

## MINI REVIEW

# Evolution of the Software and Hardware in CAD/CAM Systems used in Dentistry

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## ABSTRACT

The computer-aided design/computer-aided manufacturing (CAD/CAM) systems were introduced into dentistry in 1970s. This technology has evolved rapidly that, starting from a single crown to full mouth, rehabilitation is possible in a single day now. This article reviews the history, evolution, components, and various materials used for fabrication of prosthesis. It also evaluates popular CAD/CAM systems, its limitations, future involvement, and also the dental considerations while using them.

**Keywords:** CAD/CAM systems, Cerec system, Digitalization tool, Evolution of CAD/CAM, Milling in CAD/CAM.

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## INTRODUCTION

Computer-aided design (CAD) and computer-aided manufacturing (CAM) have become an increasingly popular part of dentistry over the past 25 years.<sup>1</sup> The CAD/CAM technology was developed to solve three challenges. One of the challenges was to fabricate posterior restorations with sufficient strength. The second challenge was to create restorations with a natural appearance. The third challenge was to make restoration easier, faster, and more accurate.<sup>2</sup> With recent versions of CAD/CAM systems it is possible to make half-arch impressions in 40 seconds and full-arch impressions in just 2 minutes. The CAD/CAM also makes designing and fabrication faster than a full-contour crown takes just 6 minutes to mill. Even by experienced technicians it takes multiple days to finish conventional restorations.<sup>3-5</sup>

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## HISTORY AND EVOLUTION OF DENTAL CAD/CAM SYSTEMS

1970s saw rapid progress being made in computer-assisted processing technology in various industries and this was reflected in the field of dentistry also. Nickel-chromium alloys became a substitute for gold alloys in 1980s due to increase in the price of gold. But, metal allergies became a problem, especially in northern Europe, and a transition to allergy-free titanium was proposed. The precision casting of titanium was still difficult at that time.<sup>6</sup> There was a strong requirement for an alternative technique. Three pioneers in particular who contributed to the development of dental CAD/CAM systems are Duret, Moermann, and Anderson. Duret developed the Sopha<sup>®</sup> system, which had an impact on the later development of dental CAD/CAM systems. He produced the first dental CAD/CAM restoration in 1983 and demonstrated his system at the French Dental Association's International Congress in November 1985 by creating a posterior crown restoration for his wife in less than an hour.<sup>5</sup> Sopha system was developed by Duret.<sup>3</sup> Dr Moermann developed the CEREC<sup>®</sup> system, which was a chairside CAD/CAM. The emergence of this system was very innovative because it allowed same day ceramic restorations. This was a turning point and it spread the term CAD/CAM.<sup>6</sup> The third is Dr Andersson, the developer of the Procera<sup>®</sup> system in 1983. Procera<sup>®</sup> system had central processing center with satellite networking centers under this unit. Rekow<sup>7</sup> used photographs and high-resolution scanners to capture the data to mill restorations by a five-axis machine.<sup>6</sup>

## COMPONENTS OF CAD/CAM SYSTEM

### Digitalization Tool/Scanner

Geometrical data will be transformed into digital data by a digitalization tool to process in a computer. The digitizing accuracy is a major factor, which has an influence on the fit of fixed restoration. Currently, the data acquisition is either performed directly in the patient's mouth (intraoral) or indirectly after taking an impression and fabricating a master cast (extraoral). Triangulation is a procedure by which three-dimensional data will be collected by the computer.<sup>8</sup> Digitalization can be contact digitalization (Fig. 1)<sup>8</sup> or optical digitalization (Fig. 2).<sup>8</sup> A

