ORIGINAL RESEARCH PAPER

Dental Science

CAD/CAM SYSTEMS IN DENTISTRY: AN UPDATE

KEY WORDS: Computer-Aided Design, Dental Abutments, Dental Implants

Dr. Volkan Coskun* DDS, Prive Practice Umran Medical Center, Istanbul Turkey *Corresponding Author

ABSTRACT

The last several decades have seen significant development of new technologies in dentistry. Certainly, one of the most important of them is the development of CAD/CAM systems. While a few systems were available in the 1980s, currently this number has reached about fifteen. Many benefits associated with CAD/CAM-generated dental restorations include: easier, faster, more compatible, more accurate restorations. Furthermore, data or information about treatment has been stored in digital media for many years. CAD/CAM systems are usually used in prosthodontic, restorative dentistry and oral surgery in dentistry. Especially, compliance of maxillofacial prosthesis increases with the development of CAD/CAM systems. All these developments have revealed higher-quality prosthesis and increased aesthetics and quality of life of patients. In this article, we review the history, systems, materials, and use in dentistry of CAD/CAM.

Introduction

The last several decades have seen significant development of new technologies in dentistry. One of the technological innovations used in the dental field is Computer-Aided Design and Computer-Aided Manufacture (CAD/CAM). CAD/CAM systems have been used in industrial manufacturing for many years, but are a little-used system in general dental practice. This high-tech dental equipment makes dental procedures easier for dentists, technicians and patients. A CAD/CAM system is a technology that collects data, designs and manufactures. By definition, CAD/CAM can be defined a milling technology.

The system has three components:

- Scanner device,
- Software that processes data, and
- Part of production that transforms the information received to manufacture.

In the general industry, for many years, this system has been used; over the past three decades, popularity of the system has been increasing gradually. With the rapid improvements being made in computer-assisted processing technology in several industries since the 1970s, research and development of dental CAD/CAM systems has been actively pursued worldwide since the 1980s, including in Japanese academies.(Hikita and Uchiyama, 1989) CAD/CAM systems are used in both the dental office and the dental laboratory, and can be applied to fixed partial dentures, veneers, crowns, inlays, onlays, implant abutments, and even full-mouth reconstruction. CAD/CAM is also being used in orthodontics.(Davidowitz and Kotick, 2011) CAD/CAM technology helps us in four issues. These issues are more natural and focus on aesthetic appearance, adequate strength of restoration, faster and easier restoration, and, finally, more compatible restorations. In this article, we explain CAD/CAM systems, history, advantages, and their use in dentistry.

Usage of CAD/CAM in dentistry from a historical perspective In the 1960s, computer-aided design and manufacturing were developed for use in the aircraft and automotive industries.(American Machinist, 1998) At the end of the 1970s, the idea of using optical instrumentation to develop an intraoral grid surface mapping system was firstly introduced by Young and Altschuler.(Sjogren et al., 2004) The major improvements in dental CAD/CAM systems occurred in the 1980s. However, the first dental CAD/CAM device was developed by Dr. Duret in 1984; Dr. Mörmann is the first developer of a commercial CAD/CAM system (Cerec, Sirona Dental Systems, Germany).

In 1983, Dr. Duret made the first dental CAD/CAM restoration and showed his system in November 1985 at the French Dental Association's international congress, making a posterior crown restoration for his wife in less than an hour.(Preston and Duret, 1997) The first chairside inlay was used by Dr. Möerman in 1985. Subsequently, Dr. Andersson developed the Procera system (Nobel Biocare, Zurich).(Andersson and Oden, 1993) He was also the first person to use CAD/CAM for composite veneered restorations.(Andersson et al., 1996) This was the application of CAD/CAM in a specialised procedure as part of a total processing system. This system was later developed as a processing centre networked with satellite digitisers around the world for the fabrication of all-ceramic frameworks.(Miyazaki et al., 2009)

At the University of Minnesota, Dr. Rekow and colleagues studied a dental CAD/CAM system in the middle of the 1980s. In this system, data was acquired using photographs and a high-resolution scanner, and to mill restorations using a 5-axis machine.(Rekow, 1987) From 1985 to present, a large number of CAD/CAM systems have been developed, including: Cerec, Cicero, Procera, Celay, DC-Zircon, and Cercon. Up to now, this technology has advanced in two directions. First of all, with optical impression, data received is transferred to the framework; then conventional impression, stone model/wax-up, and digitising data are transferred to the framework (Figure 1). However, certain systems are not fully compatible for optical impression (Table 1).

In recent years, networked CAD/CAM systems that were originally based on the Procera system have gained popularity, especially for the fabrication of high-strength ceramic frameworks. In this system the role of digitising a stone model and that of CAD/CAM processing are separated. At the satellite office, data for the abutment that are digitised are transferred via the Internet to a processing centre based anywhere in the world. Frameworks fabricated at the centre are then delivered to the satellite office to complete the restorations by layering porcelains.(Miyazaki et al., 2009) In recent years, CAD/CAM systems have become increasingly popular in most dental clinics. Approximately, more than 30,000 dentists around the world have their own scanning and milling machine. Nowadays, many CAD/CAM systems have been used for inlays, onlays, veneers, crowns, and bridges (Table 2).

