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CAD/CAM Technology Challenges in Prosthodontics

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ABSTRACT

Computer-Aided-Design/Computer-Aided-Manufacture or in short CAD/CAM technology is a revolutionary method which was utilized in dentistry in order to achieve more efficient and precise work that not only reduce time but also produce more patient satisfaction on the short and long term. Computer-Aided-Design (CAD) can be done by utilizing a specially designed software and an intraoral scanners or laboratory scanners which can construct a three dimensional image of scanned mouth or impression. Computer-Aided-Manufacture (CAM) on the other hand, can be done by subtractive or additive manufacturing. Subtractive manufacturing is done either by spark erosion or by a milling machine. Additive manufacturing on the other hand is made by layering technique in a step by step vertical buildup of the object or restoration. This review illustrates the indications, advantages, and limitations of CAD/CAM technology in construction of different types of restorations and the possible future of this technology.

Keywords: CAD/CAM, intra-oral scanners, laboratory scanners, subtractive manufacturing, additive manufacturing.

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Introduction and Brief History

In the science of dentistry there is a long history of trying restorations and prosthesis such as intra-coronal restorations, crowns, fixed bridges and removable partial dentures. During this century, the dental technologies and dental materials have been remarkably progressed. The recent technological methods are starting to replace the conventional laboratory methods such as lost wax casting methods and sintering of porcelains [1].

In 1971 Dr. Duret started the fabrication of crowns with functional occlusal surface utilizing optical impression technique of the abutments inside the patient's mouth. This was done by a milling machine that was numerically controlled. This was the evolution of the Sopha® System which was the corner stone for the development of CAD/CAM (Computer Aided Design/ Computer Aided Manufacturing) systems in dentistry [2].

On the other hand, in 1989 Dr. Moermann of Zurich University in Switzerland who is the developer of the CEREC system attempted to utilize a new technology in the clinic directly at the patient. Measurements were done to the prepared cavity utilizing an intra-oral camera. This was followed by using a compact machine to design then to carve the ceramic inlay immediately inside the clinic while the patient is waiting. After announcement for this system, the technology rapidly spread into dentistry [1].

CEREC system applications were initially restricted to inlays of ceramic. This allowed the early CAD/CAM system to be small and compact in size which contributed largely in its wide spread acceptance by the dentists [3].

Many problems were encountered during the early evolution of CAD/CAM system including the very high cost and the prolonged time of the procedure. Also, the difficulty in recognition of thin margins of the restoration and inability to construct more than a single unite restoration was an obvious limitation in this technology. These drawbacks encouraged researchers to further develop the system to become more accurate and efficient [4 5].

Andersson who is the developer of Procera® system utilized CAD/CAM technology to fabricate composite veneered restorations. He also noted that allergies from nickel-chromium alloys were quite common and the replacement of such alloy with titanium will be a good solution for the problem. But due to the difficult casting of titanium he utilized spark erosion with CAD/CAM technology for shaping titanium which was a great advancement in the technology at this time [6, 7]

In 1994 CEREC 2 was developed with more options for dental restorations. However, the milling in this system was still one bur system. The introduction of CEREC 3 with a two bur milling system and a three dimensional virtual editing display lead to further development of the technology [8].

Search strategy

An electronic search of articles from April 2019 to June 2019 was performed in two main databases: MEDLINE and the Embase Library. The search included only English-language publications with a focus on evidence based research articles. The search was focused on both randomized and nonrandomized controlled trials, longitudinal studies and retrospective studies. A list of keywords was used with different combinations as follows: “CAD-CAM,” “CAM,” “copy-milling,” “prosthodontics,” and “dental scanners”.

Classification of CAD/CAM Systems

The CAD/CAM systems are classified into chairside systems and laboratory systems. CAD/CAM can also be classified according to data sharing into closed and opened systems [9].

Chairside CAD/CAM systems are done inside the clinic in which the facility owns an image acquisition system (scanner) and milling machine. Sometimes, the facility only owns a scanner without any designing options. In this situation the scanner must have a communication with an open lab for designing and milling of restorations [10].

