

Role of Computer-aided Design/Computer-aided Manufacturing in Maxillofacial Prosthesis Fabrication

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Abstract

Due to congenital malformations, the treatment of neoplasms, and trauma, maxillofacial defects can result, which cause multiple physiologic and psychologic problems and require restoration in most of the patients. The two main treatment modalities are prosthetic rehabilitation and surgical reconstruction. Surgical reconstruction is extremely challenging in patients with extensive maxillofacial defects, including the maxilla, nose, upper lip, cheek, and orbit. Prosthetic rehabilitation can be given as an alternative to surgery to live the patient a quality life. The newer technological changes are revolutionizing the way dental practice and the methods of fabricating restorations in dental laboratories. Computer-aided design and manufacturing (CAD/CAM) is such a technology which are used by prosthodontists and laboratories to use computers to design and fabricate esthetic and durable restorations. In this article, the various uses of CAD/CAM are discussed in restoring maxillofacial defects.

Keywords: Computer-aided design/computer aided manufacturing, Maxillofacial defects, Maxillofacial prosthesis, Rapid prototyping.

INTRODUCTION

The prostheses produced by “milling technology” is synonymous with the term “CAD/CAM” in dental technology today. CAD is the abbreviation for “computer-aided design,” and CAM stands for “computer-aided manufacturing.” In recent years, manufacturing of facial prostheses has been done using CAD/CAM and rapid prototyping (RP) technologies. In this technique, a three-dimensional (3D) image of the surface of a patient’s face was reconstructed. The normal portion of the patient’s face is mirrored on the defective side, and using the mirrored image, the design of the facial prosthesis is completed.^[1] Then, using RP technology the wax pattern of the facial prosthesis is processed.^[2] Using this technique, more accurate facial prostheses are fabricated.

History

The major developments of dental CAD/CAM systems occurred in the 1980s. Dr. Duret was the first to develop dental CAD/CAM. From 1971, he began to fabricate crowns with an optical impression of abutment followed by designing and milling. Later he developed Sopha system. Dr. Mormann developed CEREC System in 1987, an innovative approach to fabricate same day restorations at the chair side in the dental office.^[3,4] Dr. Anderson developed Procera System in 1993 to

fabricate titanium copings by spark erosion and introduced CAD/CAM technology into the process of composite veneered restorations.^[5] This system later developed as a processing center networked with satellite digitizers around the world for the fabrication of all ceramic frameworks.

ADVANTAGES OF COMPUTER-ASSISTED PRODUCTION

CAD/CAM technologies have started a new era in dentistry. The quality of dental prostheses and productivity has improved significantly. Thus, it has changed dental laboratories from manufacturers to modern computerized production centers. CAD/CAM technology has also made it possible to machine new materials like high-performance ceramics and titanium with high accuracy.^[5]

DISADVANTAGES OF COMPUTER-ASSISTED PRODUCTION

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However, some drawbacks of this fabrication technology have to be mentioned. The higher price of the machines may limit their use in smaller laboratories. Some applications are limited due to software and production procedures.^[5]

Applications and indications for CAD/CAM in dentistry

Until recently, most dental CAD/CAM applications were limited to fabricating copings to replace the casting processes in the laboratory. Most chairside applications for dentists have been for inlays, onlays, and a single posterior crown. With the advent of better and multilayered materials, the applications for dental CAD/CAM have evolved into anterior restoration. However, restorations for mini or sectional veneers are limited to dental CAD/CAM processes. Because these restorations are typically paper-thin or replace only an incisal corner, the use of CAD/CAM technology for such applications would be too cumbersome. Another convenient application for CAD/CAM processes is the fabrication of customized implant abutments, either titanium or zirconia. This CAD/CAM technology is used to fabricate prostheses for rehabilitating patients with maxillofacial defects.^[3]

PREREQUISITES FOR DENTAL CAD/CAM SUCCESS

The success of CAD/CAM restorations is predicated on a good preparation, a detailed impression (in this case, an optical or digital scan), and understanding how to design (or traditionally wax-up) a restoration that will satisfy dentist and patient expectations. Marginal accuracy is always a concern, and CAD/CAM has advanced to the point where margins now fit within 50 μ m if all processes are properly followed. The clinical, functional, and esthetic success of CAD/CAM restorations necessitates operation by an intelligent dental professional who can visualize in the 3-dimensional (3-D) world what the proposed restorations should be.^[6] This includes anatomy and margin placement, as well as enamel (veneering porcelain) characterization. Such individuals also must understand the machining capabilities of the milling unit and how to optimize designs to work within those capabilities.