CAD/CAM systems we use today generally have three components, including: scanner, software, and processing devices. In CAD/CAM systems, the two different scanners used were optical and mechanical scanners. Optical scanners (Figure 3) are made with a triangulation procedure with a source of light and receptor unit as an example of Lava Scan ST (3M ESPE, white light projections). Mechanical scanner (Figure 4): in this scanner variant, the master cast is read mechanically line by line by means of a ruby ball and the three-dimensional structure 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 being that all data collected by the system can also be milled.(Rekow, 1987; Sjogren et al., 2004) The drawbacks of this data-measurement technique are to be seen in the inordinately complicated mechanics, which make the apparatus very expensive with long processing times compared to such optical systems as the Exemplarily Procera Scanner (Nobel Biocare, Goteborg, Sweden).(May et al., 1998; Webber et al., 2003)

Software is provided for the design of dental restorations (Figure 2).Due to such systems, only crowns and fixed partial denture (FPD) frameworks can be constructed ; other systems also offer the opportunity to design full anatomical crowns, partial crowns, inlays, inlay-retained FPDs, as well as adhesive FPDs and telescopic primary crowns.(Reiss, 2007) The systems available on the market are differentiated mostly in their construction software. Most systems emphasise an indication spectrum that is as broad as possible, while some manufacturers place emphasis on intuitive use and user-friendliness.(Beuer et al., 2008) Processing devices are distinguished according to a number of milling devices, including: three-, four- and five-axis devices.

- **Three-axis 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; therefore, the calculation investment is minimal. Short milling times and simplified control by means of the three axes are the advantages of these milling devices.
- **Four-axis devices:** The tension bridge for the component can also be turned infinitely and variably in addition to the three spatial axes in this milling device. As a result, it is possible to adjust bridge constructions with a large vertical height displacement to the usual mould dimensions, whereby saving material and milling time.
- **Five-axis devices:** In addition to the three spatial dimensions and the rotatable tension bridge (4th axis), there is also the possibility of rotating the milling spindle (5th axis), which is present in a 5-axis milling device. This enables the milling of complex geometries with subsections (Figure 5).

Dental CAD/CAM: Advantages and Disadvantages

CAD/CAM technologies have started a new age in dentistry. The use of CAD/CAM technology for dental restorations has numerous advantages over traditional techniques. These advantages include speed, ease of use, and quality.

Potential advantages and disadvantages of CAD/CAM systems Advantages

- Accuracy of impressions
- Opportunity to view, adjust and rescan impressions
- No physical impression for patient
- Saves time, and one visit for in-office systems
- Opportunity to view occlusion
- Accurate restorations created on digital models
- Potential for cost sharing of machines
- Accurate, wear- and chip-resistant physical CAD/CAM-derived models
- No layering/baking errors
- No casting/soldering errors
- Cost-effective
- Cross-infection control

Disadvantages

- When compared with traditional techniques, soft-tissue management is more critical
- Customisation may be required depending on the material and patient
- High learning curve
- Maintenance must perform on unit annually by trained technical personnel / a service engineer.
- Hardware calibration and unit cleaning must be performed with carefully and periodically

Due to measurements and fabrication being so precise, quality of CAD/CAM restorations is extremely high. Image scanning and viewing it on a computer screen provide the clinician with the capability to review the preparation and impression, as well as make immediate adjustments to the preparation and/or retake the impression if necessary, before being sent to the laboratory or a milling unit. This ensures no calls from a laboratory that a (physical) impression is defective — no missing margins, voids or pulls in the impression or steps between two viscosities used, which are errors seen in physical impressions.

The laboratory model that the technician will work with is different in CAD/CAM systems when compared with the traditional model. The model is milled or created with stereolithography by a computer-controlled system — CAD/CAM technology. The tolerances are in the microns making these models extremely accurate.

Very hard acrylic materials were also used for manufacturing models. This material is very different compared to stone: the hard acrylic margins do not chip away, and contacts are not worn away as the wax or ceramic. Dies are cut and trimmed by the laboratory computer, set up almost like a jigsaw puzzle with interlocking pieces, and cannot shift during manipulation. This provides a great advantage over saw-cut plaster dies, even if they are held in a special matrix.(Mormann et al., 1989)

Ceramic blocks used in CAD/CAM restorations ensure a natural appearance due to the translucent quality that imitates enamel, and a wide range of shades is available. Ceramic wears well in the mouth, even when used for posterior teeth; because it is no more abrasive than conventional and hybrid posterior composite resins, it causes minimal wear to the opposing teeth.(Mormann et al., 1989) Another benefit of CAD/CAM systems is that all the scans can be stored on the computer, whereas standard stone models take up space and can chip or break if stored improperly.(Birnbaum et al., 2009)
The quality of dental prostheses has improved significantly by means of standardised production processes, and makes very efficient quality management possible. On the one hand, it enhances the productivity enormously and dental laboratories shifting from manufacturers to modern computerised production centres. On the other hand, this increase in productivity leads to a competitive capability to produce dental prostheses independent of the manufacturing site, which might be a major factor for the high-wage countries to keep business volume in the country. Finally, CAD/CAM systems have made it possible to machine new, interesting materials, like the high-performance ceramics and titanium with high accuracy.

