ORIGINAL RESEARCH PAPER

Prosthodontics

DEVELOPMENTS IN CAD/CAM TECHNOLOGY: POSSIBILITIES FOR DENTAL APPLICATION

KEY WORDS: CAD/CAM, Computer-aided design, Computer-aided production, Dental, Dental treatment

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ABSTRACT

Examining CAD/CAM technology and their use in dental treatments is the goal of this study. The computer-controlled technology known as computer-aided design and computer-aided production (CAD/CAM) allows for the design of the material to be generated in 3-dimensions on the computer monitor. Since the 1950s, it's primarily been employed in the aerospace and industrial sectors. The development of CAD/CAM technology in dentistry has made it possible to construct restorations out of high-performance materials that were previously difficult to shape. In the past 20 years, dental CAD/CAM systems have grown in popularity. Since 1984, several CAD/CAM systems have been created, including the Cerec, E4D, Procera, Everest, DCS President, Cercon, and Lava systems. In contrast to conventional impression methods, the advancement of such systems makes it possible to create the restoration in accordance with the features of the restoration and innate dental anatomy, generate the restoration quickly at the patient 's bedside, guarantee the peripheral and inner harmony of the restoration, boost its resistance properties, and offer an improved look and feel.

1. INTRODUCTION

As a result of technological development, new materials and systems containing advanced technology have been used in dentistry. "Computer-aided design and computer-aided manufacturing (CAD/CAM)" system is one of the advanced technology products used in dentistry (1,2).

Computer-aided design (CAD) and computer-aided manufacturing (CAM) system is a technological system that uses computers to design and manufacture collected data on a wide range of products.

The development of CAD/CAM technologies aims to do away with conventional impression techniques, design the restoration in a computer program in accordance with its natural anatomy, functions and preparation, to produce the restoration at the desk, to increase the restoration quality in terms of mechanical resistance, edge compatibility, surface quality and to provide a better aesthetic (3). The aim of this study is to examine CAD/CAM technologies and their uses in dental teratments.

2. METHOD

In this study, literature review method was used. Scientific research is constructed upon the conclusions drawn from earlier scientific investigations, the concepts put out, and the strategies employed. Reviewing earlier research on the research topic is recommended in academic studies that build on one another. In academic research, this process—known as the literature review—involves activities like looking for, analyzing, reciting, categorizing, summing up, and synthesizing earlier released works that are relevant to the research topic. The primary goals of the literature review and analysis are to ascertain the significance of the prior studies on the topic, to highlight any gaps or absences in the literature, and to ascertain how our own research would fall into the body of knowledge (4). In this regard, published research on CAD/CAM in academic databases has been compiled and reviewed.

3. FINDINGS

The findings of the study are shared in this section.

3.1. The History of CAD/CAM Systems

Developments in dental CAD/CAM systems in dentistry started in the 1970s. The idea of creating an optical device was first introduced in 1977 by Altschuler and Young in order to develop the intraoral surface scanning system. Following this, the Duret system was developed by Francois Duret in 1984 and was later named the Sopha Bioconcept system. Dr. Duret started to produce crowns by forming the occlusal surface's functional form by acquiring an optical imprint of the tooth that it abuts in the mouth. Afterwards, he created a more suitable crown design, taking into account the functional movements. He produced crowns using a computer-controlled milling device and subsequently developed the Sopha System. In this way, he contributed to the development of dental CAD/CAM systems in the world (5).

The CEREC system, developed by Brandestini and Mörmann in 1985, is the first commercially available CAD/CAM system (6). With this system, the measurement of the cavity prepared with an intraoral scanner was taken and then the design was made and an inlay was produced from the ceramic block. All these procedures were performed at the chairside using a compact machine set. It was quite an innovative development that ceramic restorations could be produced on the same day. After the introduction of this system, CAD/CAM technology started to become widespread in the field of dentistry (7).

Dr. Rekow et al. created a dental CAD/CAM system with a 5-axis milling unit in the 1980s. The Procera system, which creates crowns with extreme accuracy, was created in 1983 by Dr. Andersson. Early in the 1980s, titanium became widely used in dentistry, but the casting process was delicate and challenging. Spark erosion has been used by Dr. Andersson to create titanium substructures. Additionally, it used CAD/CAM technology in the production of composite veneer restorations. Later, this technology was created as a networked production hub for the manufacturing of infrastructures made entirely of ceramic. Many businesses throughout the world now employ such networked manufacturing systems (8-10).

