The Evolution of Computer Aided Manufacturing in Prosthodontics - A Review

Type of study: Review
Running Title – The Evolution of Computer Aided Manufacturing in Prosthodontics

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Abstract: **Computer aided designing-computer aided milling (CAD-CAM) technology was introduced to dentistry way back in 1971. Over the years there has been a constant upgradation in the quality and popularity of its application to dentistry. CAD-CAM fabricated prosthesis though initially were considered costly and technique sensitive, nowadays they are being extensively used because of advancements in various CAD-CAM systems that have gained popularity. The ease of work and reduced chair side time makes them a boon while providing prosthodontics treatment. Dental CAD-CAM systems are being used not only for crowns and bridges, inlays and onlays but also for fabrication of removable prosthesis, stents, and implant components. This article reviews the evolution of the CAD-CAM system and its applications in the field of dentistry over the past two and a half decades. It also evaluates popular CAD/CAM systems, its limitations, future evolvement and other manufacturing aids with dental considerations while using them.**

Keywords: **CAD CAM, Prosthodontics, Crowns**

INTRODUCTION:

Prosthodontics is defined as the dental specialty pertaining to the diagnosis, treatment planning, rehabilitation, and maintenance of the oral function, comfort, appearance, and health of patients with clinical conditions associated with missing or deficient teeth and/or maxillofacial tissues using a biocompatible substitute [1], which is most commonly a prosthesis. In order for the prosthesis to fully function, it should be durable, aesthetic, accurate, and comfortable. These requirements should be accomplished by any prosthesis fabrication method. Conventional fabrication methods involve recording an impression of the treatment site, pouring a stone model and constructing a wax pattern and then the wax pattern is then fabricated with metal or ceramic. These steps require appropriate manipulation of materials and considerable human intervention [2]. This can translate to increased processing errors and inaccuracies, as well as increased time and cost. Further, considerable skill is required to produce a prosthesis of good quality. CAD stands for computer aided designing and CAM stands for computer aided milling or machining. This process is often known as CAD-CIM process which is referred to as to CAD-computer-integrated manufacturing process, where CIM stands for computer integrated machining or milling. Ever since the introduction of CAD-CAM to dentistry, there has been a constant phase of advancement to the technology [3] [4]. Computerized aids in prosthodontics has simplified the complex lab processes at the same time with increase in precision. CAD-CAM is one such aid. In line with CAD-CAM other recent technologies include laser sintering and 3D printing.

With the rapid evolution of CAD/CAM (Computer Aided Design, Computer Aided Manufacture), this has led to a dramatic impact on all disciplines of dentistry especially in the fields of prosthodontics and restorative dentistry. Furthermore, prosthodontic care has become a major complex of sequential techniques involving the student, clinician, patient and lab technicians. This review aims to discuss the current literature pertaining to the various methods and techniques for computerised, designing, manufacturing and production CAD-CAM generated restorations.

EVOLUTION OF CAD CAM

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. By the development of mass-produced silicon chips and the microprocessor there was a rapid growth in the use of CAD-CAM technologies after the early 1970s which resulted in more readily affordable computers. The use of CAD/CAM broadened from large firms using large-scale mass production techniques to firms of all sizes as the price of computers continued to decline and their processing power improved.

