the instructor-student evaluation process (4). In dental education, Virtual Reality (VR) and Augmented Reality (AR) technologies digitally replicate orofacial tissues (cheek, lips, teeth, alveolar bone, and gingiva) and dental instruments (surgical and restorative handpieces, burs, and implants). Haptic devices offer force feedback for virtual dental surgical instruments upon contact with virtual teeth and alveolar bone, providing operators with the sensation of manipulating objects through the senses of touch and proprioception [5]. Emerging technologies, such as "haptics" (sense of touch) and "virtual laboratory environments" for simulation exercises, are anticipated to enhance motor skills and student efficiency while reducing the required training time [6].

To optimize laboratory training time and enhance fine motor skills, blended learning designs in the form of virtual reality units, coupled with instructor teaching/feedback, should be integrated into dental education. This integration aims to increase the educational benefit and reduce the overall cost of education and training. Numerous virtual reality simulators are already accessible [7]. DentSim, one of the initial dental education simulators developed for teaching restorative dentistry, consists of a phantom head, a set of dental instruments, infrared sensors, an overhead projector with a monitor, infrared cameras, and two computers[8]. Research in this area indicates its effectiveness in enabling students to work independently without the need for an assistant/mentor to critically evaluate and monitor their performance. This suggests that simulating real-life situations can decrease training costs by allowing students to practice autonomously and enhance their clinical skills[9-11].

Digital Diagnostics And Treatment Planning

Effective management of dental issues relies on precise diagnosis and personalized treatment options, achieved through thorough examinations and accurate imaging methods. Over the years, dentistry has witnessed numerous advancements facilitating diagnosis and treatment planning.

In the context of the current digital era, often referred to as the virtual age, the ability to predict the potential success of restorations has become more realistic. This is based on three-dimensional models generated from images captured during routine patient examinations and the subsequent digital restorations. New imaging and reconstruction techniques contribute to a quicker and more accurate workflow, including prototype restorations[7]. While conventional techniques have historically proven successful in dentistry, the evolving landscape of technology presents significant potential in digital methods for a faster, more accurate, and cost-effective workflow, ultimately enhancing the quality of dental services.

Commonly Used Digital Dentistry Techniques:

- **Digital Imaging Systems**
  a. Digital Radiographs (digital radiographs, Computerized Tomography, Cone Beam Computerized Tomography**)**
  b. Magnetic Resonance Imaging
  c. Ultrasonography
  d. Scintigraphy (Nuclear Imaging System)
- Three-Dimensional Modeling Systems
- Three-Dimensional Force Analysis Systems
- Digital Cameras (Photo and Video) and Digital Dental Photography
- Intraoral Imaging Systems
- Computer-Aided Design Systems (CAD)
- Computer-Aided Manufacturing Systems (CAM, 3D Printing)
- Digital Color Acquisition Devices (Colorimeter)
- Virtual Color Matching and Digital Smile Design
- Virtual Articulators and Digital Facial Arcs
- Lasers
- Occlusion and Temporomandibular Disorder (TMD) Analysis and Diagnosis
- Orthodontic Digital Diagnosis and Planning, Invisalign Applications
- Storage and Transfer of Staff and Patient Data
- Dental Staff Training Systems
- Patient Education and Communication Systems[7].

Digital Imaging Systems

Radiography is the recording of a photographic image of an object on film or digitally on a computer using X-rays. Radiography is one of the most important diagnostic methods used in dentistry. Thanks to the careful and accurate evaluation of radiographs, many diseases can be diagnosed, and treatment planning can be made [12]. Depending on the developments in computer technology, digital radiologic systems are also developing, and many different digital radiologic methods are emerging [13,14].

In digital radiography imaging, image receptors, or sensors, are used instead of the films used in conventional methods. Image receiver sensors used in digital radiography are more sensitive to X-rays than conventional films. Thus, a digital image can be created with less radiation on the sensor. In addition, digital radiographs have 50-80% less exposure time. Since the exposure time is less, the radiation dose to which the patient is exposed is also less. In digital radiology, X-rays passing through the object are detected by sensors and transferred to the computer as electrical signals. The signals transferred to the computer are digitized by converting them into digital data, and the image becomes visible on the computer screen [12,15,16].

a. Digital Radiography:

Intraoral radiographs are still considered to be the first choice for diagnosis, treatment, and patient follow-up due to their efficiency, low dose, and low cost. Digital radiographs have many advantages, such as improvements in image quality, almost immediate availability of images, reduced working time, elimination of chemical processing, easier image storage, and communication [17,18]. After exposure, the X-ray attenuated by the tissues reaches the image receiver, which receives analog information. This information is then converted into numbers by a computerized process called analog-to-digital conversion [18,19,20].

Digital Image Acquisition Methods:

Digital image acquisition methods can be realized in three ways. The first is indirect collection by digitizing films (In indirect image collection, an image is first obtained using a radiographic film in the traditional way. This image is then digitized), the second is direct digital image acquisition using solid-state digital receivers, where a solid-state receiver, which can be either charged coupled devices or complementary metal oxide semiconductors, is used instead of the film used in the traditional method. The last one is semi-direct using a phosphor plate system (In semi-direct digital acquisition, conventional radiographic film is replaced by a phosphor plate system {Phosphor storage plates (PSP)}. When exposed to X-rays, these plates absorb and store energy, creating a latent image. To visualize the image, the PSP X-ray must be processed by scanning (data readout) the plate from each system's scanner after exposure [17,19]. The principle of digital radiography can be basically divided into three types: indirect, direct, and semi-direct digital radiography.

Indirect Digital Imaging: It is an imaging system in which conventionally obtained radiographs are scanned with special cameras or scanners and then digitized, creating copies on the computer screen with the help of various computer software. With the indirect digital imaging method, the image can now be accessed more easily, changes can be made to the image, and the image can be stored in the computer environment [13,16].

Direct Digital Imaging: In direct digital imaging systems, reading and digitalization occur simultaneously. X-rays passing through the object fall on the sensor, and the signal generated on the sensor is transmitted to the computer via a fiber optic cable. Seconds after irradiation, the image appears on the computer screen [16].

Digital X-Ray Image Sensors:
Digital image sensors come in various shapes and sizes. They are divided into two groups according to the underlying technology: solid-state detectors and phosphor plates [15,16].

Solid-State Detectors:
There are three types of solid-state sensors: charge-coupled device (CCD), complementary metal oxide semiconductors (CMOS), and flat panel detectors [15,16].

Flat Panel Detectors:
Flat panel detectors are mostly used for medical imaging, but they are also employed in various extraoral imaging devices[20]. Flat panel detectors are expensive, and their use is currently limited to specialized imaging modalities such as cone beam computed tomography [19].

Semi-Digital Direct Imaging:
Phosphor storage plate systems are used in semi-direct digital imaging that is not connected to a computer by a cable [15,21,22].

Intraoral Radiographs:
There are three types of intraoral radiography methods: periapical radiographs, bite-wing radiography, and occlusal radiography [15,21,22,23].

Extraoral Radiographs:
While intraoral radiographs are used to examine the teeth and tissues around the teeth, extraoral radiography techniques are employed when it is not possible to apply intra-oral techniques. They are used to visualize anatomical structures in the head and face region, as well as pathologies in the jaws, especially when large lesions in the jaws cannot be fully evaluated with intra-oral radiographs. These techniques include panoramic, cephalometric, temporomandibular joint (TMJ), head, and jaw radiographs [23].

Cephalometric Radiography:
The lateral cephalometric imaging technique is one of the extraoral imaging methods that displays the lateral view of the head and the soft tissue profile of the face simultaneously. It is frequently used in orthodontics for diagnosis and treatment planning, determining the growth stages of patients, detecting anomalies, predicting the future of the patient's treatment, and interpreting the treatment results [26,27,29,30]. Posteroanterior cephalometric radiography is a technique used in the evaluation of transverse skeletal and dentoalveolar relationships, skull fractures, diseases involving the skull bones, bilateral structural problems, and facial asymmetries [26,31,32].

Temporomandibular Joint Radiographs:
In TMJ radiography, the tuberculum articulare, which forms the temporomandibular joint, and the glenoid fossa condyle are examined mesio-obliquely to evaluate whether there are pathologies such as erosion, hyperplasia, and fracture in the condyle [33].

Sinus Radiography:
Lateral sinus radiography allows the examination of lesions in the posterior and superior part of the maxilla and nasal bone [33].

Lateral Jaw Radiograph:
Lateral jaw radiography is the primary imaging technique used to diagnose fractures in the angulus and ramus region of the mandibular bone after trauma. It is used to examine the relationship between the bone surfaces in the fracture line, detect impacted and ectopic teeth, and identify pathologies in the mandibular angulus and ramus region. Additionally, it is used to evaluate the presence and localization of foreign bodies [33].

Lateral Skull Radiograph:
Used in orthodontic examinations, the lateral skull radiograph evaluates the results of head trauma, facial bone injuries, findings of certain diseases in the skull bones, pathologies in the maxillary sinus, hard palate, developmental disorders, and is commonly used before and after treatment [26,33].

Posteroanterior Mandible Radiograph:
This projection provides a mesiolateral view of the mandible. It allows for the evaluation of the extent of lesions and observation of fractures in the mandible. This projection can be taken with the mouth open or closed. If the patient's mouth is opened, it is referred to as the Reverse -Towne's Projection, and it is possible to visualize condyle fractures [33].

Posteroanterior Maxillary Sinus (Waters) Radiograph:
This method, known as the Waters projection or occipitomental projection, is performed with the patient's mouth open to prevent teeth from superimposing on the sphenoid sinus. It visualizes all paranasal sinuses, mainly the maxillary sinus, and to a lesser extent, the frontal sinus and ethmoid air cells, along with the midface bones [26,33].

Posteroanterior Frontal Sinus (Caldwell) Radiograph:
This radiograph is used to evaluate the frontal and ethmoid sinuses. Additionally, information about the upper and more limited medial and lateral walls of the maxillary sinus can be obtained [27].

Bregma-Mentum Radiograph:
With this radiograph, the walls of the maxillary sinus, nasal cavity, orbital fossae, the condyle of the mandible, and the zygomatic arch can be examined [27].

Inferosuperior Zygomatic Arch (Submentovertex) Radiograph:
The submentovertex projection is especially used in the evalation of zygomatic arch fractures [26,27].