Indication areas of CAD/CAM systems (11-21):

- "Inlays
- Onlays
- Laminate veneers
- Partial crowns
- Full crown and bridge systems
- Skeletal structures of removable partial dentures
- Design and production of stents used in implant surgery
- Preparation of maxillofacial prostheses
- Production of abutments and crown-bridge in implant supported prostheses
- Design and manufacture of implant-supported hybrid prosthetic substructures"

Using CAD/CAM technology has simplified working processes and made it feasible to employ more modern and superior materials (22,23).

3.2. Working Principles of CAD/CAM Systems

Based on the transformation of data obtained from optical scanners into 3-D designs utilizing specialized computer software, CAD/CAM technologies allow doctors to construct dependable restorations and lower the risk of problems (8).

Restorations go through three stages in the CAD/CAM system until they are produced. These are, respectively, the collection of intraoral and extraoral data, the 3D design of the collected data on the computer, and the production of computer-designed restorations. The data is collected by the intraoral camera that makes optical measurement in 3D and transferred to digital media as data. Thanks to the data transferred to the digital environment, restoration designs are made in the CAD unit. Finally, the restorations designed in the CAD unit are scraped from the block materials in the CAM unit and go to the production stage (12, 16).

3.3. Components of CAD/CAM Systems

All CAD/CAM systems consist of 3 main components. These are:

i.Scanner

ii. Software

iii. Hardware (Production device) (24).

3.3.1. Scanner

It is the part of the system that collects data. It converts the preparation into three-dimensional virtual models by collecting data on adjacent teeth and surrounding tissues directly or indirectly with extraoral scanners (25, 26). The triangulation process, which is used to acquire three-dimensional photographs of structures, forms the basis of the optical scanning system. Laser projection, colored light, or white light can all be used for optical scanning. Place the light source and receptor unit at the proper angle to one another. Often these optical scanners are responsive to motion. When using optical scanners to create a digital imprint, the patient's movements might lead to picture errors. Data collection that is quick and high-resolution is one benefit of optical scanners.
Scanners can make a digital copy of the data area to the computer in colorless ".stl (Standard Triangle Language), .obj (Wavefront Object File) and colored .ply (Stanford Triangle Format) format" or in the type syntax that the producer firm has made specifically available. Scanned models can be designed in the CAD system in ".stl and .ply" formats (27). In the CAD/CAM system, the production machine must recognize the file extension of the designed model in order to perform the operation. Some companies unfortunately keep the source code of these software systems closed. This situation causes the production phase to be done in a single device. Universally, the recording formats of three-dimensional scanners are referred to as .stl and .ply, and systems that use one of these formats are called "open systems", and systems that do not use one are called "closed systems"(28).

The accuracy of the browsers used:

The quality of the digital measure depends on the accuracy of that system. Investigations on accuracy are carried out according to the ISO 5725-1 standard (29). The closeness of the obtained data to the actual values determines the degree of accuracy. For this, sensitivity and reality must coincide (29). Studies on intraoral scanners are generally comparative and are based on the determination of accuracy. Therefore, the main result that should be aimed in the material used is the perfect digital copy of the object.

Precision in browsers:

Precision is the concept that describes the closeness of measurement values. While it indicates how many random errors there are in the system, it does not tell whether an average value is correct (29).

Trueness in browsers:

Reality reflects how close the measurement is to the true value, or the level of accuracy of the measurement. It is defined as the closeness between the mean of the reference values and the mean of infinitely repeated measurement values (29).

Accuracy:

In the measurement of a physical component, the difference between the true value and the value indicated by the model is defined as accuracy. The quality of the accuracy value is determined by the closeness of reality and precision (29).
Factors affecting the accuracy of digital measurements are as follows (6):

- Type of browser
- Type of preparation
- Geometry of the tooth
- Size of the scanning area
- Experience

Color temperature and illumination intensity

The characteristics of the intraoral scanner used and the experience of the practitioner are related to the scanning speed and format. This increases the number of parameters that affect accuracy. Blurring may occur in the image obtained as the distance of the scanner head to the scanned area increases (30, 31). In very close range scans, the focus of the camera can be positioned further behind the object. For these reasons, 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, triangular scanners do not need contact (5, 30). Active triangular scanners made more precise measurements than confocal scanners (23).