The CAD/CAM technology was introduced by Duret in 1971 in restorative dentistry and in 1983, the first dental CAD/CAM restoration was manufactured (4). The Sopha system had an impact on the later development of dental CAD/CAM systems. Duret demonstrated by his system at the French Dental Association's International Congress in November 1985 by creating a posterior crown restoration. Sopha system was developed by Duret [5]. Dr Moermann developed the CEREC® system, which was a chairside CAD/ CAM.
Siemens Corporation later developed the second generation CEREC 2 system in 1994 and Sirona, Benheim, Germany brought the third generation CEREC 3 system in 1999. It was originally developed by Brains AG, and the first fully operational CAD-CAM system marketed for use in clinical dentistry [6]. The CEREC 3 system is more advantageous than the CEREC 2 as it included a three-dimensional intraoral camera, grinding unit and also manipulation of the picture manipulation of the picture.
The next is Dr Andersson, the developer of the Procera system in 1983. Procera system had central processing centre with satellite networking centres under this unit composite veneered restorations were manufactured and processed using CAD-CAM. This system was widely used and had been present over a long period of time. The current Procera system, in Sweden uses a fabrication system with a pantograph and electric discharge machining which was developed by Nobel Pharma, Inc., Goteborg the shapes of wax pattern are read by the the pantograph stylus and in order to produce electrodes in these shapes, they are then feeded into a milling machine to produce electrodes in these shapes.
The Celay system developed by Mikrona Technologic, Spreitenbach, Swiĵ erland in 1990 helped to record the shape of an acrylic which directly transfers the shape to a milling machine with the help of a contact digitizer [7].
(CICERO) system was developed by CICERO Dental System B.V. (Hoorn, The Netherlands) which stands for computer integrated crown reconstruction. The CICERO method of fabrication for crowns consists of optically digitizing a gypsum die, designing the crown layer build up, and subsequently pressing, sintering, and milling consecutive layers of alumina-based core material with increased strength and the final finish is produced in the lab. The CICERO method allows efficient production of all-ceramic restorations without compromising esthetics or function. [8]
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 centre. After fabrication, the coping will be sent back to the lab for porcelain veneering
Lava CAD/CAM System was introduced in 2002. Lava Ultimate Resin Nano Ceramic (RNC) blocks are innovative new CAD/CAM materials that make it possible to achieve superior esthetic results in easy steps. The blocks are embedded in a highly cured resin matrix made of nano ceramic particles. Therefore, composite materials can be used to characterize and adjust resin nano ceramic restorations after milling. The milled resin nano ceramic restorations can be individualized either before or after insertion i.e. intra-orally or extra-orally, Unlike conventional ceramic restorations, customization and glaze firing is neither necessary nor possible with RNC restorations. This opens up the opportunity for intraoral individualization and adaptation of the restorations [9].

CURRENT CAD CAM AND APPLICATIONS

The Cercon Zirconia system which was developed in Burlington, NJ, USA by Dentsply Ceramco, is one of the aids used for the production of Zirconia - based prostheses. Zirconia is an excellent material choice for metal-free restorations because of its biocompatibility, strength, and durability [9]. It has been proven in clinical studies for more than 8 years. The news about the durability of this material is very promising. Research shows in vitro performance equivalent to porcelain-fused-to-metal (PFM) restorations [10]. The recent development of Cercon Art CAD/CAM has brought automated and repeatable predictability and computer precision to the process. The art program is informative and allows for the fabrication of copings customized for wall thickness, cement gaps and occlusal geometry. This technology offers the dental laboratory a cost-effective means to fabricate single units without resorting to outsourcing. This also represents a significant time savings for the dental laboratory vs the hand-wax coping method because there are no interferences or tight fits that have to be hand-finished by the technician.
Nowadays, a recent application of computer-aided manufacturing is the fabrication of removable prostheses. RPD metal frameworks can be produced by a patterned framework and then cast using conventional fabrication methods [11]. For the fabrication of complete denture bases, different computerized protocols have been proposed and these are very useful for the fabrication of facial prosthesis, as the morphologies can be easily obtained by mirror image or average face form so that a more realistic and natural prosthesis can be manufactured [12]. Fabrication of complete and partial removable dentures using CAD-CAM technology has been implemented in the recent years. The fabrication of complete denture using CAD-CAM involves impression making with rubber-base impression material in a specially designed double impression tray. After the adjustment of the tray at a certain vertical dimension in the patient's mouth the data is retrieved and then transferred to the 3D laser scanning system. The impressions are scanned and a 3D digital model is obtained. This data can be used for arrangement of teeth after selection of the shade. The three dimensional image is used for development of a three dimensional model of the denture that is to be fabricated and using a milling unit it is further milled [13]. Till date there is an exponential increase in the application of computer-aided manufacturing in prosthodontics and is linked with the development and refinement of manufacturing systems which has greater ability for parallel material development, quality control and the possibility of virtual evaluation.

