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Review Article

Digitalization in Dentistry: CAD/CAM - A Review

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Abstract

In today's fast-paced world, instant gratification is expected to be synonymous with worthwhile results. This also applies to dental treatments. In dental technology, production stages are increasingly being automated every single day. CAD/CAM technology was developed to solve 3 challenges. To ensure adequate strength of the restoration, especially for posterior teeth, to create restoration with a natural appearance and lastly to make the restoration easier, faster and more accurate. This article provides an overview of the development of various CAD/CAM systems, operational components, methodologies, and restorative materials commonly used.

Keywords: CAD/CAM Systems; Components; Fabrication Techniques; Scanner; Restorative Materials

Introduction

The stage was set for exciting advances in dentistry in the 1950s and 1960s when prototypes of computer- aided design (CAD) and computer-aided manufacturing (CAM) were introduced into industrial settings [1]. As a result of continual developments in computer hardware and software, new methods of production and new treatment concepts are to be expected, which will enable an additional reduction in costs [2]. The advent of CAD/CAM has enabled the dentists and laboratories to harness the power of computers to design and fabricate esthetic and durable restorations [3].

Evolution of CAD-CAM systems

Computer-aided design and manufacturing were developed in the 1960s for the use in the aircraft and automotive industries [4]. Dr. Francosis Duret was the first person to develop CAD/CAM device, making crowns based on an optical impression of the abutment tooth and using a numerically controlled milling machine in 1971 [4,5]. He produced the first CAD/CAM dental restoration in 1983 [4]. Dr. Andersson developed the Procera Method of manufacturing high-precision dental crowns in 1983. Dr. Duret later developed the Sopha system in 1984 [4,5]. Dr. Andersson was the first person to use CAD/CAM for composite veneered restorations [4,6]. In 1987, Mörmann and Brandestini discovered CEREC system, which was the first dental system to combine digital scanning with the milling unit [4,7,8]. The E4D Dentist system, which was introduced in 2008 permits same-day in–office restorations along with CEREC system [4].

Components

All CAD/CAM systems consist of three components:

1) Digitalisation Tool/ Scanner 2) Software 3) A Production Technology Scanner

There are two different scanning possibilities: a) optical scanners, b)mechanical scanners.

Optical scanners

The basis of this type of scanner is the collection of three-dimensional structures in a 'triangulation procedure'. Here, the source of light (e.g:- laser) and the receptor unit are in a definite angle in their relationship to one another. Through this angle the computer can calculate a three-dimensional data set from the image on the receptor unit. Examples: Lava Scan ST (3M ESPE, white light projections) and es1 (etkon, laser beam).

Mechanical scanner

In this scanner variant, the master cast is read mechanically line-by-line by means of a ruby ball and the three-dimensional structure is measured. This type of scanner is distinguished by a high scanning accuracy, whereby the diameter of the ruby ball is set to the smallest grinder in the milling system, with the result that all data collected by the system can also be milled. Example: Procera Scanner. Drawbacks 1) the complicated mechanics, 2) the apparatus is very expensive 3) long processing times compared to optical systems.

Design software - Processing devices are distinguished by means of the number of milling axes:

- 3-axis devices
- 4-axis devices
- 5-axis devices.

3-axis milling devices

This type of milling device has degrees of movement in the three spatial directions. Thus, the mill path points are uniquely defined by the X -, Y -, and Z – values . All 3-axis devices used in the dental area can also turn the component by 180° in the course of processing the inside and the outside. advantages -1) short milling times and simplified control 2) cost effective. Examples: InLab (Sirona), Lava (3M ESPE), Cercon brain (Degu Dent).

4-axis milling devices

In addition to the three spatial axes, the tension bridge for the component can also be turned infinitely variably. As a result it is possible to adjust bridge constructions with a large vertical height displacement into the usual mould dimensions and thus save material and milling time. Example: Zeno (Wieland-Imes).

5-axis milling devices

With a 5-axis milling device there is also, in addition to the three spatial dimensions and the rotatable tension bridge (4th axis), the possibility of rotating the milling spindle (5th axis). This enables the milling of complex geometries with subsections. Example: Everest Engine (KaVo) [2,9,10].