The CAD/CAM process

A CAD/CAM system utilizes a process chain consisting of scanning, designing, and milling phases. The scanning device converts the shape of the prosthesis or restoration into three-dimensional (3-D) units of information (voxels). The computer transfers this information into a 3-D map (point cloud). The operator designs a restoration shape using the computer, which generates a tool path that is used by the milling device to create the shape from a restorative material.^[7,8]

CAD/CAM technique for fabricating facial prostheses^[9]

The computer-assisted technique uses a new technology for the fabrication of a facial prosthesis instead of depending on the plaster cast. Two advantages of this method are that an electro-optical unit is used to acquire the three-dimensional data needed to generate a processing image model without touching the patient, and the three-dimensional data is transferred

directly into the CAD/CAM machines, which perform the labor and thus eliminate all the hand work except for the silicon fabrication and coloration. Two alternative CAD/CAM three-dimensional modeling techniques are the laser lithographic and NC milling models. They are used to prepare the wax model for the fabrication of prosthesis. In the laser lithographic modeling approach, which was similar to the modeling approach used in the conventional plaster-cast method, an intrinsic resin model was prepared prior to the fabrication of the wax model. The resin model was built and solidified in layers by laser lighting; therefore, a complex anatomic construction that included surface and inner bony components was produced. Although some handwork was necessary to form the wax model on the resin model, an intrinsic resin model is helpful in the design of internal fixation devices, such as dental implants, for the prosthesis, particularly for a prosthesis for an extensive and complex facial defect. Using the NC milling model approach, the wax model could be fabricated automatically, from the data acquisition and image processing to the milling of the device. This approach can simplify and reduce the laboratory work to a greater extent than the laser lithographic method. The NC milled model approach may be appropriate if the defect is localized or simplified; however, current limitations in the diameters and axes of the milling tools cause difficulty in cutting the delicate wax pattern.^[3,10]

Fabrication of a maxillofacial prosthesis using a CAD and manufacturing system

A non-contact 3D laser morphological measurement system is used to obtain 3D morphological measurements of facial defects. This system enables the clinician to obtain highly accurate facial morphological measurements at highspeed using a laser system. Two semiconductor lasers are applied by the laser system to the patient's face, which are controlled by the computer. The projected light is received by four charge-coupled device cameras. Approximately 5 s of time are needed to obtain measurement data. An image processor processes the received signals and transfers them to a personal computer to generate 3D images. Using a computer, a mirror image is generated by reflecting the data of the normal side relative to the facial median line on the defect side. The facial morphological measurements are obtained with the eye open, and the morphological data on the normal side is reversed against the facial median line. This allows the technician to develop the optimal anatomic morphology of the prosthesis. This morphological data is used by the image processing system for the fabrication of a morphological cast. The processing data is then sent from the computer to the milling machine.^[9,10] Then the morphological cast is fabricated by milling a wax block with a melting temperature higher than that of paraffin wax. Facial casts of the affected side and a mirror image of the normal side are then fabricated. An artificial eye was attached to the wax pattern. Minor corrections are made to the wax pattern, and the final color tone of the prosthesis is determined during the patient visit. The wax pattern is replaced with silicone rubber. After polymerization, the surface color

tone of the prosthesis was adjusted to match the patient's skin tone, and hair was implanted. With the help of two cranio-facial implants, the prosthesis is retained. In addition, as with many patients with oral defects, a maxillary denture is retained via two palatal implants. The remaining teeth are also utilized for the retention of the prosthesis. Magnets can also be used as retentive devices for the prosthesis and the maxillary denture. In this method, the procedure for making a wax pattern is much simpler, resulting in a shorter processing time. No special skills are required for the technicians, and the 3D facial morphological data obtained can be retained as long as required without preserving actual physical casts. But sometimes the mirror image of the normal side may not perfectly match the normal morphology of the affected side because facial morphology is typically asymmetrical.^[11]