Advanced Imaging Techniques
Computed Tomography (CT):
Computed tomography is an imaging technique that allows three-dimensional visualization of morphologic structures and pathologies. CT images can show the imaged tissue cross-sectionally with the selected slice thickness (1-2 mm) and location by the user [12,26,34,35]. In dentistry, CT allows the evaluation of cysts, tumors, inflammatory diseases, oroantral fistulas, and fractures in the maxillofacial region. It provides detailed information about the structure of lesions, their mesio-distal and bucco-lingual extent, and the relationship of the lesion with surrounding tissues such as bone, nerves, and tooth roots. With CT, bucco-lingual sections of tissues can be examined without superpositions. By determining the absorption values of lesions, tissue densities can be determined, and inferences can be made about whether the content of the tissue or lesion is fluid, cellular, or vascular. The most significant disadvantage of CT is that the patient is exposed to a high radiation dose because it takes multiple sections and images from the same area [12,26].

Dental Volumetric Tomography (DVT):
Dental volumetric tomography is based on the concept of volumetric tomography[12]. The DVT imaging system is a modification of the computed tomography imaging system. Dental volumetric tomography (DVT) is one of the most advanced methods of X-ray diagnostics. It is an imaging tomography method in which 3D X-ray images are created. This way, the examining doctor receives three-dimensional

information about the structures of the head with the highest precision. As a result, they can examine the mouth and jaw area in three dimensions at all levels and recognize the finest anatomical structures[12,26,34-38].

Anatomical locations of teeth and bones, pathologies, traumas, impacted teeth, paranasal sinus neighborhoods, cysts, tumors can be examined in 3D from different angles by rotating the image obtained on the desired axis. Bone density measurement, especially crucial for implant applications, measurement of bone height and width, and implant placement simulation can be easily applied with this method[12].

Cone Beam Computed Tomography (CBCT):

Cone Beam Computed Tomography is a widely used three-dimensional imaging technique in dentistry. CBCT is applied in various dental practices, including implant planning, detecting variations in canal morphology before endodontic treatment, identifying root canal fractures, maxillofacial surgeries, impacted wisdom tooth surgeries, and temporomandibular joint evaluations. Implant planning is a prominent application for CBCT, as it provides cross-sectional and three-dimensional imaging for preoperative assessment of residual alveolar crest volume, shape, and density. CBCT is particularly useful for identifying local problems that may not be clearly assessed by clinical examination and two-dimensional radiography. It aids in understanding the anatomy of the region and its relationship with vital structures surrounding the alveolar bone, such as the nasopalatine canal, nasal floor, maxillary sinus, mental foramen, and mandibular canal [7,40].

Cone Beam Computed Tomography (CBCT) is distinct from dental CT. While both create three-dimensional images of the jaw, dental CT uses a fan beam in a helix/spiral form to transmit radiation, whereas CBCT employs a cone-shaped X-ray beam rotating around the patient's head to produce 150 to 200 high-resolution two-dimensional images digitally combined to form a 3-D image. CBCT allows dentists to review three-dimensional cross-sections of the head and neck, efficiently identifying diseases of the jaw, dentition, bony structures of the face, nasal cavity, and sinuses. This technology is particularly valuable when standard dental X-rays are insufficient, offering precise diagnostic imaging for oral and maxillofacial pathology [7,40].

Magnetic Resonance Imaging (MRI):

MRI is a medical imaging procedure using a magnetic field and radio waves to capture images of the body's interior. This non-ionizing radiofrequency (RF) wave technique is performed by placing the patient inside a powerful magnet, directing existing atoms toward the applied magnetic field. The energy released from the body is then analyzed, creating an MRI image on the computer. MRI has replaced CT in imaging soft tissues due to its high soft tissue contrast sensitivity. However, it cannot be used in patients with pacemakers affected by magnetic fields. MRI is ideal for detecting TMJ disorders and visualizing odontogenic cysts and tumors, as well as soft tissue lesions involving the tongue, cheek, salivary glands, neck, and lymph nodes [12,34].

Ultrasonography:

Ultrasonography is an imaging method based on the reflection of high-frequency sound waves outside the range of human hearing as they pass through different surfaces. This non-invasive, inexpensive, and painless imaging method utilizes high-frequency sound waves (ultrasound) to produce images of internal organs and tissues. A transducer converts electric current into sound waves, which pass through the body's tissues and bounce back to the transducer. The reflected waves are then converted into electrical signals, creating an image displayed on a monitor and saved digitally. Ultrasonography is free from harmful ionizing radiation and can be used repeatedly. It is employed to evaluate neoplasms in the thyroid, parathyroid, salivary glands, or lymph nodes in the head and neck region. Ultrasonography is also utilized to visualize stones in the salivary glands and ducts and in TMJ examinations to detect changes such as the localization of the articular disc and inflammatory effusion [12,34].

Digital Caries Detection Methods:

In order to stop the progression of caries or restore the tooth in the most conservative way, it is important to detect caries as early as possible. There are many new technologies and methods for caries detection that are more accurate and sophisticated than traditional tactile and radiographic methods.

In today's dental practice, the use of digital caries detection technology is the only way to maintain and provide the standard of care for patients with respect to minimally invasive dentistry in both the diagnosis and treatment of dental caries. The earlier decalcification or decay is diagnosed, the more conservative the treatment, whether it is restorative or preventive. This technology also eliminates the guesswork in diagnosis, thereby building the confidence and trust that patients deserve. Caries risk assessment has always been an important element of early caries detection and minimally invasive dentistry. In fact, risk assessment has become the standard of care for most practices. The CariScreen (Oral Biotech, Albany, OR) caries susceptibility screening system is now available to determine the level of a patient's caries risk. This chairside technology uses the CariScreen meter and the CariScreen Swab to measure the adenosine triphosphate (ATP) level in the oral biofilm. The higher the level, the higher the patient's risk. The CariScreen swab is used to collect samples from a patient's teeth, which are then placed in the CariScreen testing meter. The digital screen shows the ATP level and in a matter of seconds searches the biofilm for all aciduric/acidogenic bacteria that are known to cause dental caries. These numbers, in combination with other diagnostic technologies, provide important information for accurate caries diagnosis and treatment.

These digital caries detection technologies are a vast improvement in detecting decay at its earliest stages so that patients can be treated in the most minimally invasive manner. Nowadays, the discussions concentrates on technology that can be more definitive regarding the presence of caries. Although laser and LED fiber optic caries detection devices have been available for several years, they are not used in dental practices as much as they should be. These caries detection technologies are also the standard of care for diagnosing the presence or absence of decay in today's dental practice. The previously discussed technologies of digital radiography, intraoral cameras, and caries risk assessment products all enhance the ability to detect possible decay or caries. It is thought that laser or LED caries detection will provide a more definitive answer in more than 90% of cases. The sooner there is a confirmed diagnosis of caries, the more conservative the treatment required. Also, if decalcification of natural tooth structure is diagnosed before decay begins, the most conservative treatment of all can be initiated: prevention or remineralization. Today's digital caries detection technology can remove the doubt from treatment decisions, whether restorative or preventive, with respect to hidden caries, questionable stained grooves, or any other suspicious-looking tooth surface[41].

Intraoral Camera:

The camera's wand projects a magnified digital image of teeth onto a computer screen. This helps to better visualize the oral cavity and can also make it easier to explain the diagnosis to the patient.

- **Visible Light:** These techniques are based on the scattering of light and utilize different light sources.

- **Fiber Optic Transillumination (FOTI):** This technique is based on the fact that carious enamel has a lower light transmission index than intact enamel [42]. FOTI technique is used for the detection of occlusal and proximal caries.
- **Digital Fiber-Optic Transillumination (DIFOTI):** Digital imaging fiber optic transillumination (DIFOTI) was developed to reduce the disadvantages of FOTI by combining it with a digital Charge coupled device (CCD) camera. It consists of two handpieces: one for the occlusal surface and one for the smooth surface and interproximal areas. Its main indications are the detection of initial and graded caries on all tooth surfaces and the detection of cracks and secondary caries around restorations [43-45].
- **Electrical Caries Screen (ECM):** Electrical impedance measurement is a measure of the degree to which an electrical circuit resists the flow of electric current when a voltage is applied between two electrodes. Decayed tissue has a lower impedance than intact tooth. Also known as an electronic caries monitor. The ECM measures the electrical resistance of the tooth area under controlled drying. This method helps to differentiate between intact and carious dental tissues through electrical conductivity [46,47].

Digital Endodontics

The end result in the digital transformation of endodontics has certainly improved the daily clinical practice of physicians. Endodontics is the only dental discipline where we cannot see what we are doing. It relies more on clinical skills and the sensitivity of the sense of touch. Therefore, one must rely on different technological methods to predict the success and prognosis of endodontic treatment. Since the turn of the century, various advances in endodontic technologies have enabled dentists to see things that they could not see before [7].

Digitalization in the field of endodontics;

1. Pulp testing devices that help to make accurate diagnoses.
2. Digital imaging, which helps to read images more clearly and in detail. Advances in radiographic techniques such as CBCT allow dentists to see what cannot be seen on a normal X-ray.
3. Apex locators that accurately define the apex of the root for the working length.
4. Endodontic electric motors and nickel-titanium (NiTi) endodontic shaping instruments (Endodontic Rotary System) that make mechanical cleaning and shaping more predictable, safer, efficient and easier than ever before.
5. Advances in the use of sonics and ultrasonics in endodontics to clean the complex root canal system.
6. Carrier-based obturation techniques that help dentists provide a better and more successful endodontic treatment and prognosis.
7. Microscopes that enable dentists to prepare a successful access cavity and facilitate the diagnosis of difficult cases with features such as illumination and magnification.
8. 3D-guided endodontics and virtual realities that offer interactive 3D visualizations of root canal systems and enable virtual endodontics before treating a patient. [7].

Digital Orthodontics

Digital technology has already become indispensable to modern dentistry, and the use of 3D technology in orthodontics has increased in recent years. The digital technology has contributed to improve and simplify diagnosis, treatment planning and execution in Orthodontics. The developments and introduction of intraoral and facial scanners, digital radiology, and cone-beam computed tomography (CBCT) have transformed diagnosis and treatment planning from a traditional two-dimensional (2D) approach into an advanced three-dimensional (3D) technique. A more recent breakthrough is the advancement of computer-aided design and computer-aided manufacturing (CAD/CAM) and 3D printing technology that is utilized to design and create "personalized" orthodontic appliances.