Currently, besides these advantages, CAD/CAM systems have some disadvantages. First of all, cost of equipment and software is very high, and training of a practitioner takes time and money. Dentists without a large enough volume of restorations will have a difficult time making their investment pay off.(Mormann et al., 1989) Additionally, this fabrication technology has some drawbacks to be mentioned. High cost of investment for machines might overextend the budget of smaller laboratories. Furthermore, some applications are limited due to software and production procedures.(Beuer et al., 2008) Moreover, because of the need for multiple steps in digital impression, systems may not save time as they are currently used. For example, dentists who use certain scanners must first send the images for a clean-up process, which is followed by the setting of margins by a dental technician. After that, images next go to the clinician's dental laboratory for review and then back for model milling. Finally, the models and dies are then sent to the clinician's dental laboratory for fabrication of the restoration.(Henkel, 2007)

Few more disadvantages regarding maintenance of milling units – cleaning, hardware, calibration etc.

Materials used in CAD/CAM systems

Recent innovations in dental ceramic materials and processing techniques, especially CAD/CAM and milling technology, have facilitated the advancements and application of superior dental ceramics. Recently, several strategies using different CAD/CAM processes and different materials have been able to manufacture all types of all-ceramic restorations — from inlays to onlays, and from veneers to crowns to fixed partial dentures (Table 2).

By increasing the range of indications and software-hardware advancements, material evolution becoming compulsory so that the aesthetics of a restoration are created from a milled block of porcelain could be improved. Early generations of materials were monochromatic, which, for the indicated use at the time, was adequate. However, limitations in the technique dented that detailed morphology and anatomy were not possible, so, historically, material aesthetics were the least of the practitioners' worries. Then, with the eventual increased range of indications, users realised that they needed more robust and aesthetic materials to allow for increased use of this technology.

Currently, titanium, titanium alloys and chrome cobalt alloys are processed using dental milling devices. Due to the high metal attrition and the high material costs, the milling of precious metal alloys has been shown to be of no economic interest. On the one hand, resin materials can be used for the milling of lost wax frames for casting technology; on the other hand, it is possible to use resin materials directly as crown and FPD frameworks for long-term provisional or for full anatomical temporary prostheses (Table 3).(Beuer et al., 2008; Mormann et al., 1989)

Glass ceramic materials are mainly composed of a glass matrix material that has a fine, evenly distributed crystalline phase. Translucency of these materials is generally very close to tooth structure, which makes them ideally suited for inlay and onlay applications. Glass ceramic materials can be obtained with a conventional power liquid technique or they can be industrially processed into a dense machineable block. For the production of indirect restorations such as inlays, onlays, veneers, partial crowns, and full crowns, grindable silica-based ceramic blocks are suggested by several CAD/CAM systems. Also, the main dental CAD/CAM systems in the world available for zirconia are shown in Table 4.(Suttor et al., 2001; Vult von Steyern et al., 2001)

Use in dentistry

Along with using computer technology in dentistry, an increasing number of alternatives have been provided for the restoration of teeth. During the last 25 years, a great number of computer-aided design/computer-aided manufacturing (CAD/CAM) systems have been entering the dental marketplace. Several laboratory-based systems are used currently for creating all-ceramic restorations, such as Lava (3M ESPE, St. Paul, Minn.), Cercon (Dentsply Ceramco, Burlington, N.J.), InLab (Sirona Dental Systems, Bensheim, Germany), and Procera (Nobel Biocare, Yorba Linda, Calif.), whereas the CEREC system (Sirona Dental Systems) and E4D Dentist (D4D Technologies,USA) are chairside applications of CAD/CAM technology used in restorative dentistry.(Fasbinder et al., 2005)

CAD/CAM systems used today have been helping us in a wide range of fields in dentistry, exemplarily:

- **Restorative dentistry:** Indirect restorations (inlays, onlays, veneers, crowns, and bridges).
- **Prosthodontics:** Removable prosthesis (removable partial dentures, maxillofacial prosthesis).
- **Oral surgery:** Surgical guides, computer-assisted surgery, implants in oral surgery, in-laboratory protocols.

Prosthodontics: Removable denture construction requires a series of stages which include preliminary impressions, construction of a custom tray, definitive impressions, and construction of occlusion rims, creating jaw relationship records, arranging prosthetic teeth, try-in, flasking, resin packing, and denture delivery. Because many steps are associated with certain problems, the fabrication of complete dentures using a computer-aided design/computer-aided manufacturing (CAD/CAM) system has the potential to simplify the above process and resolve the associated problems.