Rehabilitation of the nose using CAD/CAM and RP technology

When a patient's nose has to be removed because of a tumor, plastic surgery using a frontal flap can be done. Other treatment options include radiation therapy and chemotherapy. Such treatments can be used alone or in conjunction with each other. Sometimes, due to the recurrence of a tumor or surgical failure, it requires a silicone prosthesis, which provides good esthetics and respiratory function. Attempts have been made to design nasal prostheses using CAD/CAM technology.^[12] Osseointegrated implants positioned in the anterior maxilla provide the best method of retention, and a metal support bar stabilizes the prosthesis. Firstly, a laser scan of the patient's facial defect was obtained, covering the patient's eyes with a protective anti-ultraviolet device. The defect is scanned from six different angles to detect all undercuts. During the scanning, the patient was asked to maintain the head firmly positioned in the headrest, orthogonal to the floor; he or she was also asked to hold his jaws in maximal intercuspal position. These data are saved as stereolithographic (STL) files with Next Engine Scan Studio software.^[13] In reverse engineering post-processing, the digitalized surfaces are elaborated using Rapid Form 2006 software to align and merge the different meshes into a single virtual model. Thus, they eliminate the surface abnormalities, remeshing the organization of the triangulated mesh of points and filling in the surface holes that remained after data elaboration. A digitized anatomic nose was taken from an "ear and nose library" to choose the correct anatomy for the patient. The volume was superimposed on the defect, considering the correct modeling of the emerging profile in the marginal zones of the prosthesis and the design of the holes for the nostrils. After the STL file of the nose is developed, the substructure is designed within this space and rapid prototyped using a 3D printer. The nose is represented as a negative volume and is transformed into a new STL file for the two-part mold design. The upper and lower parts of the mold are processed using the same procedure as that used for the substructure. Before silicone processing using the scanned bar on the implants, the substructure is positioned in the mold. Then, the conventional silicone processing procedure is completed to obtain the

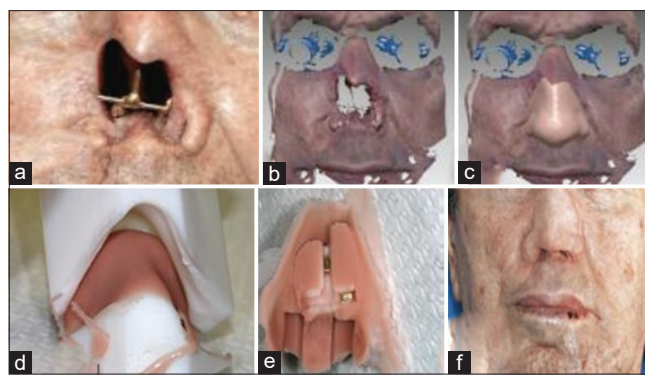


Figure 1: Fabrication of nasal prosthesis using computer-aided design/computer aided manufacturing system

definitive prosthesis (Figure 1). No separating media is applied to the rapidly prototyped mold and substructure prior to filling with silicone. A spectrophotometer is used to determine the intrinsic color of the prosthesis. Extrinsic colors are applied, and silicone adhesive is used as a sealant. Finally, matting dispersion liquid is applied to provide a matte appearance to the prosthesis.^[12,13]

Designing a facial prosthesis for extensive maxillofacial defects that cross the facial midline using CAD-CAM

Extensive, large maxillofacial defects that cross the facial midline can also be rehabilitated by designing facial prostheses using CAD-CAM technology. The patient's facial appearance can be recovered perfectly with the prosthesis. The optical 3D imaging and CAD/CAM systems can more perfectly design and fabricate facial prostheses than conventional manual sculpturing techniques. The virtual transplantation used to design the facial prosthesis for the maxillofacial defect, crossing the facial midline, and the retentive structure development for the eye are both feasible.