COMPONENTS OF CAD CAM

The CAD-CAM system is composed of a high resolution camera that reads the finest details of the surface to be scanned, this is the main function of the scanning unit. The scanned data is converted into STL format. The STL format is the format that is readable by most of the CAD-CAM software. CAD-CAM systems are composed of three parts: (1) a data collection unit, which retrieves the data from the area of the preparation, opposing and adstructures and is later on converted into a virtual impressions [14] through intraoral scanners (in-office CAD/CAM or in-office CAD or image acquisition systems) or indirectly by means of a stone model generated through making a conventional impression. (2) A software used for designing virtual restorations and then computing the milling parameters which is worked on a visual cast and (3) a computerized milling device for manufacturing the restoration from a solid block of restorative material or additive manufacturing.

MILLING IN CAD CAM

Milling/machining technology is a type of restoration fabrication that utilizes subtraction manufacturing technology from large solid blocks. The technology dentists and technicians are familiar with is computer numerically controlled machining (CNC), which is based on processes in which power-driven machine tools are used with a sharp cutting tool to mechanically cut the material to achieve the desired geometry with all the steps controlled by a computer program. The milling devices can be classified based on the number of milling axes [15].

3-axis devices: This type of milling device moves in the three spatial directions, i.e., X, Y, and Z. They are unable to mill undercuts, which is adequate for routine crown and bridge work but are capable of milling from the top or bottom of the stock material. The advantages of these milling devices are short milling times and simplified control by means of the three axes. For example, CNC milling machines (vhf, Germany).

4-axis devices: This type of milling device moves in the four spatial directions, i.e., X, Y, Z, and the rotatable tension bridge. Only one direction milling can be performed by the 4-axis device. For example, Zeno (Wieland-Imes).

5-axis devices: In this milling device, in addition to the three spatial dimensions and the rotatable tension bridge, milling spindle can be rotated (5th axis). Five-axis milling devices can mill undercuts in each direction and are beneficial when milling custom implant abutments that may have undercut areas or for large-span bridges. For example, Everest Engine (KaVo)
The milling units are categorized into two classifications: (A) dry/wet/milling and grinding in which some milling materials dry milling and others need need wet milling.
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. [Lava Form and Cercon brain, Zeno 4030 (Wieland-Imes)].
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 pre-sintering is employed for the milling process. Examples: Everest (KaVo), Zeno 8060 (Wieland-Imes), InLab (Sirona).

MATERIALS USED IN CAD-CAM

The milling process is initiated once the manufacturers fabricate the material in a solid block. The material must be capable of being milled without damage to the material. Depending on the type of material, dry or wet milling technique can be employed. Certain ceramic materials such as lithium disilicate, feldspathic porcelains, and metals require wet milling whereas zirconia and titanium can be milled dry or wet. In general, wax and acrylic are milled dry. The material must be capable of being milled generally in <20 min with a minimal post milling processing time for fabrication of chairside CAD/CAM restoration. Furthermore, materials should be aesthetically pleasing as milled and able to be customized to the desired shade. The materials used to fabricate restorations using laboratory CAD/CAM systems include ceramics, metal alloys, composites, titanium, and polyether ether ketone. The materials used for dental CAD/CAM offer benefits such as higher quality, user friendliness, and enhanced aesthetics [15].
Metals: At present, titanium, titanium alloys, and chrome cobalt alloys are processed using dental milling devices [16].
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, MN, USA). [16]
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_2O_3): Suitable for crown copings in the anterior and posterior region; three-unit FPD frameworks in the anterior region. [17]
VITA In-Ceram Spinell ($MgAl_2O_4$): Has the highest translucency of all oxide ceramics and is thus recommended for the production of highly aesthetic anterior crown copings, in particular on vital abutment teeth and in the case of young patients. [18]
Vita In-Ceram Zirconia (70% Al_2O_3, 30% ZrO_2): 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 discoloured abutment teeth. [19]
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. [20]
Aluminium Oxide (Al_2O_3): 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. [21] [22]
Yttrium stabilized zirconium oxide (ZrO_2, 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. [23] [24]

ADVANTAGES OF CAD CAM

Reduced labour:

The application of CAD/CAM technology reduces the labour cost and the chair side time. The total processing time is much shorter than that of conventional powder build-up and baking of porcelain. With regard to particular aesthetic requirements, milled crowns could be completed merely by staining, using a conventional and simple method. The aesthetic requirements can be more accurately met when compared to the conventional techniques [25] [26]

Cost effectiveness:

Production of all-ceramic FPDs using a zirconia framework fabricated by a CAD/CAM process could provide even more financial benefits to owners of dental laboratories because they can invest in small measuring machines and not in large expensive facilities; thus they could concentrate on conventional porcelain processing [27] [28]

Quality control:

Clinical and in vitro studies using finite element and fractographic analyses show that the primary causes of failure reported for all-ceramic FPDs differed from those reported for the metal-ceramic FPDs. Fractures of ceramic FPDs tended to occur in the connector areas because of the concentrated stress. Therefore, the design of the connector, particularly the dimensions, must be made independently depending on the type of ceramic material used for the framework. CAD better guarantees the durability and reduces the risk of fracture. [29] [30]

LASER SINTERING

Laser-Sintering, which means, methods that helps in the manufacturing of solid parts by solidifying powder like materials layer-by-layer, exposing the surface of a powder bed with a laser or other high energy beam. The laser sintering process is characterised by extreme rapid sintering and solidification [31]. The area of interest in this paper is all about SLS. The SLS technique has a great future potential for the rapid manufacturing of metal components that could be utilized in a variety of applications. SLS machines, such as, Direct Metal Laser Sintering (DMLS) uses single component metal powders. Powders are usually produced by ball milling technique and by other methods such as fluidized beds, blades, brushes, etc. The SLS process was originally developed at the University of Texas at Austin and then commercialized by the DTM Corporation (U.S.) [32] [33]. The SLS process is a viable time and money saving method for generating complex prototype parts in the plastics and metals industries based on the materials employed in the system. The benefits of using the system include: The ability to utilize a variety of materials and the future ability to expand the variety of materials which will work in the process. It would appear that DMLS is currently on a threshold between limited application in prototyping applications and a much larger potential in the areas of series production tooling and in particular part production. Some of the research concluded that powder with smaller size particle distribution could be easily melted and yields high density, superior mechanical strength and productivity [34] [35]

LIMITATIONS

The powder layer applied to the tooth surface results in an additional thickness of 13 to 85μm. 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 [36] [37]. Furthermore, additive technology is limited to polymeric and metallic materials and thus far does not include ceramics in dentistry. One more limitation is the limited full arch accuracy of digital impressions as compared with conventional impressions [38]

CONCLUSION

Computer-aided designing and computer-aided manufacturing continues to undergo increased improvements and in the near future, wide acceptance of its use in dentistry will occur. Dentistry has evolved from crude restorations made of wires, ivory and wood to the current aesthetic dentistry which involves use of high strength ceramics, dental implants and silicones for restoration of and maxillofacial organs and missing teeth. Presently, subtractive milling has been shown to be a suitable method for fabricating intraoral prostheses and is the most widely implemented computer-aided manufacturing protocol in dentistry. Additive manufacturing is currently an exponentially growing fabrication method and will most likely be used more frequently in dentistry in the future as its accuracy and range of applications develop. In terms of material processing, both techniques introduce material defects. The subtractive methods, however, currently produce more homogenous objects making this method more suitable for the production of intraoral prosthesis that can withstand higher occlusal loads. Additive methods have the advantage of producing large objects, with voids, surface irregularities, undercuts, and hollow morphology that makes them suitable for manufacturing facial prostheses and metal removable partial denture frameworks. There is a marked scope for newer and more aesthetic restorative procedure. The current CAD-CAM technology being expensive is still making its place in the dental market. In the future the current CAD-CAM systems are expected to decrease the conventional porcelain and all ceramic fused to metal restoration fabrication techniques. CAD-CAM technology is expected to show more development and help in the fabrication of even more precise and esthetic restorations in future [39]. Computer-aided manufacturing procedures will indisputably change many aspects of dentistry in the future, particularly in relation to treatment simplicity and production time. It is therefore critical for technicians and clinicians to be familiar with the advantages and disadvantages of computer-aided manufacturing as these procedures continue to develop and become an integrated part of dentistry [40]. 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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