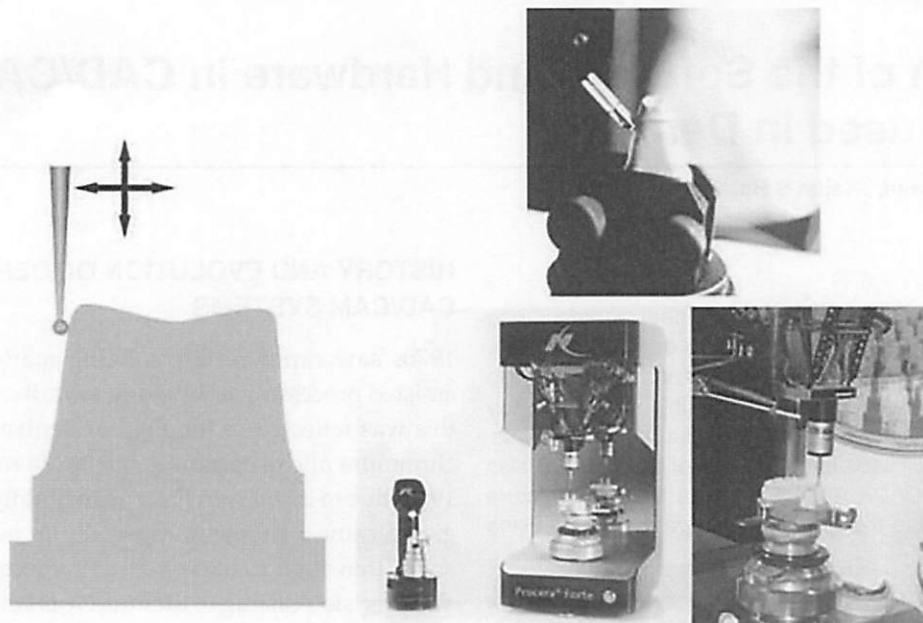


Fig. 1: Contact digitalization

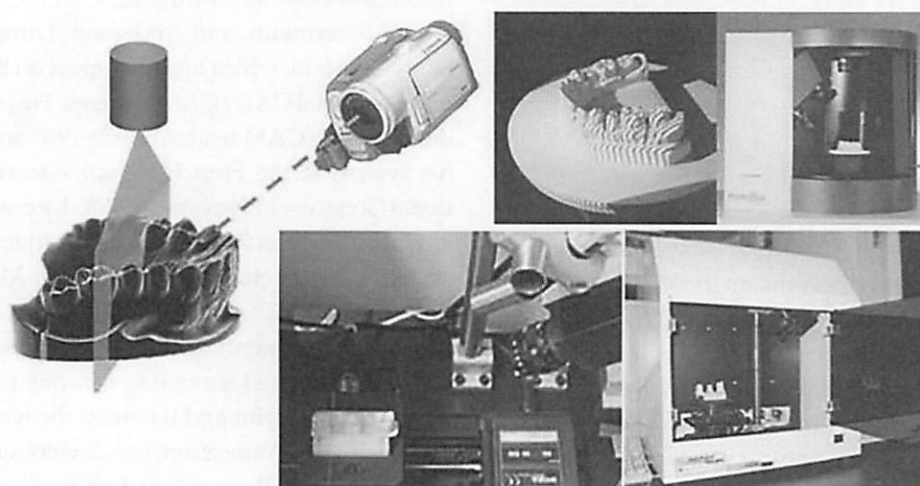


Fig. 2: Optical digitalization

fine-tipped probe is used as the contact probe; even if it is very precise, it takes time to scan. The Procera Scanner from Nobel Biocare (Göteborg) is the only example for mechanical scanners in dentistry.<sup>6</sup> 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. The 3D scanners usually consist of a light source, one or more cameras, and a motion. The light source projects the light onto the surface of the object, and the camera(s) captures the images. Based on the known angle and distance between camera and light source (jointly called the scan head), the 3D position(s) where the projected light is reflected can be calculated using trigonometry. This is known as "triangulation."<sup>9-12</sup> Special software are provided by the

manufacturer to process the data for the design of various kinds of dental restorations. The software of CAD/CAM systems presently available on the market is being continuously improved. The latest construction possibilities are continuously available to the user by means of updates. Even though the data for the construction can be stored in various data formats, it is often stored as standard transformation language data.<sup>13</sup>

### Production Technology

#### *Additive Technique by Applying Material on Die*

Alumina or zirconia is dry pressed on the die and the temperature is raised to a level, i.e., similar to the presintering state. Its outer surface is milled to the desired shape, the coping is removed from the die, and sintered in the furnace.