Among CAD/CAM system (Computer-Aided Design / Computer-Aided Manufacturing) applications in Orthodontics, It highlight the installation and removal of fixed appliance, clear aligners, customized appliances, and retainers fabricated in digital environment. This approach has several advantages for practitioner and patient, as it enhances appliances precision, directly interferes in treatment time and predictability. Such systems not only shorten treatment time, making cases more predictable and less labor-intensive, but allow doctors and patients to preview virtual results before treatment begins, thus facilitating communication, understanding, cooperation, and case acceptance. Even with all the benefits arising from the digital workflow, few orthodontists have adopted this technique in their clinical practice, most due to high cost and lack of technical preparation for proper execution[7].

Two-dimensional imaging techniques such as panoramic, cephalometric radiography and dental photographs have been used by orthodontists for years for basic orthodontic diagnosis, treatment planning and case follow-up. However, it is not possible to solve some complex cases with these two-dimensional methods. For this reason, computed tomography (CT) was the only medical option used in cases such as temporomandibular joint pathologies and impacted teeth. However, the use of CT also has some disadvantages. The high radiation dose emitted by CT made physicians very cautious when the average age of the patient population in need of orthodontic treatment was considered. Because the radiation dose emitted by CT for a simple impacted tooth localization is quite high. Newly developing technologies and alternative options with digital transformation have contributed to the solution of these problems. Some of the technologies used in orthodontics with digital transformation are as follows;

1. **Cone Beam Computed Tomography (CBCT)**: CBCT has become a great alternative to CT, especially with its relatively low radiation dose and low cost.
2. **Digital Image Collection Methods** a. Intraoral Scanners; b. Extraoral Scanners.
3. **Three-Dimensional Printers**
4. **Aligners**: Clear aligner treatment with Invisalign, introduced by Align Technology, pioneered the use of a virtual model, creating a virtual treatment plan, and producing devices from digital models [7].

Digital Restorative Dentistry

In addition to their use in daily life, developments in the field of digital technology have attracted great interest in dentistry for reasons such as new treatment options, faster, easier and higher quality treatments, reduced burden on the physician and technician, and increased patient comfort. Restorative digital dentistry (RDD) is changing the way dentistry is practiced today and the way patients receive restorative care in the future. The development of RDD is driven by advances in dental technology, occurring in parallel with developments in materials science and adhesive dentistry. We live in a world where the pace of technological developments is changing our lives and the way we live faster than ever before. The way we perform daily tasks and interact with our environment is changing rapidly. These advancements have had far-reaching consequences on society in a similar way to how RDD is affecting the landscape of restorative dentistry.

Digital Impression Systems

The process of obtaining a negative copy of the oral soft and hard tissues or maxillofacial tissues is called impression. Obtaining an accurate and complete impression is one of the important steps in the construction of fixed and removable prostheses. The success and harmony of restorations depend on the impression technique and impression materials used. In fixed or removable prostheses, the accuracy of the impression process is evaluated by the harmony between the restoration and the support tooth and/or soft tissues. The impression must clearly reveal all the details, otherwise failure will be inevitable. The more accurate and clear the impression is obtained, the greater the fit of the restoration will be [48].

Dissatisfaction with the results of the restorations obtained with the impression taken using the traditional impression method, some patients not being able to tolerate traditional impression methods for different reasons, the difficulties in casting the plaster in the traditionally obtained impressions and storing the model, the fact that the stages of the digital impression systems are shorter and easier, the The fact that it does not contain many negativities has been effective in the further development of digital impression day by day [49].

Nowadays, prosthetic treatments carried out with digital equipment aim to prevent many possible errors that may arise from impression materials in impression taken with conventional techniques. In addition, digital impression allow for much faster treatment procedures and fewer sessions compared to conventional impression. The main purpose of digital impressions in dentistry is to ensure that the 3D model of the mouth can be sent in the appropriate data format to the software programs that will be used in restorations to be produced with CAD/CAM systems. Thanks to this digital scanning, it becomes possible to produce prosthetics using CAD/CAM devices. Considering the developing technology, it will be more possible to eliminate errors and difficulties that may arise from conventional impression materials during the treatment stages performed with digital impressions [50].

In Computer Aided Design / Computer Aided Manufacturing (CAD/CAM) systems, data is obtained by scanning the oral environment or the model obtained from the impression taken in a conventional way. Dentists can simultaneously evaluate any procedure performed in the mouth in the clinic, examine its relationship with the opposing arch, apply the necessary corrections in the same session by making use of technical features such as enlargement and reduction, and do not need to renew the impression for all these examinations and corrections as in the conventional impression method [49] .

CAD/CAM technology, where dental restorations are designed and produced, is basically; It consists of three functional parts: scanning the prepared teeth or the whole mouth intraorally or extraorally and collecting data, planning and designing the restoration in 3D on the computer (CAD), and producing the digitally designed restoration (CAM) [51].

Data collection is divided into two groups, direct technique and indirect technique, according to the data acquisition methods.

Restorative treatments carried out with digital opportunities in today's technology try to prevent many possible errors that may arise from sensitive work on impression materials in impression taken with traditional techniques. In addition, digital impression enable much faster treatments and fewer sessions compared to conventional impression [50]. The main purpose of digital impressions in dentistry is to ensure that the 3D model of the mouth can be sent in the appropriate data format to the software programs to be used in restorations to be produced with CAD/CAM systems. Thanks to this digital scanning, it becomes possible to produce prosthetics using CAD/CAM devices. Considering the developing technology, it will be more possible to eliminate errors and difficulties that may arise from conventional impression materials during the treatment stages with digital impressions [52].

There are many intraoral scanners in dentistry (Some of them are Lava, BegoMedifacturing, Ce Novation, Pro 50.waxpro, DCS President, Decim, Cercon Smart Ceramics, Perfactory, Etkon, GN-1, Digident, ZFN Verfahren, Xawex dental system, Everest, Celay, Procera, Triclone, Cerec, EDC, Wol Ceram, Atlantis) [53-68].

1. Direct Digital Impression Method:
In this technique, the materials and techniques used in conventional impression methods are eliminated. It is a method that allows impression to be taken directly from the oral cavity with intraoral scanners in order to eliminate possible errors and disadvantages of the conventional technique. According to this method; The mouth and prepared teeth are scanned with intraoral scanners and the data is directly transferred to the computer environment [48,49,69].

All parts of the CAD/CAM system are available in the clinic. The design is made on the digital impression obtained intraorally with a digital 3D scanner, and the restoration is made ready in the CAM unit. The biggest advantage of this production method is that the restoration can be applied to the patient's mouth in a single session [53,70].

2. Indirect Digital Impression Method:
In this technique, impressions are taken using conventional methods and a plaster model is obtained from the impressions. This dental cast is scanned with optical or mechanical scanning systems belonging to the CAD/CAM system and a digital model is obtained. In some systems, a digital (virtual) model is obtained by scanning the impression surface taken in a conventional way. Then, the design part is continued in the digital environment. The desired restoration can be applied on the virtual model [49,69].

Intraoral digital scanning systems consist of a portable camera, a computer and software. Intraoral digital scanners precisely record the three-dimensional geometry of an object using many techniques such as laser scanning, contact data capture and video or photography with optical cameras. Some of the systems used today to obtain digital impressions are: CEREC (Sirona Dental Systems; Bensheim , Germany); E4D (D4D Technologies, Richardson, Tex.); iTero (Cadent, Inc.; Carlstadt, NJ, USA); Lava C.O.S (3M ESPE, Seefeld, Germany);Trios (3Shape, Copenhagen, Germany).

In terms of precision, the indirect technique differs from the direct technique because it includes conventional impression materials and impression techniques. Because; Dimensional stability of impression materials, storage conditions, deterioration during disinfection, separation and incompatibility from the impression tray, and conditions during transfer to the dental laboratory should be taken into consideration [35]. The discomfort caused to the patient during the impression taken with the conventional technique is also among the disadvantages of the indirect technique[71-88].

Imaging Techniques And Technologies Used By Digital Intraoral Scanners
Intraoral digital scanner systems use different techniques to record the tissues inside the mouth accurately and precisely.

1. Parallel Confocal Laser Scanning Method:
Confocal technique works on the principle of creating depth contrast of high resolution images. It saves images from region to region and creates the image on the computer. In the system, fluorescent light is cast on the object from a light source. In this technique, the lens moves, and the incident rays allow the x and y axis to be determined. Then the fluorescent light reflected from the object is collected again. The light returning to the sensor forms the z-axis. The filter in confocal microscopy ensures that only the light coming from the object

falls onto the lens. As a result, the reflected ray and other rays are blocked. The collected visual information is then electrically transferred to the computer [89].

In the parallel confocal laser scanning method, parallel light beams are projected onto the object to be scanned by the intraoral scanner, and images are obtained on the principle of obtaining focused and unfocused images at the selected depth by returning the reflected light beams through the same optical path [90-92]. Since the lenses used in scanning systems using this method are large, they may create difficulties during clinical practice. Systems using this technique: "iTero Element (Align Technology, San Jose, USA); Lava C.O.S (3M ESPE, St. Paul, USA); Trios 3 (3Shape, Copenhagen, Denmark); AADVA (GC, Leuven, Belgium); Apollo Di (Dentsply Sirona, Bensheim, Germany) and IntraScan (Zfx, Dachau, Germany)"

2. Triangular Scanning Method:
Triangulation technique is the technique in which 3D digital models that offer wide application purposes are obtained by restructuring the digital data collected from a 3D object on the computer. This technique enables scanning without contacting the scanner head by taking three points as reference. Camera, object and object form the triangular structure. In the passive technique, stereovision uses photographic algorithms. This system is created by using two stereo images with known positions and angles. The triangular plane formed by the object and the stereo camera allows the computer to establish the depth algorithm [89,93]. Triangular scanning method is divided into two: active and passive. In active triangulation methods, light is reflected to the relevant area and the reflected image of the reflected light is obtained to calculate the position of the target object. In the passive triangulation method, there is no reflection in the scanning device itself and the system is based on the detection of environmental reflections.

In the triangular scanning method, light with different wavelengths is reflected from the intraoral scanner to the object, and the light reflected from the object is captured by cameras and processed through software. The data obtained from the area scanned with intraoral scanners is obtained by calculating the angle and position of two points in a triangular plane. In imaging these two points, a double detector, a prism, or a single detector that captures images from two different points at the same time can be used.

In these systems, LED beam can be used instead of laser beam. A camera consisting of a lens and a position-sensitive photo detector determines the position of the image using a laser spot on the object. The laser beam moves parallel to the camera's field of view. The proximity of the sent laser beam to the surface allows us to determine the depth of the object. The reason why this technique is called active triangulation is that the laser point sent to the surface is mobile. Thus, cameras and laser form a triangular structure [89,94].