In recent years, CAD/CAM systems have been successfully introduced into restorative dentistry and maxillofacial technology.(Ciocca et al., 2007) Williams et al.(Williams et al., 2004; Williams et al., 2006) fabricated removable partial denture frameworks using CAD/CAM systems. Kawahata et al.(Kawahata et al., 1997) fabricated wax complete dentures using a computerised numerical control (CNC) machining centre, and Maeda et al.(Maeda et al., 1994) fabricated the shells of complete dentures using CAD/CAM systems. In a study that has been practised in Tokyo, Kanawaza et al.(Kanazawa et al., 2011) fabricated a complete denture by using a patient's worn denture.

In maxillofacial defects, prosthetic rehabilitation and surgical reconstruction are the main methods in treatment. In some patients, especially those with extensive maxillofacial defects including the maxilla, nose, upper lip, cheek, and orbital content, surgical reconstruction may be an extreme challenge, and operations can result in complications. Therefore, a highly realistic prosthetic rehabilitation, an alternative to surgery, may be the best option to elevate quality of life. In recent years, as a result of the development of computer technology, many studies have focused on the treatment of maxillofacial defects, using CAD/CAM technologies. In such studies a three-dimensional image of the surface of a patient's face was reconstructed. In a study performed in China, a man that had a large defect involving the left eye and orbital tissue, a portion of the nose and left cheek, and the majority of the upper lip and the anterior maxilla was successfully treated using CAD/CAM and 3D scanning systems.(Feng et al., 2010)

Implant Dentistry: In the last 25 years, numerous developments have been brought to dental practice, with endosseous dental implants being foremost among them. During the past two decades, CAD/CAM systems have also evolved and they have been used by dental professionals and dental laboratory professionals.(Andersson et al., 1989; Duret et al., 1988; Russell et al., 1995) Implant dentistry has come a long way since 1982, when a Swedish physician named Per-Ingvar Brånemark first presented his work on the osseointegration of endosseous dental implants.(Branemark and Albrektsson, 1982) In the last 30 years, patient preference of dental implants has risen dramatically.(Friberg and Jemt, 2010; Turkyilmaz and Nicoll, 2011) Currently in implant dentistry, we use CAD/CAM systems for production of:

- Implant
- Implant abutment
- Cast framework implant-based restorations
- Maxillofacial implants
- Surgical guide for implant surgery (Figure 6)

Implant abutments must meet biological, functional and aesthetic demands. Therefore, materials used in implant abutments and/or frameworks should be biocompatible with satisfactory mechanical properties.(Heydecke et al., 2002; Rasperini et al., 1998) In the early 1990s, CAD/CAM systems started being used in the production of implant abutments and frameworks, with the aim of facilitating their fabrication. Scientific evidence for CAD/CAM implant-supported restorations has been substantially demonstrated in most in vitro investigations, whereas the clinical outcomes of such protocols are still being investigated. Implant frameworks and abutments fabricated with CAD/CAM systems have been tested in various in vitro studies. In their study, Jemt et al. indicated a comparable fit of CAD/CAM-fabricated implant frameworks and conventional cast frameworks,(Jemt et al., 1999) whereas a few other studies have found the fit of CAD/CAM-fabricated implant frameworks to be statistically superior when compared to conventional cast frameworks.(Takahashi and Gunne, 2003)

CAD/CAM technology takes implant planning a step further, and enables fabrication of a surgical guide (Figure 6). The surgical guide directs the surgeon in the exact location and angulation to place the implant. Computer-assisted planning and use of CAM surgical guides dramatically increase the accuracy of implant placement, which directly improves the outcome of the final restoration. CAD/CAM allows the possibility of flapless surgery, which entails less bleeding, less swelling, decreased healing time, and post-operative pain.(Fortin et al., 2006)

Restorative Dentistry: Subsequent to operative and endodontic treatments, most general practitioners use crown and bridge restorations. Moreover, the recent introduction of osseointegrated implants has expanded the application of crown and bridge restorations to restore edentulous spaces.
Nowadays, we are in a new age of routinely providing all-ceramic restorations due to recently available materials such as polycrystalline alumina, highly sintered glass, zirconia-based ceramic materials, and adhesive monomers. (Anusavice, 2003) Furthermore, new fabrication systems combined with a computer-assisted fabrication system (dental CAD/CAM) and networks are becoming increasingly available.(Miyazaki et al., 2009) It is estimated that in 2007, more than 33 million crowns, 10 million bridges, and 3 million veneers were provided to patients in the United States.(iData Research Inc, 2007) Inlays represent a very small portion of all fixed restorations, an estimated 3% in 1999.(American Dental Association) While all these fixed restorations can be fabricated using current CAD/CAM technology, using traditional chairside techniques followed by traditional laboratory techniques to fabricate the restoration continues to be more common. Since inception of the CAD/CAM era in dentistry, CAD/CAM technologies have been used in restorative dentistry increasingly. Currently, restorations that can be prepared using CAD/CAM are:

- inlays, onlays
- veneers
- copings
- substructures
- full coverage crowns

Chairside CAD/CAM has been found in numerous studies to offer accuracy. In 2003 a study found that 47% of 2,328 restoration margins were underfilled and had a 95% probability of nine-year survival.(Posselt and Kerschbaum, 2003) Using Vita Mark I feldspathic ceramic as the restorative material, Otto and Schneider(Otto and Schneider, 2008) found an 88.7% success rate up to 17 years after placement for 187 inlays and onlays placed using an early-generation chairside CEREC between 1989 and 1991. There were 21 failures, for which the most common reason was ceramic fracture. Wiedhahn et al.(Wiedhahn et al., 2005) found that CAD/CAM veneers offered good clinical results and success rates. Of 617 veneers placed over an eight-year period (1989-1997) and then re-evaluated, the survival rate was 94% after up to nine years; of these veneers, 98% were clinically acceptable.

Future of CAD/CAM

In the last three decades, dental technologies and materials have improved dramatically, especially prosthodontics and operative dentistry. Due to increasing use of CAD/CAM systems, advantages have outshined disadvantages. Many developments are expected from CAD/CAM systems in the future. Rapid development in current systems and the introduction of new systems show increasing user-friendliness, expanded capabilities, and improved quality, and range in complexity and application. Materials produced in these systems are also more aesthetic, wear properties more like enamel, and are strong enough for full crowns and bridges.(Liu, 2005) Scanning, designing and milling devices are expected to become increasingly simple and convenient to use. In anticipation of future advances, some CAD/CAM systems are prepared for voice control and voice output.(Tyas, 2005) Another potential use of dental CAD/CAM systems could be in low-income countries where laboratories and skilled ceramists might not be readily available.(Preston and Duret, 1997) CAD/CAM technology could allow technicians to do much of the work, and restorations could be created on the spot.(Liu, 2005)

The use of CAD/CAM systems in the dental area ensures an innovative, state-of-the-art dental service to patients and is also beneficial for general practitioners. It should be noted that conventional laboratory technology and dental technician skills are still important because dental restoration and prostheses are not just industrial products, but medical devices that need to function in the body. Recent and conventional technology, therefore, must be combined to meet patient demand.(Miyazaki and Hotta, 2011)

Table-1 CAD/CAM Systems and Digital Impression (Feuerstein)

	CEREC	E4D	iTero	LAVA COS
Full-arch digital impression	Yes	No	Yes	Yes
Powdering required	Yes	Sometimes	No	Some
Acquisition Technology	Blue light LED	Red light laser	Confocal	Blue light Led Video
In-Office Milling	Yes	Yes	No	No
Connectivity to Labs	Yes	No	Yes	Yes
Restoration Design (CAD) Software	Yes	Yes	No	No

Table 2. Restorations and Material options in CAD/CAM Systems(Miyazaki et al., 2009)

CAD/CAM SYSTEM	RESTORATION TYPES				MATERIAL OPTIONS				
	Veneers	Inlays / Onlays	Crowns/ Single Unit Cores	Bridges / Frame-works	Ceramic-Alumina	Ceramic-Zirconia	Other Ceramics	Metal Alloys/ Titanium	Composites/ Acrylics/ Other
CEREC 3D Sirona, Bensheim, Germany "www.sirona.de"	x	x	x				x		
CEREC InLab Sirona, "www.sirona.de"	x	x	x	x	x	x	x	—	x

Cercon Degudent, Frankfurt, Germany "www.degudent.de"			x	x		x			
Decim Cad.esthetics AB, Skellefteâ, Sweden "www.cadesthetics.com"		x	x	x		x			
Evolution 4D* D4D Technologies, Richardson, Texas "www.d4dtech.com"									
etkon etkon AG, Grafelfingen, Germany "www.etkon.de"			x	x	x	x		x	x
Everest Kavo, Leutkirch, Germany "www.kavo-everest.com"	x	x	x	x	x	x	x	x	x
GN-1 GC International, Tokyo "www.gcdental.co.jp/cadcam/index.html"			x	x	x	x	x	x	x
DigiDent DentaCAD Hint-ELs, Griesheim, Germany "www.hintel.de"			x	x	x	x		x	x
Lava 3M ESPE, Seefeld, Germany "http://cms.3m.com/cms/US/en/2-21/kzikuFW/view.jhtml"			x	x		x			
Medifacturing BEGO Medical AG, Bremen, Germany "www.bego-medical.de"			x	x		x		x	
Precident DCS DCS AG, Allschwil, Switzerland "www.dcs-dental.com"			x	x	x	x	x	x	x
Procera Nobel Biocare, Göteburg, Sweden "www.nobelbiocare.com"	x		x	x	x	x		x	
Pro 50 Cynovad, Saint-Laurent, Quebec "www.cynovad.com"	x	x	x	x	x	x	x	x	x
Wol-Ceram Wol-Dent, Ludwigshafen, Germany "www.wolzdental.com"			x	x	x				
ZENO Tec Wieland Dental + Technik GmbH, Pforzheim, Germany "www.wieland-dental.de"			x	x		x		x	x