### **Subtractive Technique from a Solid Block**

The CAM technique most commonly applied for single crowns and fixed partial dentures (FPDs) is to cut the contour out of an industrially prefabricated solid block of material.<sup>14</sup>

### **Milling in CAD/CAM**

A production technology that transforms the set data into a desired product. Three-axis devices, four-axis devices, and five-axis devices enable the milling of complex geometries with subsections.<sup>13</sup>

### **Dry Processing**

Dry processing is used with zirconium oxide blanks with a low degree of presintering and these results in higher shrinkage of the frameworks. Some manufacturers also offer the option of milling resin material in a dry milling process [Zeno 4030 (Wieland-Imes), Lava Form and Cercon brain].<sup>13</sup>

### **Wet Milling**

A spray of cool liquid protects the milling diamond or carbide cutter against overheating of the milled material. This kind of processing is necessary for all metals and glass ceramic material in order to avoid damage through heat development. "Wet" processing is recommended, if zirconium oxide ceramic with a higher degree of presintering is employed for the milling process. Examples: Everest (KaVo), Zeno 8060 (Wieland-Imes), InLab (Sirona).<sup>13</sup>

### **Spark Erosion**

Electric current under carefully controlled conditions is used for the metal removal process. It is used in fabrication of fixed, removable, and implant prostheses.<sup>15</sup>

### **Three-dimensional Printing**

It is another manufacturing approach to build objects, one layer at a time and adding multiple layers to form an object. It is also known as additive manufacturing or rapid prototyping (RP).<sup>16,17</sup> It may be used for the fabrication of metal structures either indirectly by printing in burn-out resins or waxes for a lost-wax process, or directly in metals or metal alloys like FPD and removable partial denture (RPD), polymerized prostheses, and silicon prosthesis.

### **Selective Laser Sintering**

A scanning laser fuses a fine material powder, to build up structures layer by layer, as a powder bed drops down incrementally, and a new fine layer of material is evenly

spread over the surface. Resolution as high as 60  $\mu\text{m}$  may be obtained, and the structures printed are supported by the surrounding powder.<sup>18-20</sup>

### **Stereolithography (SLA)**

Light-sensitive polymer cured layer by layer by a scanning laser in a vat of liquid polymer. It is a widely employed RP technology. It was invented by Charles Hull. It is an additive manufacturing process in which a liquid photocurable resin acrylate material is used. Stereolithography uses a highly focused Ultraviolet (UV) laser to trace out successive cross-sections of a 3D object in a vat of liquid photosensitive polymer.<sup>21</sup>

### **Photojet**

Light-sensitive polymer is jetted and cured layer by layer on an incrementally descending platform.

### **Digital Light Processing**

Liquid resin is cured layer by layer by a projector light source. The object is built upside down with multiple increments.<sup>21</sup>

### **Powder Binder**

Plaster or cementaceous material is set by drops from "inkjet" print head. Object will be built layer by layer in a powder bed.<sup>21</sup>

### **Fused Deposition Modeling**

First 3D printing is most used in "home" printers. Thermoplastic material extruded through nozzle onto built platform.<sup>22</sup>