3Shape's Dental System is a unique combination of the most advanced 3D scanning technology and management software.

D700 scanner: This revolutionary scanner is optimized for impression scanning, and is capable of scanning full dental gypsum models up to 40% faster and with greater details. The 3-axis allows the object to be tilted, rotated and translated so as to be scanned from any viewpoint, corresponding to a dental model.

Q700 scanner series: It provides a choice of 2 scanners - the Q700 with 1.3MP camera resolution and the Q740 with 5.0MP resolution. Both scanners are designed for productive quality control of small complex objects through excellent detail level, high scan speed and accuracy [11].

Different CAD-CAM systems

Cercon: It does not have a CAD component. In this system, a wax pattern (coping and pontic) with a minimum thickness of 0.4 mm is made. The system scans the wax pattern and mills a zirconia bridge coping from presintered zirconia blanks. The coping is then sintered in the Cercon heat furnace (1,35^{0}C) for 6 to 8 hours [3].

Everest: The Everest system consists of scan, engine, and therm components. In the scanning unit, a reflection free gypsum cast is fixed to the turntable and scanned by a CCD camera in a 1:1 ratio with an accuracy of measurement of 20 µm. Its machining unit has 5-axis movement that is capable of producing detailed morphology and precise margins from a variety of materials. Examples: leucite-reinforced glass ceramics, partially and fully sintered zirconia, and titanium [5].

Lava: This system uses yttria stabilized tetragonal zirconia polycrystals (Y-TZP) which have greater fracture resistance than conventional ceramics. Lava system uses a laser optical system to digitize information. The Lava CAD software automatically finds the margin and suggests a pontic. The framework is designed to be 20% larger to compensate for sintering shrinkage [3,5].

Procera: This system has combined pantographic reproduction with electrical discharge (spark erosion) machining. It uses an innovative concept for generating its alumina and zirconia copings. First, a scanning stylus acquires 3D images of the master dies that are sent to the processing center via modem. The processing center then generates enlarged dies designed to compensate for the shrinkage of the ceramic material. Copings are manufactured by dry pressing high-purity alumina powder (> 99.9%) against the enlarged dies. These densely packed copings are then milled to the desired thickness. The Procera restorations have excellent clinical longevity and strength [5].

DCS Precident: It is comprised of a Preciscan laser scanner and Precimill CAM multitool milling center. It can scan 14 dies simultaneously and mill up to 30 framework units in 1 fully automated operation [3]. Materials used: Porcelain, Glass Ceramic, In- Ceram, Dense Zirconia, metals, and Fiber- Reinforced Composites. This system is one of the few CAD/CAM systems that can mill titanium and fully dense sintered zirconia [5].

CICERO System: The computer integrated crown reconstruction was developed by CICERO Dental System B.V. (Hoorn, The Netherlands). The CICERO method for production of ceramic restorations uses official scanning, ceramic sintering, and computer assisted milling techniques to fabricate restorations with maximal static and dynamic occlusal contact relations. The system makes use of optical scanning, near net-shaped metal, ceramic sintering and computer-aided fabrication techniques [8].

CEREC system: The computer- aided design/computer-aided manufacture (CAD/CAM) CEREC (computer-assisted CERamic REConstruction) system is used for electronically designing and milling restorations.

CEREC 1: In this, the ceramic block could be turned on the block carrier with a spindle and feed against the grinding wheel, which grinds the ceramic block to a new contour with a different distance from the axis at each feed step.

CEREC 2: The introduction of an additional cylinder diamond enables the grinding of partial and full crowns. It introduced the design of the occlusion in three modes: extrapolation, correlation and function. However, the design still was displayed two-dimensionally [7].

With CEREC 1 and CEREC 2, an optical scan of the prepared tooth is made with a couple charged device (CCD) camera, and a 3-dimensional digital image is generated on the monitor. The restoration is then designed and milled [5].

CEREC 3: This system skipped the wheel and introduced the two-bur-system. The "step bur", reduced the diameter of the top one-third of the cylindrical bur to a small- diameter tip enabling high precision form grinding with reasonable bur life [7]. The most significant factor for three-dimensional scanning with the Cerec 3 intraoral camera is that tooth preparations for crowns and inlays have a unique characteristic: all points of interest can be seen from a single viewing line, representing the preparation and insertion axes, respectively [12].