Table 3. Resin Materials for CAD/CAM

Name	Manufacturer	CAD/CAM system	Description
CAD-Waxx	Vita	inLab	Filler-free acrylic polymer for lost wax technique
Cercon base cast	DeguDent	Cercon	Residue-free cauterisable resin for lost wax technique
Everest C-Cast	KaVo	Everest	Residue-free cauterisable resin for lost wax technique
CAD-Temp Block	Vita	Cerec 3, inLab	Fibre-free acrylic polymer with micro-filler for long-term temporary full and partial crowns and FPDs up to two pontics
Everest C-Temp	KaVo	Everest	Fibre reinforced polymer for long-term temporary crowns and FPD frameworks, requiring an additional veneering
Artegral imCrown	Merz	Cerec 3, inLab	Semi individual blanks for anterior long-term provisional single crowns

Table 4. CAD/CAM Systems for Zirconia and other materials

CAD/CAM system (Manufacture)	In	Veneer	Cr	Br	Resin	Titanium	Gold	Ceramic	Alumina	Zirconia
Etkon® (Etkon AG)			Y	Y	Y	Y	Y	Y		Y
Everest® (KaVo electrotechnical work GmbH)	Y	Y	Y	Y		Y		Y		Y
Lava® (3M ESPE Dental AG)			Y	Y		Y		Y		Y
Pro 50, WaxPro® (SYNOVAD)			Y	Y		Y	Y	Y		Y
Procera® (Nobel Biocare Germany GmbH)		Y	Y	Y		Y		Y	Y	Y
Hint ELs DentaCAD system® (Hint-ELs GmbH)			Y	Y	Y	Y				Y
KATANA system® (Noritake dental supply co.,LTD)			Y	Y						Y
Cercon smart ceramics® (DeguDent GmbH)			Y	Y						Y
CEREC3®/inLab® (Sirona Dental of system GmbH)	Y	Y	Y	Y				Y		Y
DCS Dental® (DSC Dental AG)	Y	Y	Y	Y	Y	Y		Y		Y
ZENO® Tec System (Wieland Dental & Technik GmbH)			Y	Y	Y	Y			Y	Y