## **CAD/CAM PRODUCTION: AN OVERVIEW**

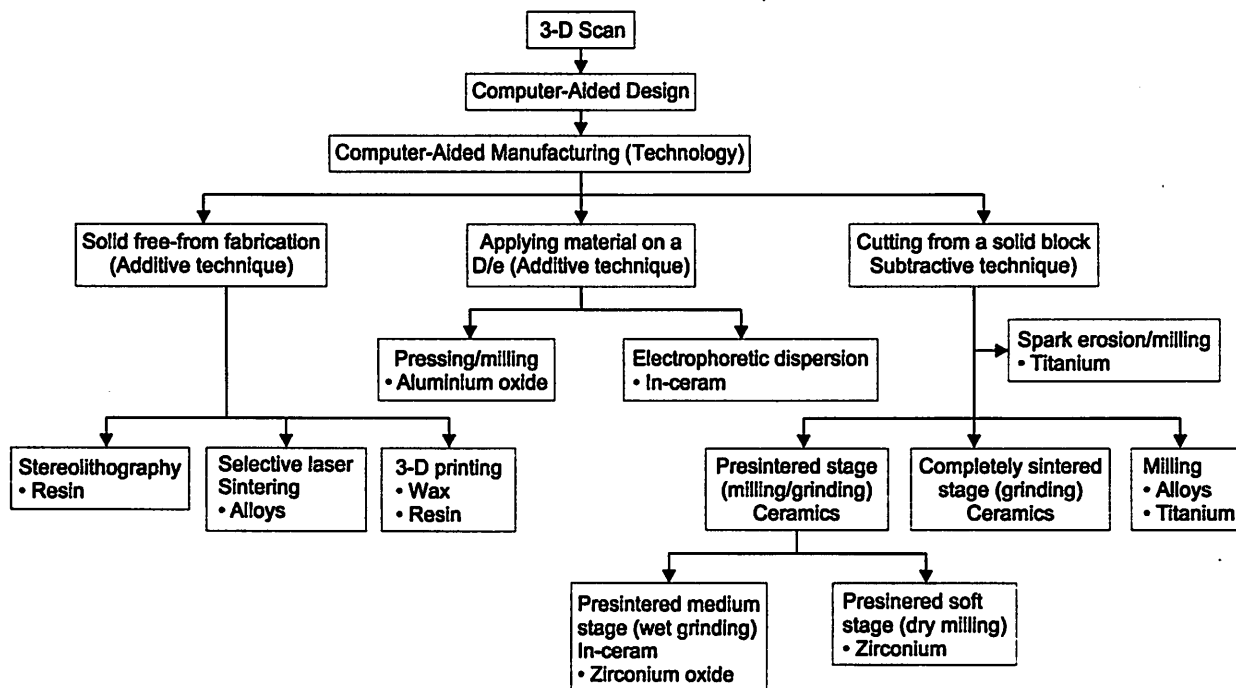
The CAM employs computer-generated paths to construct an object. A diverse set of technologies have been used to create dental restorations (Flow Chart 1).<sup>23</sup>

## **CLASSIFICATION OF DENTAL CAD/CAM SYSTEMS**

Based on production methods, CAD/CAM systems are divided as follows:

- *In office systems:* Most popular and accepted is Cerec system. It scans the tooth preparation intraorally and with this system the dentist can fabricate the restorations in the same appointment.<sup>24</sup>
- *CAD/CAMs for dental laboratory models:* These indirect systems scan a stone cast or die of the prepared tooth, in the dental lab (e.g., Cerec-in lab). Many of these systems produce copings which require the dental

Flow Chart 1: Overview of CAD/CAM production



technician to add esthetic porcelain for individualization and characterization of the restoration.<sup>24</sup>

- *CAD/CAM for outsourcing:* "Satellite scanners" situated in the dental laboratory will be connected to a production center via the internet. Data sets produced in the dental laboratory are sent to the production center for the restorations to be produced with a CAD/CAM device. The benefit of outsourcing CAM production is found to be in the small investment requirement, since only the digitalization tool and software have to be purchased, still having access to a high-quality production process.<sup>24</sup>

**WORKFLOW OF DENTAL CAD/CAM SYSTEMS**

The workflow of the CAD/CAM systems can be summarized as below (Fig. 3).<sup>23</sup>