Laboratory systems can be classified into 3 types. The first is complete laboratory CAD/CAM system including a laboratory scanner and a milling machine. The second is the laboratory CAD system only without a milling machine in which is connected to another lab that owns a milling machine. The third is when the lab owns a milling machine only [9] [10]

Closed CAD/CAM systems do not allow interchange between different systems and brands from other companies. The acquisition of data by the scanner, the designing software, and the milling machine must be all made by the same company. On the other hand, open CAD/CAM systems allow STL files (Standard Tessellation Language files) to be read and milled on any other open system [10].

CAD/CAM systems can be also classified based on the production chain into: Direct, Semi-direct and Indirect CAD/CAM. Direct systems, which are also called chair-side or in office system are done by a specially designed 3D intra-oral camera or scanner, which captures the dental structures in 3D. After this process which is called image acquisition, the designing of the restoration begins on a specially designed software (CAD system). Finally, the process ends by manufacturing the restoration using a chair side milling machine (CAM system) at the same appointment. This reduces the number of appointments and increases patient satisfaction [11].

On the other hand, semi-direct CAD/CAM system can only take a 3D image of the dental structures and send this image to the laboratory as an STL file via a network. All the following steps including designing and manufacturing of the restoration is done in the lab and the final restoration is then delivered [12].

Finally, the indirect system as its name implies is done by taking a conventional impression using elastomeric materials and then it is sent to the laboratory. In the laboratory the impression is poured into a plaster cast then this cast is scanned using a specially designed 3D scanner. The design and manufacturing of the restoration is also done in the laboratory [11].

Classification of Scanners

Scanners for CAD/CAM systems can be classified into two types: intraoral scanners and laboratory scanners. Intraoral scanners can scan the tooth surfaces directly inside the oral cavity (i.e. optical impression) without the need for impression materials. This will reduce the clinical steps of the procedure and avoid feeling of discomfort or gagging by the patient [13]. Intraoral scanners utilize three technologies or methods. The first is the triangulation method in which light is projected on the body and then it is reflected back to be captured by a sensor. Both the projected and the reflected light are analyzed using special algorithms. Example for this technology is the CEREC scanner [14] [15]

The second method that is used in intraoral scanners is the confocal laser scanning. This method utilizes a red laser beam to scan the object. The reflected laser is the passed on a focal filter to allow only the image inside the focal point to reach the sensor. This requires continuous adjustment of the lens during the process of scanning. An example for this method is the iTero scanner [14] [16].

The third and final method is the active wave front sampling technique. In this method a three dimensional video system is used. The reflected images of the object are captured by multiple lenses in the scanner. Then the focal distance is measured when the image appear in focus by using a mathematical estimation formula. Example for this system is the Lava COS scanner [14] [17].

Some companies use non-reflective powder while video capturing to offer a uniform reflective surface, making video capturing more quick and easy. These reflective powders are made of titanium dioxide, which allows for assembly of multiple scans into one image. Example of such scanners are CEREC AC [18].

Laboratory scanners on the other hand, can be classified according to the type of object to be scanned into a model or cast scanner and an impression scanner. They can also be classified according to the type of technology into: optical scanners and mechanical scanners. A model or cast scanner can collect the data only from a poured cast. The impression scanner has the ability to scan directly the impression without cast pouring or trimming. Although this method reduces the time of production, a problem in some narrow areas within the depth of the impression may be encountered due to inability of the light of the scanner to reach these areas [10, 19].

The optical laboratory scanner is based on the same method utilized in the intraoral scanner, which is the triangulation method. A light source or laser beam may be used to scan the cast. Also the use of multiple cameras increases the accuracy of scanning. The data are then collected to form a three dimensional model which can be edited to design the restoration that perfectly fits the tooth preparation [20].

Another type of laboratory scanners is the mechanical scanner in which it utilizes a contact probe for scanning the object. The contact probe is very small in size to allow for an accurate recording of the fine details of the preparation. It has the advantage of high accuracy and precision. On the other hand, it requires a very long scanning time and complicated mechanics. This caused the cost of this technology to be very high. The only commercial example for this system is the Procera scanner [21, 22].