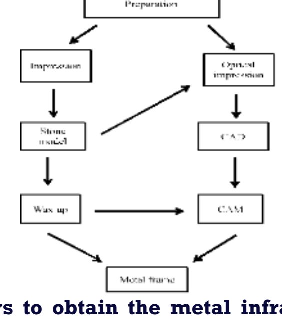

Figure 1. Ways to obtain the metal infrastructure with CAD/CAM Systems

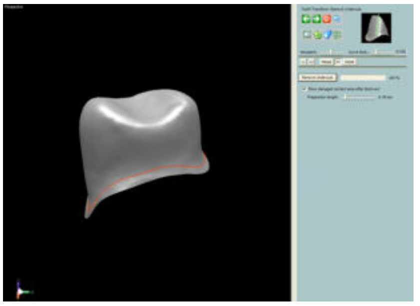

Figure 2. CAD Software in System

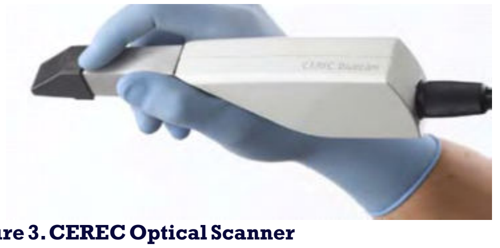

Figure 3. CEREC Optical Scanner

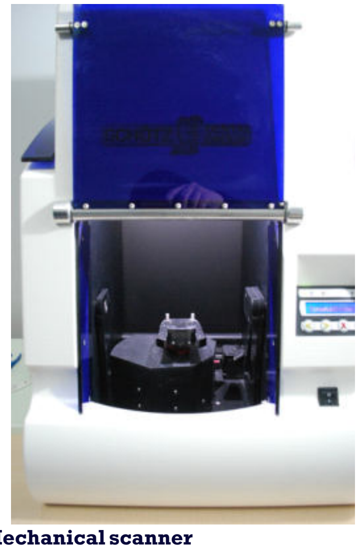

Figure-4 Mechanical scanner

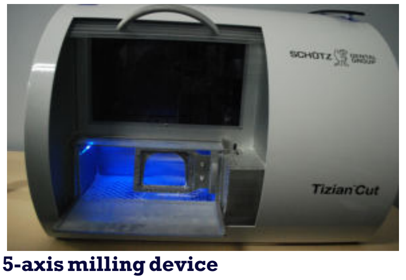

Figure 5: 5-axis milling device

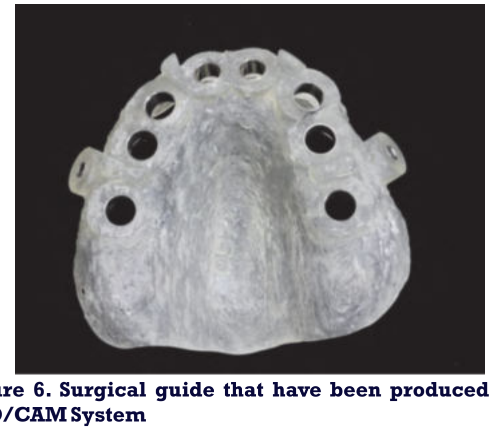

Figure 6. Surgical guide that have been produced with CAD/CAM System

REFERENCES

1. American Dental Association 1999 Survey of Dental Services Rendered.
2. American Machinist (1998). The CAD/CAM hall of fame: http://www.Americanmachinist.Com/304/Issue/Article/False/9168/Issue.
3. Andersson M, Bergman B, Bessing C, Ericson G, Lundquist P, Nilson H (1989). Clinical results with titanium crowns fabricated with machine duplication and spark erosion. *Acta Odontol Scand* 47(5):279-286.
4. Andersson M, Oden A (1993). A new all-ceramic crown. A dense-sintered, high-purity alumina coping with porcelain. *Acta Odontol Scand* 51(1):59-64.
5. Andersson M, Carlsson L, Persson M, Bergman B (1996). Accuracy of machine milling and spark erosion with a CAD/CAM system. *J Prosthet Dent* 76(2):187-193.
6. Anusavice KJ (2003). Dental ceramics. In: Phillips' science of dental materials. KJ Anusavice and RW Phillips editors. St. Louis, Mo. ; [Great Britain]: Saunders, pp. xxv, 805 p.
7. Beuer F, Schweiger J, Edelhoff D (2008). Digital dentistry: an overview of recent developments for CAD/CAM generated restorations. *Br Dent J* 204(9):505-511.
8. Birnbaum NS, Aaronson HB, Stevens C, Cohen B (2009). 3D digital scanners: a high-tech approach to more accurate dental impressions. *Inside Dentistry* 5(4).
9. Branemark PI, Albrektsson T (1982). Titanium implants permanently penetrating human skin. *Scand J Plast Reconstr Surg* 16(1):17-21.
10. Ciocca L, Mingucci R, Gassino G, Scotti R (2007). CAD/CAM ear model and virtual construction of the mold. *J Prosthet Dent* 98(5):339-343.
11. Davidowitz G, Kotick PG (2011). The use of CAD/CAM in dentistry. *Dent Clin North Am* 55(3):559-570, ix.
12. Duret F, Blouin JL, Duret B (1988). CAD-CAM in dentistry. *J Am Dent Assoc* 117(6):715-720.
13. Fasbinder DJ, Dennison JB, Heys DR, Lampe K (2005). The clinical performance of CAD/CAM-generated composite inlays. *J Am Dent Assoc* 136(12):1714-1723.
14. Feng ZH, Dong Y, Bai SZ, Wu GF, Bi YP, Wang B *et al.* (2010). Virtual transplantation in designing a facial prosthesis for extensive maxillofacial defects that cross the facial midline using computer-assisted technology. *Int J Prosthodont* 23(6):513-520.
15. Feuerstein P An Overview of CAD/CAM and Digital Impressions. http://wwwineedcecom/coursereviewaspx?url=2042%2fPDF%2f1103cei_cadcampdf&scid=14490.
16. Fortin T, Bosson JL, Isidori M, Blanchet E (2006). Effect of flapless surgery on pain experienced in implant placement using an image-guided system. *Int J Oral Maxillofac Implants* 21(2):298-304.
17. Friberg B, Jemt T (2010). Rehabilitation of Edentulous Mandibles by Means of Four TiUnite™ Implants after One-Stage Surgery: A 1-Year Retrospective Study of 75 Patients. *Clinical Implant Dentistry and Related Research* 12(e56-e62.
18. Henkel GL (2007). A comparison of fixed prostheses generated from conventional vs digitally scanned dental impressions. *Compend Contin Educ Dent* 28(8):422-424, 426-428, 430-421.
19. Heydecke G, Sierraalta M, Razzoog ME (2002). Evolution and use of aluminum oxide single-tooth implant abutments: a short review and presentation of two cases. *Int J Prosthodont* 15(5):488-493.
20. Hikita K, Uchiyama Y (1989). Studies on three dimensional measurement and restoration of tooth crown form by CAD/CAM. *J Jpn Prosthondont Soc* 33(S82):142.
21. iData Research Inc (2007). U.S. Market for Dental Prosthetic Devices.
22. Jemt T, Back T, Petersson A (1999). Precision of CNC-milled titanium frameworks for implant treatment in the edentulous jaw. *Int J Prosthodont* 12(3):209-215.
23. Kanazawa M, Inokoshi M, Minakuchi S, Ohbayashi N (2011). Trial of a CAD/CAM system for fabricating complete dentures. *Dent Mater J* 30(1):93-96.
24. Kawahata N, Ono H, Nishi Y, Hamano T, Nagaoka E (1997). Trial of duplication procedure for complete dentures by CAD/CAM. *J Oral Rehabil* 24(7):540-548.
25. Liu PR (2005). A panorama of dental CAD/CAM restorative systems. *Compend Contin Educ Dent* 26(7):507-508, 510, 512 passim; quiz 517, 527.
26. Maeda Y, Minoura M, Tsutsumi S, Okada M, Nokubi T (1994). A CAD/CAM system for removable denture. Part I: Fabrication of complete dentures. *Int J Prosthodont* 7(1):17-21.
27. May KB, Russell MM, Razzoog ME, Lang BR (1998). Precision of fit: the Procera AllCeram crown. *J Prosthet Dent* 80(4):394-404.
28. Miyazaki T, Hotta Y, Kunii J, Kuriyama S, Tamaki Y (2009). A review of dental CAD/CAM: current status and future perspectives from 20 years of experience. *Dent Mater J* 28(1):44-56.
29. Miyazaki T, Hotta Y (2011). CAD/CAM systems available for the fabrication of crown and bridge restorations. *Aust Dent J* 56 Suppl 1(97-106.
30. Mormann WH, Brandestini M, Lutz F, Barbakow F (1989). Chairside computer-aided direct ceramic inlays. *Quintessence Int* 20(5):329-339.
31. Otto T, Schneider D (2008). Long-term clinical results of chairside Cerec CAD/CAM inlays and onlays: a case series. *Int J Prosthodont* 21(1):53-59.
32. Posselt A, Kerschbaum T (2003). Longevity of 2328 chairside Cerec inlays and onlays. *Int J Comput Dent* 6(3):231-248.
33. Preston JD, Duret F (1997). CAD/CAM in dentistry. *Oral Health* 87(3):17-20, 23-14, 26-17.
34. Rasperini G, Maglione M, Cocconcelli P, Simion M (1998). In vivo early plaque formation on pure titanium and ceramic abutments: a comparative microbiological and SEM analysis. *Clin Oral Implants Res* 9(6):357-364.
35. Reiss B (2007). Cerec standard 3-d occlusal contouring in comparison with the new biogeneric occlusal morphing: a case report. *Int J Comput Dent* 10(1):69-75.
36. Rekow D (1987). Computer-aided design and manufacturing in dentistry: a review of the state of the art. *J Prosthet Dent* 58(4):512-516.
37. Russell MM, Andersson M, Dahlmo K, Razzoog ME, Lang BR (1995). A new computer-assisted method for fabrication of crowns and fixed partial dentures. *Quintessence Int* 26(11):757-763.
38. Sjogren G, Molin M, van Dijken JW (2004). A 10-year prospective evaluation of CAD/CAM-manufactured (Cerec) ceramic inlays cemented with a chemically cured or dual-cured resin composite. *Int J Prosthodont* 17(2):241-