In this method, the real colors of the object can be used in reconstruction. Systems using this method: "Cerec Omnicam (Dentsply Sirona, Bensheim, Germany); Cerec Bluecam (Dentsply Sirona, Bensheim, Germany); Planscan (Planmeca, Helsinki, Finland); CS3500 (Carestream, Rochester, USA); Rainbow (Dentium, Su-won, Korea); MIA3d (Densys 3D, Migdal Ha`Emek, Israel); Lythos (Kavo, Biberach/Riss, Germany) and Ormco Lythos (Ormco, Orange, USA)" [89,92].

a. Stereophotogrammetry Method:
Stereophotogrammetry involves sensors and light emitting sources strategically placed in different positions relative to each other to obtain a 3D model of the object to be scanned. Each sensor placed at different angles allows a 360-degree image to be obtained. Using only sensors ensures that the cost is lower than other technologies. It is expected that the active stereophotogrammetry method records movements better than other techniques. In this system, as the number of sensors increases, the accuracy of the image increases [93,95]. The scanner may be smaller, easier to use, and cheaper to produce (5,12). Systems using this technique: Condor (MFI, Gent, Belgium) and PIC camera (PIC Dental, Madrid, Spain).

b. Scheimpflug Image Principle and Polarization-Division Multiplexing Method:
This system is used to obtain the image when the two lenses are not positioned parallel to each other. Clear images can be obtained even if three planes intersect at one point. This technique is used with polarization-division multiplexing in intraoral cameras [93,95]. Polarization-division multiplexing and the Scheimpflug principle enable the creation of the topography of the scanned area using the active triangular technique [95].

c. Active Stereoscopic Vision Method with Structured Light:
Inspired by human visual systems, technological developments have been created in this field. As with humans, two cameras scan the image from different angles. It uses two-dimensional images to form the vision system. It also uses structured light technology to determine the correct coordinates of the image. Since two cameras and objects form a triangular plane, these systems are included in triangular systems [95].

3. Optical Coherence Tomography Method (OCT):
This technique is an interferometric imaging technique. In this technique, light waves in the same phase are used. The emitted light phases progress by passing between each other. The algorithm is created from the ray phases reflected from the object [95].

4. Active Wavefront Method (AWF):
The word wavefront means "the set of all points where the wave and sinusoid formed by a ray field advancing in time have the same phase" or "wave front". In other words, the wavefront is a line spread by the ray wave coming out of the source and it spreads. In active wavefront technology, the propagating wave passes through two or one holes rotating in a moving cylinder, the resulting images are dropped onto an image plane and the image algorithm is created. The rotating cylindrical structure contributes to reducing the blurriness of the image [95]. This method, produced by 3M ESPE, is used in LAVA COS and True definition intraoral scanners. Since light reflection is high, powder spray must be used in this system [90-92].

5. Accordion Fringe Interferometry Method (A.F.I):
In this system, laser beam is scattered from two sources. Scattered rays create a fringed (parallel striped structure) structure on the surface. Then, the geometry of all planes on the surface is obtained with the help of the camera. AFI technology has more advantages than visible light scanners. It is less sensitive to ambient light. Allows infinite projector depth of field recording. It can also record surface geometry without photographic systems. There is no need for powder and spray for recording. These systems are not currently used in the dental industry [95].

6. Near Infrared (NIR) Imaging (Spectroscopy) Technology:
Near infrared imaging is a technology developed by taking advantage of high wavelength rays storing different amounts of energy on the tissue. NIR technology can be called infrared imaging. Wavelengths of 700 nm – 1 m, which are longer than the wavelength of visible light and cannot be seen by the human eye, are called infrared. This technology was developed based on the principle that high wavelength rays store different amounts of energy on the tissue [96]. It is used to diagnose caries as an add-on to intraoral scanners in the

computer environment. Although this technology is not available in many intraoral scanners today, some new generation intraoral scanners have this feature [93]. This technology can be used in digital caries diagnosis as an additional feature to intraoral digital scanners [92].

7.Structured-Light 3 Dimensional Surface Imaging:
This imaging system is used to obtain images of uneven and uneven surfaces in the x, y, z axes. A projector creates a pattern containing two-dimensional parallel lines on the surface. In recessed areas, this parallel structure is disrupted. The resulting structured light is sent to the computer via the camera. Then, a 3D algorithm of the scanned shape is created. Two-dimensional surface patterns differ in improved techniques. Structured light imaging technique is also used in the triangular technique to obtain 3D images [98,99].

Digital Recording Of Dental Scannings
The CAM system must recognize the file extension of the model designed for production. Unfortunately, some companies keep the source code of these software systems closed. Therefore, production can be carried out in the CAM units of that system. The recording formats of three-dimensional scanners that are generally accepted in the world are .stl and .ply. For this reason, systems that use one of the .stl and .ply formats are called 'open systems', and systems that do not use these formats but have their own file format are called 'closed systems' [100].

Intraoral scanners provide a digital copy of the area to be recorded; It enables the computer to be transferred to the computer in colorless .stl (Stereolithography), .obj (Wavefront Object) and colored .ply (Stanford Polygon Format) formats or in the format language specifically released by the developer company. Scanned models can be designed in any CAD system in ".stl and .ply" formats. In other words, we can share these file formats with any dental laboratory or technician we want [98].

Scanned 3D data creates a polygonal structure combining x, y, z planes. The greater the amount of polygonal structure, the better the quality of that structure. However, the high polygonal structure both prolongs the scanning time and requires the use of computers with higher processing power, which is reflected as a negative feature for us [101,102].

Slower scans allow us to have higher resolution and contrast information. The computer uses the two-dimensional photographs or videos it sequentially collects to create the 3D model. The recording of depth and details is directly related to the technology of the scanner used [93].

Accuracy Of The Dental Scanners
The accuracy of dental scanners is affected by many factors. First of all, the scanning style of the scanner, scanning speed, location of the scanned area and spatial position of the scanned tooth, oral fluids, anatomical obstacles, surface brightness and light transmittance directly affect the accuracy of intraoral oral cameras [93].

Many methods are currently used to call a measurement successful. In order to compare these methods, traditional measurements must be digitized with extraoral scanners, transferred to the computer environment and analyzed. There are three methods for this analysis. Among the most used methods, a plaster model is obtained from a traditional impression. This model can then be digitized using an extraoral scanner.

Another method is; After a traditional impression is obtained, the inside of the measuring spoon is scanned and transferred to the digital environment before the plaster is cast. It can be evaluated after the negative of the transferred image is obtained. Finally, it is also possible to make direct comparisons on restorations produced using both traditional and digital impressions in in vivo or in vitro environments [103,104].

Scanning speed and type of scanning are interrelated with the features of the intraoral camera used and the experience of the practitioner. This increases the number of factors affecting accuracy. As the distance between the scanner head and the scanned area increases, the clarity of the images may deteriorate and the image may become blurred [105]. In scans made from a very close distance to the surface, the camera's focus may be positioned further behind the object. For this reason, the distance of the scanner to the object should be adjusted according to the technology it has. For example, while confocal scanners contact the object during scanning, there is no need for contact in triangular scanners. In passive wavefront technology, blurring increases as you move away from the object, while blurring decreases with active wavefront technology. Active triangular scanners can make more precise measurements than confocal scanners [89].

The structure of the scanned surface may cause the beam to be refracted and reflected incorrectly. Some intraoral scanners have recommended the use of powder and spray to prevent this situation. However, with the new generation cameras, this has disappeared and clear images can now be obtained without the use of dust and spray [88]. In addition, the position of the tooth and implant to be scanned also affects the accuracy value. As the scanning speed increases, the resolution of the scan decreases. In addition, some quickly scanned areas may be displayed incompletely, and the physician who scans these areas again can correct these deficiencies by changing the angle of the camera. A different angle may cause distortions to increase and accuracy to decrease. This shows the importance of both the scanning method and an experienced practitioner [106]. In line with the experience of the practitioner, the area to be scanned should be made in accordance with a specific plan. Especially in the posterior regions, the head sizes of the scanners make scanning difficult and cause the application angle of the cameras to be changed. This situation can naturally cause distortions in images [107,108].

DIGITAL WORK FLOW
Conventional Digital Workflow:
The reason why it is called 'Conventional Digital' is that this workflow starts with conventional measurement and ends with digital production. In the stages of this concept;

- The dentist takes measurements using the conventional method using a measuring spoon and impression material,
- The dentist sends the measuring spoon to the laboratory,
- The laboratory technician pours plaster into the measuring spoon,
- Once the plaster has hardened, the technician scans the plaster model with an extraoral scanner to create a 3D virtual digital model of the entire dental arch,
- The technician designs the prosthesis in the CAD system and transfers this design to the CAM system,
- CAM system creates the prosthesis,
- The prosthesis is applied to the patient's mouth by the dentist and occlusion adaptation is made with the necessary adjustments.

This method is the oldest method among digital measurement techniques. A 3D model can also be obtained by directly scanning the measuring tray without producing a plaster model [52].

Digital Workflow:
This workflow starts with a digital intraoral impression. However, the preparation part of the restoration can be completed conventionally, if preferred. The digital workflow

is the workflow performed by the clinician with a standalone intraoral scanner without a milling unit. Stages of digital workflow concept;

- The dentist takes the digital impression through an intraoral scanner,
- The dentist sends the digital data to the laboratory,
- The laboratory loads the digital file and uses a special software program to mark the day cut and margins,
- A stereolithographic (SLA) model is created using a 3D printer,
- Proceeds with the preferred restoration construction procedure. (Can be done analog or completely digital with CAD/CAM system)
- The final restoration is sent to the dentist to be delivered to the patient.
- The prosthesis is applied to the patient's mouth by the dentist and occlusion adaptation is made with the necessary adjustments [52].

Fast Digital Workflow

This concept can be carried out in cases where the clinician has an intraoral scanner operating in conjunction with the milling machine in the clinic. In this concept, the restoration is delivered to the patient on the same day. Stages of rapid digital workflow concept;

- The dentist takes the digital impression through an intraoral scanner,
- The dentist designs the restorations in special CAD software and sends the resulting data to the CAM device for production,
- The final restoration is prepared in the CAM unit in a short time,
- The prosthesis is applied to the patient's mouth by the dentist in the same session and occlusion adjustment is made with the necessary adjustments [52].

Open and Closed Systems in Digital Workflow

CAD software used in the design phase of workflows used in digital dentistry varies. It is possible to examine this diversity in two groups as 'Closed system' and 'Open system'.