As the scanning speed increases, the scanning resolution decreases. In addition, some fast scan regions may appear incomplete. The physician who scans these areas again can change the angle of the camera. Different angles can cause increased distortions and decreased accuracy. This highlights both the screening method and the importance of an experienced practitioner (10). In line with the experience of the practitioner, the area to be scanned should be done by following a certain strategy. The head sizes of the scanners make scanning difficult, especially in the posterior regions, and cause the camera's application angle to be changed (30, 32).

To provide precise scanning results, most systems require a certain scanning route.

(Figure 1).

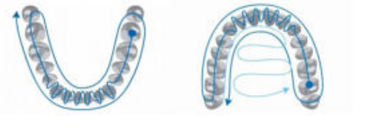

Figure 1. Intraoral scanning strategies in the mandible and maxilla (3)

3.3.2. Software

It has a computer unit for planning and designing the restoration in 3-D on a computer monitor. Numerous software tools have been created to facilitate the creation of restorations with unique designs. The user can create new designs by making certain alterations or they can utilize the pre-existing designs in the current CAD program directly. The majority of software applications are CAD/CAM system-specific and incompatible with other platforms. The restoration's digital content is exchanged and created in a distinct format between the CAD program and the CAM equipment (25).

Companies provide specialized software for designing different dental restorations. Various designs can be applied with different software of the manufacturers.

Figure 2. Restorations on a disc designed in inLab software (13)

3.3.3. Hardware

This component refers to computer-controlled milling and grinding machines. Restoration can be obtained by milling from material blocks, and there are systems that produce by adding material. The dental technician can perform some manual adjustments, coloring, porcelain installation, and final polishing following CAM manufacture (25,26).

Transferring the scanned data to the production unit for restoration can be done by four methods. Method 1 consists of only scanning teeth and implants in the mouth without any model. Method 2 involves scanning teeth and then digitally producing models with printers. Method 3 involves scanning an impression taken by conventional methods. The fourth method includes scanning the plaster model obtained from this measurement together with the physical measurement.

An intraoral scanner is used in Method 1 to scan "the maxillary and mandibular arches", containing implants and teeth (16, 33, 34). By using a buccal scan, which involves instructing the patient to close their mouth completely and scanning the opposing arches while they are still, it is possible to create a virtual interocclusal recording. This technique is mostly recommended for monolithic restorations.

In Method 2, digital printers are used to create polyurethane models. After "the maxillary and mandibular arches" have been intraorally scanned, including the teeth and implants, pictures are electronically sent to the laboratory CAD system using a ".stl file." These models may be made using additive manufacturing or milling. The "maxillary and mandibular models" are created, and then they are linked to the actual articulator. The articulator is put in the lab scanner together with replicas of "the maxilla and mandible" (35,36).

Only conventional imprints including teeth are scanned using a lab scanner in Method 3. Additionally, a typical interocclusal recording is acquired. The second option follows the same guidelines as technique 2, whereas the first option involves scanning the imprint to produce a 3-D digital model (33).

The conventional measurements gathered from the teeth and implants are used in Method 4 to create a plaster model. There are two alternative methods that may be used to maintain plaster models in the maxilla and mandible. The first option is to transfer the maxillary and mandibular plaster models to the articulator. The articulator is placed in the lab scanner. The other option includes the procedure of placing "the maxillary and mandibular" plaster models in the laboratory scanner without interocclusal registration and then continuing the operations on the virtual articulator (33,37,38).

Today, CAD/CAM systems use two main production mechanisms, subtractive and additive. The subtractive method is generally used in the systems. The use of additive methods has also begun to increase in dentistry. In addition to the systems available in the market that use the subtraction method, there are also systems that use the material addition method (Figure 3) (39).

Wet milling and dry milling are the two categories into which milling equipment fall. Certain substances require dry milling, whereas others require wet milling, and depending on the quantity of axes, they can be 4 or 5-axis machines. A 5-axis milling device produces restorations with greater precision than a 4-axis milling machine (41).