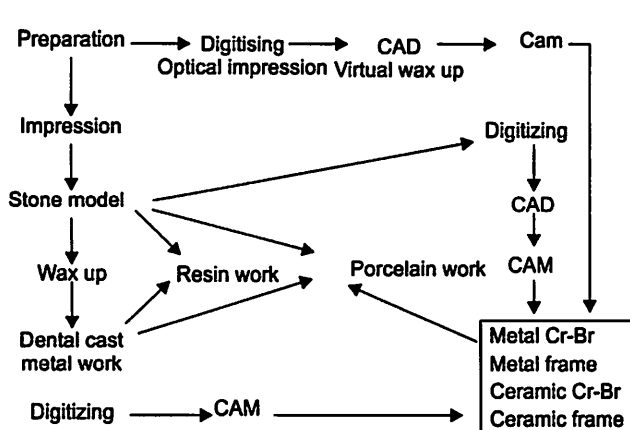


Fig. 3: Workflow of dental CAD/CAM systems

**Evolution of CAD/CAM Systems**

- *First generation (Fig. 4)*<sup>25</sup>: The final crown is fabricated by milling a block using a numerically controlled machine.<sup>25</sup>
- *Second generation (Fig. 5)*<sup>25</sup>: Digitizers, such as contact probe 8, laser beam with a position sensitive device sensor, and a laser with a charge-coupled device camera are used. Sophisticated CAD software and compact dental CAD/CAM machines were also developed. Consequently, both metallic and ceramic restorations were able to be fabricated by the second-generation CAD/CAM systems.<sup>25-34</sup>
- *Third generation (Fig. 6)*<sup>25</sup>: Since these high strength industrial ceramics were not available to conventional dental laboratories, the application of networked

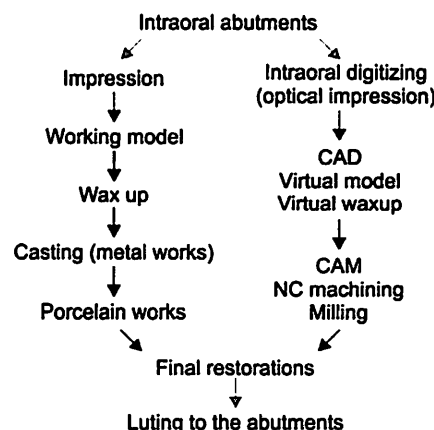


Fig. 4: First-generation CAD/CAM systems – workflow

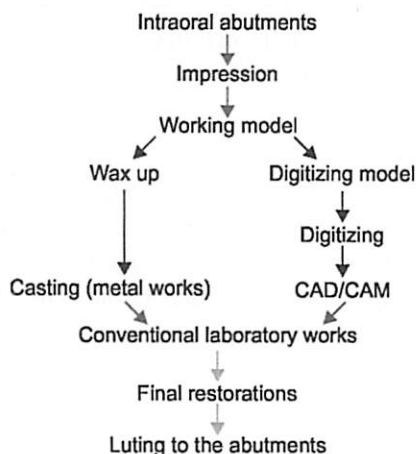


Fig. 5: Second-generation CAD/CAM systems workflow

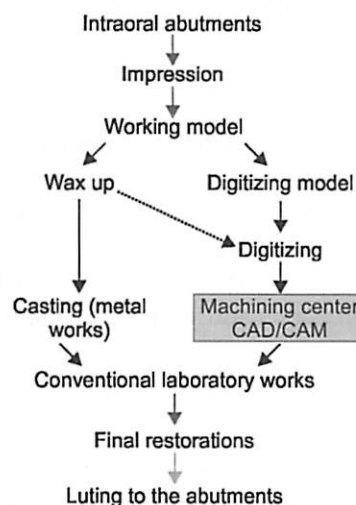


Fig. 6: Third-generation CAD/CAM systems workflow

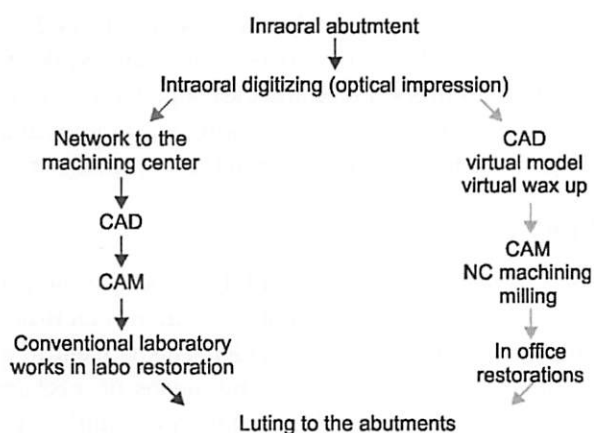


Fig. 7: Fourth-generation CAD/CAM systems workflow

CAD/CAM in a processing center was innovative in the history of dental technology. Such networked production systems are currently being introduced by a number of companies worldwide. Zirconia frameworks are now very popular in the world market. The framework is fabricated by CAD/CAM technology and final restorations are completed by veneering conventional porcelain used by dental technicians.<sup>25,34-37</sup>