Closed system CAD software is software that belongs to the manufacturer of the intraoral scanner used in the workflow. In this system, scanning data obtained with the intraoral scanner is obtained in a special format that can only be processed in the CAD software of the scanner used. In this system, the intraoral scanner and CAD/CAM units are located together in the same place. It does not allow choosing between CAM systems [52,109]. Since the model obtained from closed-system digital intraoral scanners does not need to be converted to a file in a different format and can only be processed in the CAD software of the scanner, there is no data loss. This positively affects the accuracy of the measurement taken [52].

Workflow in closed system CAD software; 1-Data obtained from scanning with intraoral digital cameras → 2-The obtained data (without changing the format) are transferred.

In open system CAD software, data is accepted in STL format. To enable digital design in an open system CAD software, either scanners that directly output data in STL format should be used, or the data obtained with scanners that scan in a special format should be converted to STL format and sent that way. Open system CAD software is CAD software that can be used with all browsers, not with software for any browser. However, since the data obtained in these systems must be converted into a suitable format that can be run in the relevant CAD software, some data loss occurs, which negatively affects the accuracy of the measurement taken [51]. Open systems provide the opportunity to choose between different hardware and different production centers [18,119-121]. to CAD software and a digital model is obtained. → 3-The restoration is designed using CAD software on this digital model. →4- The digital model of the designed restoration is sent to the CAM unit and the restoration is produced in the CAM unit. 5- The produced restoration is placed in the patient's mouth." [110-119].

Workflow in open system CAD software;

1-Data obtained from scanning with intraoral digital cameras → 2-Data obtained. The obtained data is converted to STL format. 3- Data in STL format is transferred to CAD software and a digital model is obtained. → 4- The design of the restoration is made using CAD software on this digital model (model obtained from the data accepted from each scanner). →5- The digital model of the designed restoration is sent to the CAM unit and the restoration is produced in the CAM unit. 5- The produced restoration is placed in the patient's mouth. Ceramics, metal alloys and various composites offer a wide range of materials used in CAD/CAM systems. The most commonly used ceramics in digital dentistry are alumina and zirconia based ceramics [120].

In ceramics produced with the CAM system, it enables the restoration to be prepared larger before sintering in order to cover the 25-30% shrinkage that occurs during increasing the density of the restoration. On the sintered infrastructure, layering ceramics with suitable physical properties recommended by the companies or produced by them are applied [121-123].

Although polymer-based materials seem to be more advantageous than ceramics in terms of intra-oral adaptation, polishing, and additions to occlusal or interface areas, they are disadvantageous in terms of low wear resistance and bending strength [123].

The most preferred metallic material is titanium. This is because of its superior biocompatibility, corrosion resistance and fine machinability. Their costs are less than noble metals. Compared to the traditional method made with casting techniques, there are no porosity gaps in the materials since all metal block materials used in CAD-CAM systems are produced industrially. For this reason, their durability is higher and the particles in the materials are distributed homogeneously [122].

With the widespread use of CAD/CAM systems, aesthetic and functional expectations have increased greatly. With increasing expectations, materials with different combinations, structural and physical properties have been developed. The block materials used in production vary depending on the type of restoration, the location of the restoration in the mouth, the patient's expectations, socioeconomic status and the physician's preference[110-119,124,125].

Digital Design- Manufacturing (cad/cam) Systems

Computer-aided design (CAD) and computer-aided manufacturing (CAM) system; It is a technological system that uses computers to design and produce the collected data in a wide range of products [126-130]. CAD/CAM systems have an important place among the currently used systems in dentistry. The purpose of developing these systems is; to eliminate traditional measurement methods and the disadvantages associated with these methods, to design a restoration suitable for natural tooth anatomy and functions in 3D in a computer environment, to produce the restoration in a single session at the chairside, to increase the quality of the restoration (mechanical properties, edge compatibility, aesthetics, physical durability) and to make the restorations more durable. It can be prepared in a short time. Today, the CAD/CAM system consists of transferring the preparation area or the obtained model measurement to the computer, recording the data, realizing the designs on the digital data obtained, and producing the restoration by abrasion from ceramic, composite, metal... blocks obtained specifically for this system [131].

CAD/CAM systems basically include three structures. The first is collecting data by scanning the preparation intraorally or extraorally, the second structure is CAD, that is, the restoration is planned and designed in 3D on the computer, and the third structure is CAM, which is the production of the digitally designed restoration [132].

The first CAD-CAM systems developed were the so-called 'subtraction method', which allowed restorations to be produced only by milling prefabricated blocks with burs or diamond discs. In this method, block material is reduced to achieve the desired shape. In this method, almost 90% of the prefabricated blocks are removed in order to produce the designed restoration, so most of them are wasted [51].

The method of producing a restoration by sintering the material in the ceramic or metal powder pool with continuous additions is called 'additive' production. In this method, there is no wasted material [51].

In some CAD/CAM systems, addition and subtraction methods are used together. The material to be used is applied to the metal die in powder form by adding it under pressure to form a large block. This block is milled to give the external shape of the restoration. To compensate for the shrinkage that will occur after the sinterization of the final restoration, an enlarged die is used and it is sintered intensively to reach its normal dimensions [133].

Current CAD/CAM systems are divided into three groups according to production methods. These:

1. In-office (chair-side) systems: The prepared tooth is scanned digitally. The restoration is produced at the bedside. The restoration is delivered to the patient in the same session [134].
2. In-lab systems: The restoration is produced by scanning the measurements taken conventionally in the clinic or the plaster models obtained from them with a digital scanner in the laboratory [134].
3. Centralized production: Digital measurements are obtained in the clinic and sent to the laboratory via the internet. Production is also carried out in the laboratory [134].

Most CAD/CAM systems today use open STL or locked STL and similar formats as digital formats, the most common. Systems that use a locked STL format, whose scanning data are coded in such a way that they can only be used by the system itself, and thus all stages, including the design and production of the restoration, have to be carried out through the same system, and do not allow the use of a different system at any stage, are called "Closed System". Systems in open STL format that allow the data obtained using any manufacturer's intraoral digital scanner to be processed by another company's software and even the restoration produced using another company's CAM device are called "Open System" [71].

CAD/CAM Systems, Eliminating traditional measurement methods, Making the design in great detail using computers according to the natural anatomy, function and preparation of the restoration to be produced, Being able to produce the restoration at the chairside, Increasing the quality of the restoration (mechanical resistance, edge harmony, surface quality) and providing a better aesthetics was developed to provide.

Advantages of CAD/CAM System

- It allows symmetrical restoration to be made on the tooth to be restored (biogeneric, biogeneric reference technique) and restoration in the original form of the tooth (correlation technique).
- Since standardization is achieved in the restorations produced, it also enables quality control in the laboratory.
- Production processes in laboratories are accelerated and high quality automation is achieved [135].
- It allows all transactions to be completed in a single session.
- It allows the preparation of biologically compatible, tooth-colored aesthetic restorations.
- Traditional measurement methods are eliminated; Procedures such as waiting time while taking measurements and plaster casting are eliminated [136].
- Since applications can be performed in a single session, it saves time for both patients and dentists. In this way, in addition to traditional measurement taking, which can cause various clinical problems, the necessity of preparing temporary crowns is also eliminated, and the elimination of these factors provides economic gain, albeit small.
- Since infrastructures and restorations are designed with CAD software, the work of technicians becomes easier and the quality of the work done increases [137].
- It significantly reduces the potential for error and prevents possible cross-contamination that may arise from indirect restorations [138].
- With the use of CAD/CAM system in dentistry, condensation, melting and fusing processes of ceramic materials are relatively reduced [139-149].
- Making the design in a digital environment allowed the patient to be involved in this stage, and thus, patient satisfaction was increased by producing restorations in line with the patient's wishes[49,51].

Disadvantages of CAD/CAM System

- CAD/CAM systems are high cost systems.
- Transferring teeth with deep subgingival margins to the computer environment is also a problem. Therefore, it becomes necessary to perform good gingival retraction, as in the construction of traditional fixed dentures [150].
- The presence of blood and saliva makes it difficult for the intraoral scanner to record data.
- The use of the scanner is quite difficult, especially in the posterior region and in patients with mouth opening restrictions. Anatomical obstacles reduce the measurement taking and the quality of the measurement to be taken.
- The resolution of the intraoral cameras or extraoral scanners used is limited [151].
- The use of monochromatic blocks may cause ideal aesthetic expectations not to be met. However, with the gradual development of blocks in different colors, this problem has begun to be overcome [152].
- Experienced personnel are required to use CAD/CAM systems 49,51,92,140-149].

Parts of a CAD/CAM System

All CAD/CAM systems contain 3 functional components. These; Scanner is the part of the system that collects information. It scans the tooth cut made by the dentist, adjacent teeth and the geometry of the teeth in occlusion, intraorally or extraorally [153]. It transforms the preparation into three-dimensional virtual models by collecting data about adjacent teeth and surrounding tissues, either directly with intraoral scanners or indirectly with extraoral scanners [154,155]. Scanners are basically divided into two: mechanical scanner and optical scanner.

a.Design Software:

CAD software is included in a computer unit to enable 3D design and planning of the planned restoration on the computer screen. The user can directly use the templates in the CAD software, or can manually make the designs he wants by creating modifications. Software programs are often specific to the CAD/CAM system and are not compatible with other systems. When the design of the restoration is completed, the CAD software sends the file output of the virtual model in the appropriate format to the CAM unit [153]. The virtual data of the restoration designed between CAD and CAM is produced by converting it into another format [154]. Manufacturers develop special software to design different dental restorations. Thanks to these various software, many different designs can be implemented.

b. Computer Aided Design (CAD):
After the data is recorded in the computer environment, it is converted into a virtual model consisting of dots, thanks to the computer program. Once the design of the restoration is complete, CAD software translates the virtual model into a set of custom commands. These, in turn, operate the CAM unit that will produce the designed restoration. The boundaries and design of the restoration are completed on the virtual model with CAD software. The contact points or equatorial regions of the restoration can be added or subtracted as desired, depending on the available data [153].

c. Production Device Hardware:
The designs designed in this component are produced by computer-controlled milling and erosion machines. In the production of restorations, there are systems that produce blocks made of various materials by abrading them, and there are also systems that produce various materials by adding them to each other. Systems produced by eroding blocks are called subtractive, and systems produced by adding onto materials are called additive systems. At the same time, technicians can then apply final operations such as coloring, polishing and correction to the restorations produced by CAM [154,155].