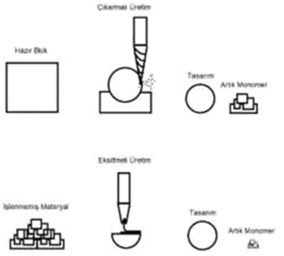

Figure 3. Subtractive and additive manufacturing (40)

The method of mixing materials to produce items from 3-D design data is known as additive manufacturing. The finished CAD design is separated into multiple-section pictures. The production machine builds up the melted liquid or powder materials sequentially, layer by layer, to form the final shape (42). Techniques with this production technology are as follows:

- Direct Metal Laser Sintering Stereolithography
- Photolithography 3D printer
- Selective laser melting
- The evolution of the z-plane, which depicts the vertical elements of restorations, is connected to the distinction in additive manufacturing technologies (42).

3.4. Advantages and Disadvantages of CAD/CAM Systems

Traditional laboratory technologies involve time-consuming, expensive methods and require experienced technicians (43). The more efficient CAD/CAM technology has many advantages. For example, intraoral scanning is easier and faster than the conventional impression method (43). Since the process in the design and production of the restoration progresses to digitalization, it eliminates the stages such as plaster model, wax-up, casting and firing. As a result, time savings and labor savings reduce restoration costs (44).

In addition, CAD/CAM blocks are of higher quality because they have fewer internal defects than porcelain restorations obtained by conventional layering and firing (8). Software-based design allows the restoration to be made at the desired thickness depending on the material used, as well as making quality control possible. All data can be stored digitally, so there is no need to store large numbers of plaster models that can deteriorate over time or are easily damaged (44). On the other hand, it has some disadvantages such as high cost of equipment and software, difficult to use and requiring experience (8,43).

3.5. Current CAD/CAM Systems

3.5.1. CEREC (CEramic REConstruction System)

Cerec system is the first CAD/CAM system developed and started to be used in 1988 (Figure 2.2). Poor marginal fit and inadequate surface shaping are seen in early Cerec systems (45). Cerec 2 systems have been developed to solve these problems and successful restorations have been achieved. The Cerec 2 system was put into use in 1994 and the Cerec 3 system in 2000, respectively. As we move from Cerec 1 to the Cerec 3 system, restorations become more detailed and harmonious (12,46).

In the CEREC system, tooth preparation is done as in all-ceramic restorations. The preparation is coated with an opaque powder (47,48). The image taken with an oral optical scanner is saved on the computer. Restoration in the appropriate form is designed on the computer. An appropriately sized CAD/CAM block is placed in the milling unit and the designed restoration is milled (48,50).

Figure 4. CEREC System (49)

In the latest CEREC 4 system, all restorations to be made on the patient can be designed at the same time (Figure 4). The designed restorations can be prepared by milling from prefabricated blocks in the desired color and size with the MCXL milling device (51).

3.5.2. E4D Dentist

The E4D Dentist system was introduced in 2008 and now together with CEREC they enable one day restoration in the clinic (Figure 5) (52).

Figure 5. E4D Dentist System

The IntraOral Digitizer, a laser scanner, a milling unit, and a design center make up this system. Patients are not required to expand their lips wide because the scanner is tiny. Except in certain circumstances, opaque powder is not required for scanning.

Partial crown, full crown, inlay, onlay, bridge restoration design can be made. The E4D Dentist system has an "autogenesis" feature and can make personal designs compatible with anatomical structures. In the E4D system, resin based composite blocks, resin nanoceramic blocks, leucite reinforced ceramic blocks, lithium disilicate glass ceramic blocks, zirconium blocks and temporary acrylic blocks can be used.

3.5.3. DCS President (Digitizing Computer System)

In this system, which was first used in 1990, restoration infrastructures are shaped from fully sintered Y-TZP blocks (DC-Zircon) (53).

DCS President system performs both "computer-aided design and computer-aided production" (54). Thanks to the device, 14 prepared teeth can be scanned and the infrastructure up to 30 members can be produced in the Precimill milling unit (54-56). Thanks to the DCS Dentform software, the size of the connector fields and the body forms are automatically suggested.

Porcelain, glass ceramic, zirconia, metals and fiber reinforced composites can be used in the DCS system. In addition, being able to mill titanium and completely sintered zirconia makes this system one of the few CAD/CAM systems available (55).

3.5.4. Cercon

The Cercon system was previously called the CAM system, as it was not a CAD component (55). After the 3D optical scanner (Cercon eye) and CAD design software (Cercon Art) were added to the system in 2005, it became a complete CAD/CAM system. Good grain, highly sinterable zirconium blocks are used in the system. These blocks can be used for restorations of telescope crowns, single crowns, abutments and bridges with three to five members.