- *Fourth generation (Fig. 7)*<sup>25</sup>: The application of dental CAD/CAM systems is expected to shift to the fourth generation, as illustrated.<sup>24,35-37</sup>

**MATERIALS USED FOR CAD/CAM SYSTEMS**

- *Metals*: At present, titanium, titanium alloys, and chrome cobalt alloys are processed using dental milling devices.<sup>13</sup>
- *Resin materials*: Resin materials can be directly used as crown and FPD frameworks as long-term provisional or long-term temporary prostheses. Example is Paradigm MZ100 (3M ESPE, St. Paul, Minnesota, USA).<sup>13</sup>
- *Silica-based ceramics*: Silica-based ceramic blocks are offered by several CAD/CAM systems for the fabrication of inlays, onlays, veneers, partial crowns, and full

crowns. Lithium disilicate ceramic blocks are highly stable. Glass ceramics are good for chairside application because of their translucent characteristics.<sup>13,38-41</sup>

- *Infiltrated ceramics*: Infiltration ceramics are manufactured in a porous, chalky condition and then infiltrated with lanthanum glass. All blanks for infiltration ceramics originate from the Vita In-Ceram system (Vita) and are offered in three variations:
  - *Vita In-Ceram Alumina (Al<sub>2</sub>O<sub>3</sub>)*: Suitable for crown copings in the anterior and posterior region; three-unit FPD frameworks in the anterior region.<sup>42,43</sup>
  - *Vita In-Ceram Zirconia (70% Al<sub>2</sub>O<sub>3</sub>, 30% ZrO<sub>2</sub>)*: Suitable for crown copings in the anterior and posterior region, three-unit FPD frameworks in the anterior and posterior region. This ceramic is suitable for discolored abutment teeth.<sup>42,43</sup>
  - *VITA In-Ceram Spinell (MgAl<sub>2</sub>O<sub>4</sub>)*: Has the highest translucency of all oxide ceramics and is thus recommended for the production of highly esthetic anterior crown copings, in particular on vital abutment teeth and in the case of young patients.<sup>42,43</sup>
- *Aluminum Oxide (Al<sub>2</sub>O<sub>3</sub>)*: This high-quality ceramic is ground initially and then sintered at a temperature of 1520°C. They are used for fabrication of copings, crowns in the anterior and posterior regions. It is also used for three-unit anterior FPD frameworks.<sup>13</sup>
- *Yttrium stabilized zirconium oxide (ZrO<sub>2</sub>, Y-TZP)*: Zirconium dioxide is a high-performance oxide ceramic with excellent mechanical characteristics. Its high flexural strength and fracture toughness compared with other dental ceramics offers the possibility of using this material as framework for crowns and FPDs, and, as an appropriate indication, for individual implant abutments.<sup>13</sup>



## POPULAR SYSTEMS

### Cerec System

This was introduced in 1987. It comes with digital scanning with a milling unit. The system enables dentists to cement restorations in a single visit. The earliest models produced inlays and onlays only, but the newest model, known as CEREC AC has the ability to take half-arch or full-arch impressions and create crowns, veneers, and bridges.<sup>44,45</sup>

### The E4D Dentist System

This was introduced in 2008. This is another system which permits cementation of restorations in the same visit. It comprises a laser scanner, called IntraOral Digitizer, a design center, and milling unit. As the scanner is small, patients do not need to open the mouth wide. The E4D system requires the use of powder in some but not in all cases. The office milling machine will then manufacture the restoration from the chosen blocks of ceramic or composite.<sup>2,46</sup>

### Cadent Introduced iTero

In 2007, it was developed as the first digital impression system for conventionally manufactured crowns and bridges. In order to capture the data, iTero employs parallel confocal imaging. The device projects red laser light and captures the reflected light to transform into digital data. This technology allows scans to be taken without coating the teeth in powder.<sup>46-48</sup>

### The Lava

This was introduced in 2008. The system includes a mobile cart, a touch screen display, and a scanner with a camera at the end. The camera consists of light-emitting diodes (LEDs) and lens systems. It uses active wavefront sampling to capture images. After signing off on the scans, the data are sent through wireless to the laboratory, where the die is cut and the margin marked digitally.