CEREC in Lab: Is a laboratory system in which working dies are laser-scanned and a digital image of the virtual model is displayed on a screen. After designing the coping or framework, the laboratory technician inserts the appropriate VITA In-Ceram block into the CEREC in Lab machine for milling. The technician then verifies the fit of the milled coping or framework [5].

E4D Dentist System: Presently it is the only system besides CEREC that permits same day in-office restorations. This system includes a laser scanner (Intraoral digitizer), a design center and a milling unit. The scanner is placed near the target tooth, and has 2 rubber feet that hold it to specific distance from the area being scanned. As each picture is taken, the software gradually creates a 3D image. The design system automatically detects the finish lines and marks them on the screen. As soon as the restoration is approved, the data are transmitted to either the in-house milling machine or a dental laboratory. The office milling machine will then manufacture the restoration from the chosen blocks of ceramic or composite [4].

Restorative materials for CAD-CAM processing

According to the Fabrication Method

Pre-sintered [13]

Material	Company	Composition
Cercon	Dentsply	Partially stabilized zirconia
DC-Zirokon	DCS (Kelkheim, Germany)	Partially stabilized zirconia
Everest ZS-Blanks	Kavo	Partially stabilized zirconia
IPS e.max ZirCAD	Ivoclar vivadent	Partially stabilized zirconia
LAVA Frame	3M ESPE	Partially stabilized zirconia
Procera All Ceram	Nobel Biocare	Alumina
Procera All Zircon	Nobel Biocare	Partially stabilized zirconia
Vita YZ	Vita Zahnfabrik	Partially stabilized zirconia

Densely sintered [13]

Material	Company	Composition
Denzir	Cad.esthetics	Partially stabilized zirconia
Degiceram L	Digident	Leucite-glass
Digizon	Digident	Partially stabilized zirconia
Everest G- Blanks	Kavo	Leucite-glass
Everest ZH- Blanks	Kavo	Partially stabilized zirconia
IPS e.max CAD	Ivoclar vivadent	Lithium disilicate-glass
ProCAD	Ivoclar vivadent	Leucite-glass
Vitablocs Mark II	Vita Zahnfabrik	Leucite-glass
Vitablocs TriLuxe	Vita Zahnfabrik	Leucite-glass
Zirkon	Cynovad	Partially stabilized zirconia

Glass infiltrated [5,13]

Material	Company	Composition	Flexural strength (MPa)
In cerem Alumina	Vita Zahnfabrik	Glass-alumina	500
In cerem Spinell	Vita Zahnfabrik	Glass-alumina-spinel	350
In cerem Zirconia	Vita Zahnfabrik	Glass-alumina-PS zirconia	750

Stages in fabrication of prosthesis with CAD/CAM technology

1. Computer surface digitization
2. Computer-aided designing
3. Computer assisted manufacturing
4. Computer-aided esthetics
5. Computer-aided finishing

The last two stages are more complex and are still being developed for inclusion in commercial systems.

Computer surface digitization

Scanning of prepared tooth is done either with LED based or Laser based scanners.

LED based scanner: A small hand held video camera with a 1cm wide lens (scanner) when placed over the occlusal surface of the prepared tooth, emits infrared light which passes through an internal grid containing a series of parallel lines. The pattern of light and dark stripes which falls on the prepared tooth surface is reflected back to the scanning head and onto a photoreceptor, where its intensity is recorded as a measure of voltage and transmitted as digital data to the CAD unit.

Laser based scanner: A high speed laser takes digital scans of the preparation and proximal teeth to create an interactive 3D image. Rapid scan allows automatic capture of digital images at the operator's preferred speed to scan in the mouth or extra-orally on conventional impressions or models, all without powder. Newer laser based scanners can scan at subgingival level based on optical coherence tomography (OCT).

At least 9 scans are required to produce the image. There are stabilizers present with the scanning device. If scanned image is correct it will appear in green color, if it is near correct it appears in yellow color but if scanned image does not meets the requirements software discards the image and shows it in red color [14].