Figure 6. Cercon System

The wax sample of the infrastructure of the tooth prepared in the Cercon system is prepared and placed on the main part of the Cercon device (Cercon brain). This sample is scanned with the laser system of the device, transferred to the milling unit, and a substructure is obtained from semi-sintered zirconium blocks. During this process, the amount of shrinkage of 20% that may result from the final sintering is calculated and the infrastructures are prepared at this rate. Sintering process is applied in Cercon furnace for 6 hours at 1350 degrees (Figure 6) (57).

3.5.5. Everest

Everest system was released by Kavo company in 2002 (Figure 7). It consists of the scanner, etching unit, sintering furnace and the computer that provides the connection between these units. The resulting plaster model is placed on the rotating table. It is scanned with a CCD camera. The three-dimensional digital image of the scanned model is transferred to the computer. The restoration is designed using Windows-based software. After the design process is completed, the substructure blocks are milled in the etching unit. The grinding unit has a milling feature in five axes. With the Everest CAD/CAM system, inlay, onlay, crown and bridge restorations can be performed (55).

Figure 7. Everest System

3.5.6. Procera

The Procera AllCeram system was developed by Andersson and Oden in collaboration with Nobel Biocare and Sandvik Hard Materials in 1993 (Figure 8) (58).

Figure 8. Procera System

Restorations with aluminum oxide (Procera AllCeram), zirconium oxide (Procera AllZirkon) and titanium (Procera AllTitan) infrastructures can be obtained with the Procera system using CAD/CAM technology 59-61).

In the Procera system, the CAD process is carried out in the dental laboratory, while the CAM unit is located in two centers, Sweden and the USA. The data in the model is transferred to digital media using the scanner. The obtained digital data is sent to the relevant center via e-mail (62). A bigger size day is made to account for the ceramic material's shrinking. Copings are produced by sintering high purity aluminum powder at 2000° C by dry pressing technique, although enlarged days are used (55). The obtained restoration infrastructure is sent back to the laboratory, where the allceram porcelain is stacked by layering, fired and the restoration is completed (63).

3.5.7. LAVA

The Lava system has been marketed by 3M ESPE (Figure 9). The system consists of a three-dimensional optical scanner called Lava Scan, a computer-aided milling machine called Lava Form, and a sintering furnace called Lava Term. The model obtained with the measurement taken is scanned with the optical scanner without model contact. The obtained data is transferred to digital media. With Lava CAD software, the restoration edges and body are automatically determined. 20-25% shrinkage occurs in the infrastructure of the restoration caused by sintering. In order to prevent this situation, expanded infrastructures are prepared automatically by the system at these rates. For maximum aesthetics, the infrastructure can be colored in seven different options before the milling and sintering processes. After the infrastructure design is completed, the tetragonal zirconium polycrystalline material stabilized with yttrium is selected in suitable sizes for the production of the infrastructure and the restoration is produced on the milling machine (62). Finally, sintered substructures are finished with Lava Ceram porcelain (63).

Figure 9. Lava System

4. CONCLUSION

The term CAD/CAM, which means "computer-aided design and computer-aided manufacturing", is a technology that works with computer control and that the material to be produced is designed in three dimensions on the computer screen, which has been used mostly in the aircraft and industrial industries since the 1950s. The development of CAD/CAM technique in dentistry has made it possible to construct restorations out of high-performance materials that were previously difficult to shape.

In the past 20 years, dental CAD/CAM systems have grown in popularity. Since 1984, many CAD/CAM systems such as Cerec, E4D, Procera, Everest, DCS President, Cercon, and Lava systems have been developed. With the development of these systems, it is aimed to design the restoration according to the functions of the restoration and natural tooth anatomy, to produce the restoration in a short time at the bedside, to ensure the marginal and internal harmony of the restoration, to increase its mechanical resistance and to provide a better aesthetic, instead of traditional impression techniques.

Today, CAD/CAM systems are widely used in many branches of dentistry, in addition to prosthetic and restorative treatments such as "inlays, onlays, laminate veneers, partial crowns, full crown-bridge systems, skeletal structures of removable partial dentures, crown-bridge and hybrid prosthesis infrastructure design". The fact that these systems include treatments in the fields of periodontology, orthodontics, implantology and maxillofacial surgery is a sign of the evolution of CAD/CAM from the past to the present.

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