CAM uses computer-aided methods to shape a part. The first systems achieved restoration by cutting from a prefabricated block with the help of burs, diamonds or diamond discs. This approach is based on the system called subtractive method, which is to reduce material from a block and leave the desired shape at the end. If blocks of appropriate sizes are available, all shapes can be obtained by the subtraction method, but most of these expensive materials are thrown away. Approximately 90% of the block can be removed to obtain a typical dental restoration. The other method, rapid prototyping (solid free form fabrication) technology, which is an additive CAM approach, has begun to be used in dental CAD/CAM systems. Selective laser sintering is one such technology that can be used to produce both metal and ceramic restorations.

In this method, the computerized design of the part is the same as in other CAD/CAM systems. However, instead of cutting, the system combines the material by adding ceramic or metal powders on top and continues this until the entire part is completed. Thus, no material is wasted and the disadvantage of the subtractive method is eliminated [153].

Computer Aided Manufacturing (CAM):
This is the section where the restoration is achieved with the help of a CAM unit, according to the design created in CAD software. Once the one-piece restorations are obtained in this way, they are ready to be cemented to the patient with the glazing process. Restorations prepared in the form of infrastructure are; It becomes ready to be applied to the patient's mouth by applying the appropriate superstructure ceramic and the subsequent glazing process [153].

Four different ways can be applied to transfer the scanned data to the production unit for production.

Process1:
Maxillary and mandibular arches are scanned with an intraoral scanner without any models, including teeth and implants. This route is essentially only indicated for monolithic restorations.

Process 2:
It involves scanning the teeth with an intraoral scanner and then digitally casting them into the model by printers.

Process 3:
It involves scanning an measurement taken by traditional methods through a digital scanner.

Process 4:
It involves scanning the plaster model obtained from the impression taken by traditional methods through a digital scanner.

Digital Smile Design
An attractive smile is always a desire for the individual's social well-being and confidence. Aesthetics, one of the most important foundations of dentistry, has always been a part of research for better results. Smile analysis and design has been a topic of focus in dentistry for the last decade and brings a comprehensive approach to patient care. Interrelationships between dental anatomy and physiology and information about the patient's soft tissue treatment limitations are important in this regard [110].

Digital smile design is a method that allows patients to design a natural and aesthetic smile, where their smiles are simulated in a digital environment and the patient is involved in his own smile design process. Involving patients in the treatment process at the very beginning, at the planning stage, makes it easier for them to find common ground with the physician by ensuring that their expectations and needs are better understood. The communication between the doctor and the patient is strengthened, patient satisfaction is achieved more easily and a personalized treatment is provided (156-159).

From the first generation used to communicate with the patient and explain the final result through smile designs designed by hand drawing on printed photographs of the patient, it has now evolved into a complete digital drawing in Digital Smile Design (DSD) software on a computer. DSD is a treatment planning for aesthetic dentistry that uses digital software as an effective tool, where the evaluation of the aesthetic relationship between teeth, gums, smile and face is achieved through drawn lines and digital drawings. DSD is a multi-use conceptual tool that can enhance diagnostic vision, improve communication, and increase predictability throughout treatment. DSD allows careful analysis of the patient's facial and dental characteristics, as well as any critical factors that may have been overlooked during clinical, photographic, or diagnostic cast-based evaluation procedures [111].

The main goal in digital smile design is to create a new and ideal smile by using digital measurements, lines and drawings in the program with images obtained from the patient and transferred to the program [157]. For an aesthetic smile, facial composition and dental composition must be compatible with each other. The facial composition includes the hard and soft tissues of the face, while the dental composition relates to the teeth and their relationship to the gums. When designing a smile, facial and dental composition should always be evaluated and analyzed together.

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. The horizontal lines used in frontal analysis are the interpupillary and intercommissura lines, and the vertical reference lines are the lines containing the midline of the face, dental and mandibular midline. While the symmetry of the jaws relative to each other can be evaluated with these evaluations, symmetry is also evaluated by dividing the face into five parts vertically and into three parts horizontally [157].

Dentogingival analysis includes parameters such as interdental papilla, black triangle formation, zenith points, gum line, gingival contour, color and structure, smile line, smile arc, amount of gingival exposure during smiling, gingival and incisal asymmetry, and aims to analyze the health and morphology of the gingiva [157]. It is very important that the gingival tissue is healthy before starting any treatment, as the gum serves as a framework for the teeth and gingival health greatly affects aesthetic success.

Dental analyzes include parameters aimed at obtaining ideas in terms of shape, size and color for the restoration and are necessary for the ideal smile design. There are several theories for deciding the most aesthetically appropriate tooth size; golden ratio, width-to-height ratio, RED (Recurring Esthetic Dental Proportion) recurrent dental ratio and recently visagism are among these theories [157].

According to the recurrent dental ratio (RED) theory, the width ratios of consecutive teeth from the midline to the posterior when viewed from the front should be constant and generally between 60-80% [157].

The golden ratio says that when viewed from the front, the width of each anterior tooth should be 60% of the width of the tooth on its side. Adhering to the golden ratio in all cases may cause cosmetic errors and a design that is beyond the patient's expectations[157].

According to Visagism, personality consists of four main temperaments: impulsive/strong, extrovert/dynamic, melancholic/sensitive, harmonious/peaceful, one or two of which are more dominant. In Visagism theory, the form of the teeth is determined according to the dominant personal characteristic of the person [157].

For digital smile design, knowledge of the basic aesthetic rules regarding the smile, basic photographs taken from the patient and a short video and design program are required. Since the reference lines that form the basis of smile design are created on photographs, the photographs taken must be of high quality, precise, with correct posture and standard techniques. Bad photography means misrepresentation of the reference image, misdiagnosis and planning[157].

Digital Color Selection

Digital cameras have recently become very popular in color measurement and communication between the physician and the laboratory. These devices, also known as RGB devices, are the simplest among technological systems. They enable highly reliable color measurement under standard lighting conditions [160]. Since digital cameras are not measuring devices alone, we transfer the photographs we take to the computer and make color selection by analyzing them on the computer [160,161].

Digital cameras capture the image with a sensor (CCD) containing millions of small, light-sensitive elements (photocytes) (57; 58). Each of the photosites in CCDs participate in image formation by responding to the light coming on them. To obtain an image with all colors, sensors use filters to look at light in its three primary colors, and in these devices, the camera can record all three colors at each pixel[160,161].

Image quality of digital photos; It varies depending on the type of camera, camera settings, ambient lighting conditions, size of the image, position of the relevant tooth and color key, and it is of great importance. Because digital photographs are a color evaluation method that can only be useful if they are obtained under appropriate conditions and used with appropriate devices. However, it should not be forgotten that evaluations made with digital photographs are completely subjective and may not be sufficient[160,161].

While the most important advantage of using digital photographs is that the color view of the entire area, rather than a single area, can be obtained, another advantage is that it is a method that accelerates and facilitates the communication of the physician and the technician, even without being side by side, through the use of digital photographs [160].

The basic working principle of the spectrophotometer is to measure the ratio of the light reflected from an object to the light reflected from a white surface [160-162]. The combination of digital photography and spectrophotometry is a new method for color detection. Crystaleye, SpectroShade Micro, Shadepilot, Zfx Shade and VITA Easyshade V devices can be given as examples of this working principle [161]. SpectroShade consists of a dual digital camera system connected to a spectrophotometer, a halogen light lamp is used and can measure the entire tooth surface. SpectroShade Micro and SpectroShade Mobile types are portable.

Colorimeter measures color with tristimulus values. There are three different sensors in the colorimeter detector, which resemble cone-type cells in the human eye, and these sensors in the detector analyze the reflected light rays in the ratio of red, green and blue colors without any mathematical operations and give the X, Y and Z values of CIE. ShadeScan is a handheld device that has a color "liquid crystal diode (LCD)" display and combines digital imaging and colorimetric analysis. The halogen light source illuminates the tooth surface at a 45 degree angle through the fiber optic cable. At 0 degrees, the light reflected from the tooth is collected and the image of the tooth is recorded on the memory card, thus eliminating the need for a computer. The data on the memory card is transferred to the computer where ShadeScan software is located, the color and translucency map of the tooth is created in the program for the production of the restoration, and the data can be transferred to the laboratory by e-mail or by printing [161].

VITA Easyshade V: It is a digital spectrophotometer that can perform fast, reliable and repeatable color detection of natural teeth and ceramic restorations without being affected by environmental conditions, thanks to LED technology. It has a touch screen and easy software. VITA mobileAssist app enables easy information exchange between the technician and the dentist. With VITA Assist, VITA Easyshade V measurements and digital patient photographs can be integrated and has additional image editing tools.

Digital Dental Photography

Dental photographs are frequently used for various reasons. For example, it is used when making diagnosis and treatment planning, storing oral cavity photographs, case presentations, transmitting oral cavity photographs to the laboratory environment, choosing colors, for evidence in malpractice cases, identification in forensic medicine, and deciding on treatment options between the patient and the physician [163].

Selection of Camera and Accessories:

For dental photography, digital single lens reflex (DSLR) cameras are the most suitable cameras because their lenses can be changed [162]. When taking dental photographs with DSLR cameras, 60 mm, 85 mm and 105 mm lenses and (R1C1) Twin flashes and Ring flashes produced for dental macro shots are preferred [162]. Especially if an aesthetic application will be made in the front area, for example, front area prosthesis, lamina, etc. While twin flash is recommended, ring flash is recommended for applications that do not require much detail in the rear area [163].

Before taking photographs, the patient must be prepared; the patient must be informed about why the photographs will be taken and that the photographs will be used only for scientific purposes, and a consent form must be obtained from the patient[163].

After the patient, physician and camera preparations are completed, full face, profile and intraoral photographs can be taken[163].

1. All face and profile photos:
Photography can be done in a specially prepared studio or in a clinical environment prepared with a suitable background. They are generally used to show the changes caused by orthodontic, maxillofacial and restorative treatments that will change the face [163].

2. Smile:
The patient should be asked to smile to show as much of the gums as possible. For maximum depth of field, focus should be on the canines, and for lateral smile photography, focus should be on the upper laterals [163].

3. Lips are retracted and teeth are in centric occlusion:
Soft tissue should be removed from the buccal surfaces of the teeth in an upward-outward direction with the lip retractor. Focusing on the lateral teeth provides an appropriate depth of field to cover all teeth in an ideal focal range. Although alignment errors in digital photographs can be corrected later with editing programs, the occlusal plane should be kept in a horizontal plane as much as possible to fit the upper and lower edges of the viewfinder [163].