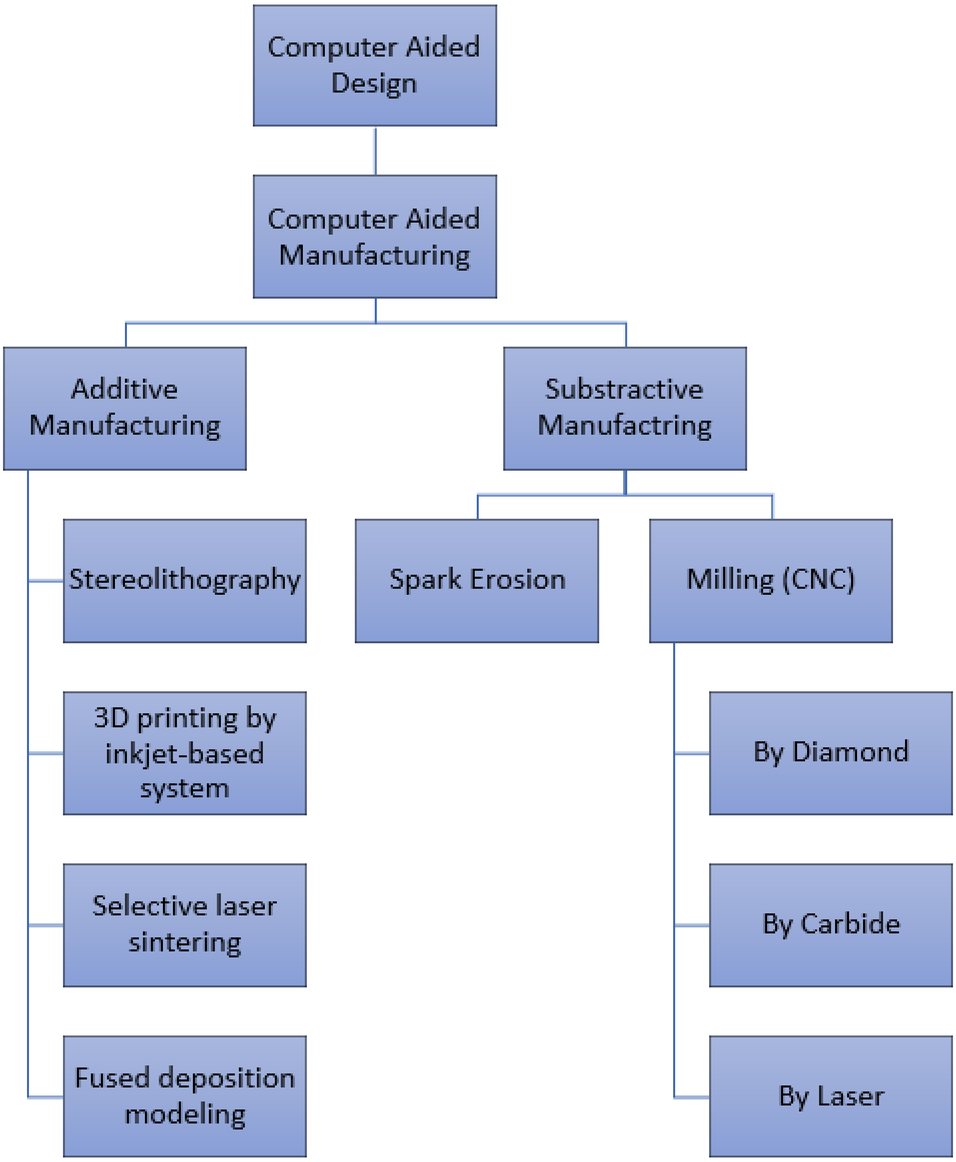
It is also possible to merge the three dimensional image of the teeth obtained from an intraoral or laboratory scanner with a 3 dimensional facial image obtained by stereophotogrammetry technique or cone beam computed tomography (CBCT) to generate a virtual model of the patient. This model can be integrated in some CAD/CAM systems to offer a virtual articulator simulation such as 3Shape TRIOS; 3Shape A/S [23 24, 25].

However, to be able to mount the virtual cast on a virtual articulator two methods could be utilized. The first is little complicated in which the actual mounted casts are scanned in position on a mechanical articulator to produce a 3D image of the articulator. This method of course does not solve the problem of mechanical articulators so it is only used for research and comparative studies. The second method is done by utilizing a digital facebow. This is done by scanning the position of a pointer in multiple positions with reference to the head. This allow for digital mounting of upper cast and as for the lower cast, mounting is done by scanning both the upper and lower dental arches in centric occlusion intraorally. This allows the operator to operate on the virtual articulator more easily and comfortably. It also allows for a far more accurate analysis and measurement of jaw movement with minimal time and effort [24, 26].