### Procera All Ceram System

It was launched in 1994. It is based upon an outsourced fabrication using a network connection. The master die is scanned and data sent to processing center. After fabrication, the coping will be sent back to the lab for porcelain veneering.<sup>6,24</sup>

### DCS Precident

Comprises a Preciscan laser scanner and Precimill CAM multitool milling center. It can scan 14 dies simultaneously and mill up to 30 framework units in one fully

automated operation. It can mill titanium as well as fully dense sintered zirconia.<sup>6,24,25</sup>

### CICERO System

It incorporates optical scanning, sintering, and milling. Basic reconstruction includes layered life like ceramic for natural esthetics, a precision milled occlusal surface, and a machined high strength ceramic core. The aim of CICERO is to mass produce ceramic restoration at one integrated site.<sup>6,24,25</sup>

### Cercon

It is used for the fabrication of zirconia-based prostheses. Impression of the abutment teeth is made and sent to the laboratory, to make a model. A wax pattern is made for each coping or the crown areas of the framework of a FPD. The pattern is scanned and the blank is rough-milled and fine-milled on occlusal and gingival aspects in an enlarged size to compensate for the 20% shrinkage.<sup>6,24,25</sup>

### CELAY System

This is developed by Dr Stefan I. Eidenberg at the University of Zurich. The model of restoration is fabricated using a resin on the master model. This is fixed in an attachment unit and is copied by means of mechanical sensing. Following this, restoration is milled. The degree of freedom and the interpretation of the CELAY system's reader allows it to shape any forms from industrially presintered ceramic blocks.<sup>6,24,25</sup>

## DENTAL CONSIDERATIONS

Even though the CAD/CAM systems possess lot of advantages, the dentist's working procedures will have to be adapted to the methods of CAD/CAM and milling technology. These include appropriate tooth preparations with the creation of a continuous preparation margin, which is clearly recognizable to the scanner. Based on the present knowledge, a tapered angle of between 4 and 10° is recommended. Subsections and irregularities on the surface of the prepared tooth as well as the "creation of troughs" with a reverse bevel preparation margin can be inadequately recognized by many scanners. In addition, sharp incisor and occlusal edges are to be rounded. Sharp edges cannot be milled exactly using rounded grinders in the milling device.<sup>13</sup>

## FUTURE TECHNOLOGIES

In future, prices should come down as dentists become familiar and comfortable with the new technology. This will popularize CAD/CAM systems for various application in dentistry like FPD and RPD. In anticipation of

future advances, the CEREC AC is prepared for voice output. Another important factor is that the prices should come down.<sup>2,6,13</sup>

## LIMITATIONS OF CAD/CAM

The powder layer applied to the tooth surface results in an additional thickness of 13 to 85 µm. The restricted measuring conditions in the mouth, including the presence of adjacent teeth, gingiva, and saliva, make accurate recognition of the margin of an abutment difficult. Regardless of the digitizing mode applied, clinical parameters, such as saliva, blood, or movements of the patient can affect the accurate reproduction of teeth. This has been a critical limitation of the system to fabricate final precision restorations. The CAD/CAM milling procedures may induce surface and subsurface flaws that may adversely affect the strength of this ceramic. Enhancement of strength (to approximately 160 MPa) can be acquired by a combination of polishing and glazing.<sup>2,13</sup>

## CONCLUSION

As Duret stated, "The systems will continue to improve in versatility, accuracy, and cost effectiveness and will be a part of routine dental practice in coming time". Incorporation of these systems into dental practice is yet limited. Dentists should get training and access to these systems, technologies, and developments. We must combine new and conventional technologies to meet the patient demands.

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