4. Lips retracted and teeth slightly open:
There is a gap approximately one finger thick between the posterior teeth [163].

5. Close-up with lips retracted :

- Photographs should be taken from the right, left and front, with the lips excluded (65).
- The interpupillary line should be parallel to the upper edge of the photograph[163].
- Frontal-profile view is obtained[163].

6. A black or gray background should be used to prevent shadow formation [163].

Lateral View:
Lateral photographs can be taken with or without a mirror. When taking lateral photographs without a mirror, it is more appropriate to use a narrow-angle lip retractor between the upper and lower lips, so that the buccal surfaces up to the 2nd and 3rd molar teeth can be clearly visualized. If lateral photography will be taken using a mirror, the patient is asked to relax and leave his/her tongue freely in the middle of the mouth before the mirror is placed. In this way, space is created by pulling the cheeks outwards, providing more space for the mirror in the sulcus and providing a better angle between the mirror and the camera [163].

Occlusal View :
A mouth mirror should be used to obtain occlusal images. Lip retractors should be used to retract the lips and cheeks from the buccal surfaces of the teeth. In occlusal shots, the focus should be on the first premolar. Care should be taken to ensure that the mirrors do not fog up during shooting. Since the mirror must be positioned more posteriorly in the mouth in order to view the second and third molar teeth, a gag reflex may develop. In case of a gag reflex, precautions taken during radiography and measurement should be taken to reduce nausea. If the problem cannot be resolved, the mirror should be positioned to show only the relevant area and the remaining occlusal area should be ignored so that it does not appear in the photograph [163].

When photographing the upper jaw, the patient should tilt his head back and the physician should take the photo at the 12 o'clock position. When photographing the lower jaw, the physician should be in the 9 o'clock position, leaning over the patient and towards the patient. When shooting the lower jaw, care should be taken to ensure that the vestibule edges of the incisor teeth are within the photograph frame and the tongue should not cover the teeth and distort the image[163].

7. Digital Implantology
Dental implants have been used in dentistry for years to replace lost aesthetics, function and phonation. Over time, it has become one of the most preferred treatment options in the rehabilitation of partially or completely edentulous jaws[164]. The most important stage that affects the success of implant treatment is diagnosis and planning. In order to place the implants correctly, the physician must carefully perform intraoral and extraoral clinical examination and detailed radiography examination. Knowing the shape of the jaw bones, the resorption status of the crests, the mineralization structure of the bone, its height and width in radiographic examinations; It is necessary to clearly see and evaluate adjacent anatomical structures such as the mandibular canal, foramen mentale, nasal floor, and maxillary sinus [165].

Radiological Stents:
Many dentists have difficulty determining the areas to be implanted on CT, especially in cases of complete edentulism. Since it is of great importance to know where the teeth will be located in the finished prosthesis, the idea of preparing radiological stents from acrylic resin or thermoplastic materials has been adopted to eliminate this difficulty. Radiological stents are prepared from acrylic by taking measurements of the seating areas of the prosthesis. To ensure the visibility of radiological stents on CT, radiopaque markers such as gutta-percha, metal balls, pins, tubes and barium sulfate teeth are placed on the acrylic, which can be seen on CT. Metal balls are not preferred by physicians because they can move during radiography. Nowadays, barium sulfate teeth are most commonly used in radiological stent construction [163].

Various software programs have been developed to plan the locations on the jaw bones where implants will be placed. Some of these programs are: [163] Artma Virtual ImplantTM (Vienna General Hospital, University of Vienna, Vienna, Austria); coDiagnostiX (IVS Solutions AG, Chemnitz, Germany); Easy Guide (Keystone-dental, Burlington, MA, USA); Implant LogicsTM (Implant Logic Systems, Ltd., Cedarhurst, NY, USA); Implant Master TM (I-Dent Imaging Ltd., Hod Hasharon, Israel); Med 3D (med3D AG, Zurich, Switzerland); NaviGuide System (RoboDent GmbH) (Humboldt-Universitat, Berlin, Germany); Procera Software (Nobel Biocare, Goteborg, Sweden) Simplant, SurgiCase (Materialise Inc., Leuven, Belgium) and Vimplant (CyberMed).

These various software programs allow the person using the software to find the receptor site where the implant will be placed and to simulate the position of the implant after placement and surgery [164].

Surgical Stents:
The most important stage in dental implant treatment is the placement of implants. We can examine surgical stents in 3 groups [163]:

1. Traditional Surgical Stents,
2. CAD-CAM (Sterolithographic) Surgical Stents and
3. Stents Used with Navigation Method.

1. Traditional Surgical Stents:
Traditional surgical stents enable the determination of the areas where implants will be placed, instead of transferring the placement angles of planned implants to the surgical stage and providing guidance. Thus, the distances and positions of the implants can be adjusted as desired,

depending on the size of the missing teeth.

2. CAD-CAM (Sterolithographic) Surgical Stents:
In order for CAD-CAM surgical stents to be used in treatment, implant planning must be made with special programs and this planning must be put into production. In order to plan and produce in this way, the sections obtained with high-resolution CT must first be transferred to the implant planning program to be used. Planning should be made in the light of the calculations made from the transferred sections and then production should begin. Production is generally done with a laser sintering device. Apart from this, milling devices can also be used for production. This technique, in which computer programs are used, is called "interactive computed tomography (ICT)". With the ICT technique, the positions and angles of the implants are planned in all sections and on the simulated 3D jaw model. These programs are more advantageous in that they are not limited to planning, but also have the opportunity to produce surgical stents and jawbone models in accordance with the planning. Thus, digital planning can be transferred to the surgical stage with minimum deviation, and the jaw bone can be examined before surgery thanks to the produced model.

To ensure the best surgical calibration possible, CAD-CAM surgical stents are produced separately for each drill. Two different surgical stents can be produced: over-bone or over-mucosa. Since soft tissue boundaries cannot be monitored in detail in conventional CT scans and we can only have an idea about hard tissue details, the surgical stents to be produced will be on bone. In CT images obtained using the prepared radiographic stent, the inner borders of the radiopaque prosthesis will show the upper border of the mucosa. With the use of the radiological stent, mucosal data will be transferred to the program. With these data, a transmucosal surgical stent will be produced. Preparation of the radiological stent is the same as the steps of the traditional removable prosthesis, except that the base material contains 10% barium sulfate and 90% acrylic. Duplicates of the patient's old dentures can also be used. Barium sulfate in the base material should be incorporated in a way that does not cause radiopaque artifacts on CT.

CAD/CAM surgical stents must fit into the patient's mouth with the maximum precision possible. If maximum compliance is not achieved, planning will not be transferred to the surgical stage and sensitivity will deteriorate. Therefore, the production phase must be done very carefully. Surgical stents can be stabilized with mini screws or fixation pins through previously prepared screw holes on the stents for stabilization. In this way, adaptation precision is ensured.

Stents Used with Navigation Method
Systems used with navigation, such as CAD-CAM surgical stents, aim to precisely transfer digital implant planning to the surgical stage. For this reason, when using this technique, obtaining data from IT is the most important step. The aim of the navigation method is to correctly position the implant by monitoring the relationship between the sensor-connected contra-angle handpiece used by the surgeon and the other sensor connected to the surgical stent placed in the patient's mouth, in space, and monitoring it via CT [165].

Three Dimensional Planning Steps:
Step 1: Diagnosis; Step 2: Scanning Prosthesis; Step 3: 3D Scanning (CT); Step 4: Conversion of Data; Step 5: Planning on the Computer; Step 6: Surgical Stent, Step 7: Surgical Phase [165].

Step 1: Diagnosis: As a result of clinical and radiographic examination, it is decided whether treatment can be performed with 3D planning [165].

Step 2: Scanning Prosthesis: Scanning prostheses are temporary prostheses that have been made radiopaque by adding barium sulfate and allow us to more easily decide on the positions of the implants when planning implants on CT. While the scanning prosthesis can be obtained by duplicating the patient's existing prosthesis, it can also be prepared as a temporary prosthesis that meets function, phonation and aesthetic needs. A successful surgery requires good planning and a screening prosthesis is required for good planning[164].

Step 3: Three-Dimensional Scanning (CT): Rules to be followed during scanning:
- The patient's head must be stable during the scan[165].
- To prevent artifact formation during scanning, a bite block should be placed between the lower and upper jaws to increase the distance between the jaws [165].
- For a typical mandibular scan, 40-50 axial images should be taken. To obtain a quality 3D simulation model, the distance between axial images should be at most 1 mm [164].
- After scanning, the data needs to be converted[165].

Step 4: Conversion of Data: The raw data obtained from IT is transferred to the computer program where planning will be done without being lost. The new information obtained by transforming the raw data is a 2D and a detailed 3D representation of the patient's anatomy[165].

Step 5: Planning on the Computer: In the resulting 3D digital model, the scan prosthesis, bone, teeth and other anatomical structures can be seen and selected by color separation. Bone quality in the area where implants will be placed can also be determined and classified[165].

Step 6: Surgical Stent (guide): After 3D planning is completed, 3 different types of surgical guides can be prepared; mucosa supported, bone supported and tooth supported[165].

Mucosa-supported surgical guide:
It is an individual drill guide prepared according to the patient's mucosa. The mucosa-supported surgical guide is fixed to the mucosa with osseosynthesis fixation screws so that it does not slip during the surgical procedure or does not fit properly, impairing the precision of the treatment plan [165].

Bone-supported surgical guide:
Since this guide is supported directly from the bone, the flap must be lifted in order for the guide to be positioned correctly. After the flap is removed, the first surgical guide is placed directly on the bone. If the reliability of the program and CT data used in planning the placement of implants is in question, the surgical guide must fit precisely into the bone. Therefore, fixation screws are not required in bone-supported surgical guides [165].

Tooth-supported surgical guide:
In order to produce a tooth-supported surgical guide, CT images must be run with a 3D simulation of the patient's jaw[165].

Step 7: Surgical Stage: Surgical stents were produced and sterilized in accordance with the pre-treatment planning made digitally according to the CT scans. Implant placement is performed by opening the implant slots under the guidance of surgical stents [165].

Virtual Articulators
The recent use of digital technologies in dentistry has created a virtual working environment. With digital developments in the virtual environment, the levels of clinical diagnosis, treatment planning and treatments have increased and the duration of all these procedures has been shortened[166].

Thanks to virtual articulators, the limitations of conventional articulators are reduced (69). The virtual articulator requires digital 3D data of the lower and upper jaw and the patient's personal jaw movements data. Using this data, it simulates the patient's jaw movements and enables the visualization of dynamic occlusal contacts[166]. In this way, it is thought that restorations made using virtual articulators will not contain interference, and as a result, stability will be ensured [166,167].