Subtractive Manufacturing versus Additive Manufacturing Systems

Subtractive manufacturing is a computerized shaping of a block made from certain material in which a software is used to design the restoration model and translate this design to a computerized machine (CAM) to achieve it [27]. It is done either by spark erosion or by a milling machine called computer numeric controlled (CNC) machine which utilizes 3 methods for milling. The first method is by utilizing diamond grinding technique, the second method is by carbide milling and the third and most recent is laser milling. The spark erosion is a method in which sparks are generated to remove the material form a metal block. However, the accuracy and fit must be compensated during milling to reach the desired size without any magnifications, shrinkage or distortion in shape [28].

Milling also depends on dimensional approach and number of working axis. It may be three axis milling, four axis milling or five axis milling. Three axis milling refers to the three spatial direction X, Y and Z. Four axis milling refers to the three spatial direction and tension bridge. While five axis milling have the three spatial directions and tension bridge with milling spindle. A milling machine with five axis is usually necessary to produce large restorations with complex shapes [28, 29].



Systems Utilized in Computer Aided Manufacturing

Additive manufacturing on the other hand is made by layering technique in a step by step vertical buildup of the object or restoration. The three dimensional design on the software (CAD) is fragmented into thin slices or layer. Each layer is printed over the other until the object is completed by addition of many layers of the material over each other. The machine needs to lay down 5 to 10 layers of the material to build a one millimeter of the restoration. That is why this technique is called additive manufacturing, rapid prototyping, layered manufacturing, solid freeform fabrication or simply 3D printing [30, 31].

Systems utilized in dentistry to do additive manufacturing are stereolithography, 3D printing by inkjet-based system, selective laser sintering and fused deposition modeling. Many materials can be used with this technology including: metals, ceramics, acrylic resin, composite and wax which enable the construction of both fixed and removable prosthesis [31-33].

Stereolithography is a method of called additive manufacturing in which layers of the material (usually composite or acrylic resin) are cured over each other by ultraviolet (UV) laser. This method is mainly utilized in the construction of surgical drilling guides or templates during insertion of dental implants [34 35]. Advantages of Stereolithography are great accuracy, surface of the restoration does not require finishing or polishing and increased mechanical strength. Disadvantages on the other hand are the high cost, post-curing is always required and is strictly used for polymers [33, 36].

3D printing by inkjet-based system is similar in principle to the inkjet printer. Powder of the material which may be a heat cured polymer or a nanoscaled ceramic powder. The powder is dispensed from the source in layers until the prosthesis is completed then a process of heat treatment is initiated to produce the final prosthesis. Advantages include coloring ability of the restoration and relative varieties in the materials used. Disadvantages of this method are low strength, rough surface and it may be less precise due to the shrinkage of the material [35, 37].

Selective laser sintering is done by a computer-directed laser, which is used for melting metal or sintering porcelain powder without the need to use a high heating temperature inside the machine as heating is concentrated in a very small area by the laser beam. Many powdered materials can be utilized in this process including cobalt-chrome spherical powder, which can be shaped to a removable partial denture, powdered ceramics, wax, nylon and composite. The main drawback of this system is the high cost of both the material and equipment [28, 36].

Fused deposition modeling is a technique that utilize a nozzle apparatus or head that extrudes a thermoplastic material layer by layer. As its name implies the heated material is delivered through a head apparatus, which is controlled by the computer. Once a layer of the material is deposited, it immediately solidify within 0.1sec and bond to the preceding layer. This method allows for usage of several materials with several colors including investment casting wax and polycarbonates. It can be used in production of models such as edentulous mandible and surgical templates or guides. The main disadvantage of this technology is the a rough surface finish and its limitation to thermoplastic materials [36, 38].

The additive manufacturing differs from subtractive manufacturing in many aspects. First, there is very little if any material wastage during manufacturing so it is more economical. Second, it allows for production of large objects such as surgical models. Also, complex prosthesis such as complete and partial dentures or even obturators can be accurately made. In addition, this method may not need any compensation in size [31, 39].