246.
39. Suttor D, Bunke K, Hoescheler S, Hauptmann H, Hertlein G (2001). LAVA--the system for all-ceramic ZrO2 crown and bridge frameworks. *Int J Comput Dent* 4(3):195-206.
40. Takahashi T, Gunne J (2003). Fit of implant frameworks: an in vitro comparison between two fabrication techniques. *J Prosthet Dent* 89(3):256-260.
41. Turkyilmaz I, Nicoll RJ (2011). State-of-the-Art Technology in Implant Dentistry: CAD/CAM. In: Implant Dentistry - A Rapidly Evolving Practice. I Turkyilmaz editor.
42. Tyas MJ (2005). Placement and replacement of restorations by selected practitioners. *Aust Dent J* 50(2):81-89; quiz 127.
43. Vult von Steyern P, Jonsson O, Nilner K (2001). Five-year evaluation of posterior all-ceramic three-unit (In-Ceram) FPDs. *Int J Prosthodont* 14(4):379-384.
44. Webber B, McDonald A, Knowles J (2003). An in vitro study of the compressive load at fracture of Procera AllCeram crowns with varying thickness of veneer porcelain. *The Journal of Prosthetic Dentistry* 89(2):154-160.
45. Wiedhahn K, Kerschbaum T, Fasbinder DF (2005). Clinical long-term results with 617 Cerec veneers: a nine-year report. *Int J Comput Dent* 8(3):233-246.
46. Williams RJ, Bibb R, Rafik T (2004). A technique for fabricating patterns for removable partial denture frameworks using digitized casts and electronic surveying. *J Prosthet Dent* 91(1):85-88.
47. Williams RJ, Bibb R, Eggbeer D, Collis J (2006). Use of CAD/CAM technology to fabricate a removable partial denture framework. *J Prosthet Dent* 96(2):96-99.