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. In addition, it provides the dentist and dental technician the opportunity to work in a completely digital environment by eliminating the casting stage to obtain plaster models of the jaws. In order to work with virtual articulators, an intraoral scanner, digital camera and special software are required [166,167].

There are two types of virtual articulators, fully adjustable and mathematically simulated:

Mathematically Simulated Virtual Articulator:
Although it is a virtual articulator, it has average values that use values that can vary from person to person and can simulate movements that only mechanical articulators can do. It cannot provide individualized movement paths for the patient, and in this case, it may produce erroneous results[168].

Fully Adjustable Virtual Articulator:
These articulators record the movement paths of the mandible with a jaw recording system called jaw movement analyzer (JMA) (70). The software creates the jaw movements visualized on the screen by analyzing static and dynamic occlusion data. This system can provide an ideal occlusion by providing occlusal surface shaping with information such as individual-specific condylar path inclination, Bennet angle, Bennet movement, protrusion, retrusion, sudden lateral sliding movement, and eliminating the interference of personalized treatments and restorations [167,168].

1. Semi-Conventional Virtual Articulators:
Plaster models connected to the conventional articulator can be scanned and digitalized with scanners, and at the same time, the plaster models and the conventional articulator can be digitized separately and transferred to the digital environment. Another method is that plaster models obtained from the patient's intraoral measurements can be digitalized by scanning with extraoral scanners and can be digitally connected to each other by selecting one of the virtual articulators in the virtual articulator software [168].

2. Full Digital Virtual Articulators:
The patient's lower and upper jaw can be scanned with an intraoral scanner and connected directly to a virtual articulator in the system. If the selected virtual articulator system is one of the systems that also performs jaw movement analysis, all mandibular movements of the patient, including chewing movements, can be simulated virtually after being transferred to the digital environment [168]. In order to create a fully digital treatment and at the same time increase the patient's satisfaction, the position of the upper jaw in space should be transferred to the virtual articulator by using various virtual facial arch systems [168].

3. Systems that analyze jaw movements:
Articulators analyze jaw movements using different mechanisms [168]. These systems;

- **Systems using ultrasonic measurements**: Jaw Motion Analyzer (JMA); ARCUS digma 2 and Axioquick Recorder
- **Systems using the voltage division method:** Cadiax Compact 2 and Cadiax 4
- **Those using optoelectronic systems**: Freecorder, BlueFox.

Digital Orthodontics : Within the framework of adapting to the ever-developing technology, digitalization has become widespread in diagnosis, planning and treatment methods in orthodontics.

Uses of Cone Beam Computed Tomography in Orthodontics
Imaging techniques used in the diagnosis, planning and treatment stages of orthodontics have moved from the conventional 2-dimensional approach to the 3-dimensional approach.

a) Diagnosis of impacted teeth and intraoral anomalies:
It enables the correct location of ectopic teeth and intraoral anomalies to be determined and, if a surgical procedure is to be performed, minimally invasive surgery can be performed [169].

b) Evaluation of the airway:
Since lateral cephalograms used in airway evaluation give a 2-dimensional image, completely accurate results cannot always be obtained. More accurate evaluations are obtained with the use of CBCT[169].

c) Evaluation of alveolar bone:
It is used in orthodontics to clinically analyze bone quality after alveolar surgery in patients with cleft lip and palate. Images obtained by CBCT are used to evaluate whether the teeth in the treated area can be moved at the desired level with orthodontic treatment by providing better evaluation of bone areas [169].

d) Temporomandibular joint morphology:
CBCT is used to examine the size, shape and position of the condylar heads and the joint space. While the condyle can only be viewed from the lateral side with lateral cephalometry, the frontal and axial sections of the condyle can also be viewed and examined in detail in CBCT [169].

e) Analyzing the face:
Thanks to new software, photographs obtained from the front or profile can be converted into the DICOM (Digital Imaging and Communications in Medicine) database, a three-dimensional image of the face can be created in different directions, and the anatomical relationships of hard tissues and soft tissues can be evaluated by changing the translucency of the facial image[169].

f) Three-dimensional registration:
Thanks to the use of various software programs with CBCT, images obtained at different times can be superimposed and compared, and changes occurring as a result of growth or treatment can be evaluated by making measurements on these images [169].

Digital Orthodontic Model:
Digitalization of dental orthodontic models has led to significant developments in orthodontic treatments. Digital orthodontic models can be obtained by scanning the inside of the mouth directly or indirectly by scanning the impression taken from the mouth. Compared to conventional plaster models, digital orthodontic models are easier to use, have no risk of physical damage and thus have a longer life, and reduce the need for physical space for storage, making this method more advantageous and useful. In addition, if a physical model of the tooth row is required for the production of an orthodontic appliance, digital models can be printed in 3D with a rapid prototyping technology [170].

Digital models can be used to determine and interpret the shape of the teeth, the arch, the amount of crowding or excess space in the arch, and the type of malocclusion. In addition, measurements such as the amount of overjet and overbite, size of the teeth, arch length, transverse distances and Bolton discrepancy can be obtained using digital models. With digital models, a digital diagnosis can be made, a treatment plan can be created, bracket positioning and indirect bonding can be performed. Special software is available for shaping and trimming the threaded base, bracket design, hook angles and guide jigs. Titanium Herbst, Andresen and sleep apnea appliances can be designed in digital programs and produced to fit perfectly on the teeth and gums. Various orthodontic appliances can be produced with 3D printing by making designs on digital models [170].

Stereophotogrammetry: Stereophotogrammetry is a method of creating a 3D image of a 3D object by using images obtained from various angles on the same plane and is based on the principle of stereoscopic vision that exists in all living things. While the brain uses images obtained from various angles through two eyes to create the perception of depth in the image, stereophotogrammetry enables us to obtain a 3D image of the object by reconstructing the images obtained with at least 2 calibrated cameras, at equal distance from the object and on the same plane [171].

With the developed systems, it is possible to obtain a 3D image of the entire body or a limited area in a very short time. Stereophotogrammetry has been shown to be the most ideal method in today's technology to examine soft tissue morphology [171,172].

Stereophotogrammetry:

- In analyzing facial aesthetics
- Analyzing facial type and facial proportions
- In the evaluation of smile aesthetics and smile types
- In the evaluation of asymmetries
- Digital storage of the patient's 3D image
- In the evaluation of craniofacial syndromes
- Superimposition of images obtained before and after orthodontic treatment
- 3D evaluation of lip deformity in patients with cleft lip and palate, comparison of preoperative and postoperative periods, and follow-up of development in the future.
- Comparing the images taken before orthognathic surgery with the images taken after orthognathic surgery in terms of soft tissue change and detecting edema Comparison of soft tissue differences according to age, gender and race characteristics
- It is used for periodic monitoring of growth and development [171].

Since stereophotogrammetry does not have the ability to show hard tissues, it can be used together with images obtained from CT and CBCT in order to eliminate this deficiency and at the same time enable hard tissues to be examined in detail. It is seen that these two techniques are insufficient if the teeth and occlusion are also visualized. In this case, the best method is to use a combination of CBCT, stereophotogrammetry and digital dental models to obtain 3D modeling in which all maxillofacial tissues are accurately visualized. Especially in treatments that will change the patient's appearance, such as in orthognathic surgery cases, choosing this combination will provide the necessary information for accurate diagnosis and treatment planning [171].

Digital Patient Records:

Digital medical records are "health information transferred to digital media; "They are computer-aided records used in various fields where personal health history, diagnosis and treatment reports are recorded." Registration processes, which used to be done by writing on paper, can now be done in a digital environment, regardless of your location. With the digital medical record system, it is aimed to access medical information about patients who benefit from healthcare services accurately and without wasting time [173].

The digital recording system has been effective in increasing the efficiency of healthcare institutions, demonstrating an environmentally friendly attitude by reducing paper consumption, preventing medical errors due to misreading and interpreting handwriting, facilitating patient follow-up, and increasing the satisfaction of patients using healthcare services [173,174]. It provides the opportunity to store a large amount of medical data and access the stored data quickly by saving time [173].

Contrary to many advantageous situations when medical information is transferred to the digital environment, patients' information security risks, data abuse and cyber crimes have emerged with the inappropriate use of technology. The fact that patients' medical information is accessible to healthcare professionals and people who are not authorized to use the information creates a serious security problem, and problems such as failure to ensure the security of patients' medical information and copying of health data may occur[173].

CONCLUSION

Digital measurement systems, which are frequently used today, prevent many disadvantages and limitations of traditional measurement materials and methods and make the work easier and more acceptable for both the physician and the patient.

With the development of digital technology, new tools, new programs, new ideas and new treatment opportunities have emerged. With these innovations, faster, more accurate, more precise and personalized treatments can be performed, and disease diagnosis and treatment planning can be made more easily.

Digital technology is used in many areas in the dental clinic. Thanks to intraoral scanner technology, digital measurements are used instead of conventional measurements and many disadvantages of conventional measurements are eliminated. With digital smile design, patients can be better involved in the planning phase and communication between the technician and the dentist is easier. With digital implantology, implant planning is done in digital programs and guides are produced to place the implants correctly according to this planning during the surgery phase. More reliable color choices can be made with digital color selection. Digital photographs are very important both in the diagnosis and treatment phases and in terms of monitoring the effects and results of the treatments. As a result of studies made with 3D digital radiographs and various programs, digital orthodontic models are used instead of conventional orthodontic models, and if a physical model of the tooth row is required for the production of an orthodontic appliance, digital models can be printed in 3D with a rapid prototyping technology. With digital articulators, the limitations of conventional articulators are eliminated and all movements of the mandible can be simulated virtually.

The fact that digital technology is developing day by day creates a desire to obtain more efficient results in the clinic. In the future, with the use of digital radiographs and 3D imaging devices that we use for diagnosis in the clinic, the radiation dose to which the patient is exposed should be reduced, image quality should be improved, soft tissue imaging ability should be improved, and early pathology and caries diagnosis should be made. The scanning ability of currently used intraoral digital scanners should be improved, and the aim should be to minimize the formation of residue in restorations obtained with subtractive systems using CAD/CAM technology. Reducing waste materials or recycling waste materials will have significant effects in terms of both reducing costs and reducing damage to the environment. In addition, training experienced personnel will play an active role in the adaptation of computerized technologies to dentistry, therefore the number of competent personnel should be increased. In short, efforts to develop digital systems should continue.

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