Some drawbacks may be seen in additive manufacturing such as micro-porosities, which may reach up to 30 to 45%. This may negatively affect the mechanical properties of the material. It was reported that these micro-porosities may affect the strength of zirconia restorations [37]. However, it was found that it may be an advantages with implant body fabrication as it can produce implants with elasticity similar to that of bone. Also, these micro-porosities was found to enhance bone growth and can encourage osseointegration. Another disadvantage of additive manufacturing is that some techniques can produce rough surface in the restoration or the prosthesis [31, 40].

Subtractive manufacturing on the other hand, can produce prosthesis without micro-porosities, having a reduced manufacturing flaws and higher quality control processes. Disadvantages of subtractive manufacturing include: inability to produce large or complex prosthesis especially if coloring is needed. Also, the process of milling produce microscopic cracks which affects the mechanical properties of the restoration. The short running cycles of milling tools, which need maintenance and frequent replacement. Finally, when compared to additive manufacturing, the subtractive method waste a large amount of material in the form of parts from blocks which are discarded [31, 41].

Advantages of CAD/CAM Technology

Regarding digital impressions CAD help in elimination of time consuming steps including: selection of trays, dispensing and setting of impression materials, disinfection and shipment of the impressions to the laboratory. It also helps in saving costs in terms of the absence of trays, impression material, and even shipping and delivery costs. The data can be easily stored and used during follow up visits. The elimination of gag reflex and enhanced patient comfort due to rapidity of the procedure is an additional advantage. It was also found that digital impressions produce better marginal fit than conventional methods with higher accuracy [42 31].

The advantages of production of digital models are also obvious. This includes the elimination of polymerization shrinkage which occur in the impression, the need to disinfect the impression, the need for vacuum mixing to avoid air bubbles, rapid pouring of the impression to avoid distortion, waiting for the stone to set, inaccuracies due to stone expansion and the time consuming steps to pour the base and pin models. Ditching of dies can also be done digitally and the inaccuracies of hand trimming can be removed. Dies are made digitally and are cut and trimmed by the laboratory computer. For the multi-unit prosthesis interlocking pieces cannot shift during manipulation. The margins cannot be altered by the technician, and there is no need to fabricate a solid model. [1 31].

The advantages of production virtual articulators and the ability to utilize a digital facebow are numerous. Most importantly is the ability of a perfect simulation of the fully adjustable articulator in all possible movement with much more accuracy, ease, and speed. This method also prevents the discomfort induced by the physical facebow. It also allows taking buccal scans in centric occlusion directly on the patient intraorally. This prevent the discomfort and possible errors that may occur with the conventional interocclusal record [43].

One study compared mounting with conventional face-bow devices and three dimensional virtual facebow mounting of casts for orthognathic surgeries. The results of the study showed many methodological and technical inaccuracies, which were found to occur in the conventional method as well as high possibility of deviations from reference planes during mounting. The study concluded that digital facebows and articulators are far more accurate than conventional ones [44].

Other advantages of digital facebows and virtual articulators are elimination of the variables associated with the materials for the interocclusal record, proper trimming, positioning of the record, and post-operative deformation. Also, there is no need to wait for the setting of the plaster for maxillary and mandibular casts. Finally it avoids errors caused by improper attaching of the mandibular cast to maxillary cast which may lead to improper occlusal adjustment [31].

CAD/CAM Technology is Filling the Future

It may be a matter of time to overcome the obvious limitations in these systems and allow the production of more types of dental prostheses for the different applications in dentistry. So as we now live in a digital world where everything is becoming digitized, a need for gradual transformation to digital dentistry is a must.

Incorporation of digital solution in dental practice can benefit both the practitioner by saving time and effort combined with increased accuracy and reduction of errors. Also, it benefit the patients by reducing number of visits and providing them with a more durable and lasting restorations. **Conclusion**

With this rapid advancement in various CAD/CAM systems, it is now possible to benefit from these advanced techniques in our routine dental practice. Also, with mass production and the rapid spread in use of CAD/CAM systems, it will be possible in the near future to benefit from these systems with lower cost which one day may become a more economic option than the conventional techniques.

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