Optical camera, LASER surface scanning device, three dimensional (3-D) scanning device (digitizer), photogrammetry, computed tomography (CT-Scan), magnetic resonance imaging(MRI), 3-D ultrasonography etc. are some of the technologies used for computer surface digitization [15].

Computer-aided designing (CAD)

A three-dimensional image of the die is produced over the screen and can be rotated for observation from any angle [16]. Once the 3-D image is captured through any of the computer surface digitization techniques, 3-D image processing is done and the digitized data is entered in the computer. Finally, curve smoothening data reduction and blocking of undercuts can be done at this stage. Designing of the restoration is done using CAD software, which in turn sends commands to the CAM unit, for fabricating the restoration [15].

Computer-aided manufacturing (CAM)

Third and the final stage is Computer-aided manufacturing (CAM). The CAM technologies can be divided in three groups according to the technique used:

a. **Subtractive technique from a Solid Block:** In this stage the milling is done with computerized electrically driven diamond disks or burs which cut the restoration from ingots [15]. The CAM technique most commonly applied in manufacturing frameworks for single crowns and. The size of the material blocks available for the milling units limits the size of the FPDs [16].

b. **Additive technique (by applying Material on Die):** Here in this technique Alumina or Zirconia is dry pressed on the die and the temperature is raised to a temperature similar to the presintering state. At this stage, enlarged and porous coping is stable. Its outer surface are milled to the desired shape and coping, removed from die, and sintered into the furnace for firing to full sintering.

c. **Solid free form fabrication:** This category includes new technologies originating from the area of Rapid Prototyping (RP), which have been adapted to the needs of dental technology.

Rapid Prototyping Techniques

1) Stereolithography 2) Selective Laser Sintering (SLS) 3) 3-D Printing 4) Fused Deposition Modeling (FDM) 5) Solid Ground Curing 6) Laminated Object Manufacturing (LOM) [10,16].

Stereolithography (Perfactory, Delta Med, Frieberg, Germany): It is the technique for creating 3 dimensional objects in which a computer controlled moving laser beam is used to build up the required structure layer by layer [10]. Occlusal splints and diagnostic templates for oral implantology can be produced with this technique [16]. herence tomography (OCT).

Selective Laser Sintering: Starts by converting the CAD data in series of layer. These layers are transferred to the additive SLS machine which begins to lay the first layer of powder. As the laser scans the surface, the material is heated and fuse together. Once the single layer formation is completed, the powder bed is lowered and the next layer of powder is rolled out smooth and subjected to laser. Hence layer by layer formation of the object takes place [10].

3-D Printing: In which after computer-aided designing, the machine is used to build (print) a wax pattern of the restoration. Then this wax pattern is cast similar to normal lost-wax technique. Advancement has taken place in such a way that instead of wax, resin-type material is being used to fabricate patterns [10,15].

Advantages of CAD-CAM technology [10,16]

1. Applications of new materials – High strength ceramics that are expected to be the new materials for FPDs frameworks have been difficult to process using conventional dental laboratory technologies.
2. Time effectiveness
3. Reduced labour
4. Quality control
5. A digital impression also means that patients do not have to have impression material and trays used, saving them discomfort.
6. Latest innovation in CAD/CAM system allows occlusion to be viewed and developed in dynamic state.

Disadvantages of CAD-CAM technology [10,16]

1. Greater learning curve required.
2. Capital costs of these systems is quite high and rapid large scale production of good quality restoration is necessary to achieve financial viability.
3. Some CAD/CAM system relies on margin capture for digitization, thus making subgingival margin capture challenging.

4. CAD/CAM is ever advancing technology. Upgrades and updates are often required.
5. Matching the patient's tooth shade to the blocks of materials used to fabricate the restorations can be a challenge to the dentist initially.

Conclusion

An array of CAD/CAM systems have evolved, but dental CAD/CAM systems are, still in their infancy. Developments are continuing on both existing and new systems. With each iteration, the capabilities of these systems expand, and improvements in technique sensitivities, user friendliness, computing power, and the quality of the restorations are usually evident as well. But as the future approaches, the systems and materials available to us will continue to evolve, improve, and enhance dentistry.

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