Design and fabrication of auricular prostheses by CAD/CAM system

Firstly, a spiral CT is performed on a patient who has an ear defect. A 3-D image is reconstructed with the CT data. Through imageware, the image of the normal ear was extracted, mirrored, and operated with the image of the deformed side of the face. It is modified and smoothed in the Free Form model system so that it can be perfectly adapted to the deficient side of the face. A paper model ear is then produced by RP from the digitally obtained data. Finally, silicone was poured into a silicone mold from the paper ear to create a silicone auricular prosthesis.^[14,15]

Advantages of design and fabrication of auricular prostheses by CAD/CAM

The skill of the technician is not an important criterion in this method. The patient can visualize the result on the screen of the computer before the ear is fabricated. It is much faster than the traditional process. The digital image and silicone mold can be preserved. The latter is durable, which permits multiple pourings.^[14] This is important for future reconstruction because

discoloration of the pigments in silicone elastomer generally occurs after 2 years.

CAD and rapid manufacture of an orbital prosthesis^[2,16]

Using an optical digitizing scanning system, digitization of the patient's face is carried out. It is operated using structured light and utilizes a phase shift to increase the precision effect. Using Geomagic software, the acquired data are then transformed into a color surface model by triangulation. Using the facial median sagittal plane as a mirror, the surface contour of the healthy side of the patient's face is flipped and superimposed onto the defective side. This produces an orbital prosthesis model reflecting the presurgical facial appearance of the deformed region. Using a nonuniform rational B-spline rendering model, the margins of the mirrored healthy section were adapted to the resection margins. The ocular model was selected from the prefabricated ocular prostheses database to match the orbital prosthesis model. Resembling with the patient's remaining eye, the size and color of the iris and sclera are selected (Figure 2). Depending on anatomic parameters of gaze and optimum esthetics, placement of the ocular model within the orbital prosthesis is done. The solid ocular prosthesis matching the virtual ocular model is then selected for assembly with the solid orbital prosthesis.^[17] The definitive orbital model was sent as an STL file, the standard file format for RP systems, and later transferred into an SLS system.^[16,17] The accompanying software slices the model into thin layers. The SLS machine produces the models by building them layer-by-layer on a moveable platform. The machine deposits a film of powdered wax material for each layer, and the laser projector then melts the selected areas. The platform is then moved down to the required layer thickness, a fresh film of powder is then applied, and the next layer is melted by the laser. This process is continued until the wax orbital pattern is completed. According to the given anatomic parameters, the solid ocular prosthesis is positioned in the wax orbital pattern. For modification and correction, this assembly is later tried on the patient's face. It is

then flaked and processed with room-temperature vulcanized silicone material according to routine procedures.

Limitations of CAD/CAM

There are several setbacks and limitations encountered in CAD/CAM. When laser surface digitizers are unable to capture complete facial profiles, missing data sets arise because some facial regions are obscured from their line of sight. Adequate knowledge and experience are required to reproduce accurate data. As the laser can be directed to expose areas that are normally obscured during scanning with modern portable scanners, some of the limitations faced by earlier non-portable digitizers are alleviated.^[18] Data manipulation techniques can also be successfully applied to virtually recreate surface patches that will blend into existing surface models to form natural complements of missing tissues. Alternatively, databases of facial organs can be developed to aid in prosthesis design, which eliminates the need for manual and artistic manipulation of the models. Errors in data conversion generated while converting CAD to STL file format for RP fabrication can lead to distorted representations of the patient's facial profiles and the prosthesis designs.^[19,20] However, the conversion process will generate prohibitively large file sizes and would require significant computing resources and lengthy processing times. For missing or reversed surfaces, STL files also create problems. Finally, cost can be a limitation for CAD/CAM. However, new developments in RP techniques have significantly lowered the costs of RP systems and materials over the last few years. Also, the decline in computer hardware and software prices has made high computing capabilities affordable for CAD and CAM systems.^[21]

CONCLUSIONS

The procedures described here represent a preliminary approach to the use of CAD/CAM techniques as a new method to fabricate various maxillofacial prostheses. The results achieved by these methods for producing highly realistic facial prostheses with accurate adaptation to the external contours. The application of computer-aided technology will undoubtedly allow reproducible and consistently high-quality prostheses. However, further development in the accuracy of the hardware and software currently available and the decreasing cost of the recently developed technology will allow its more widespread clinical acceptance among the population.

CONFLICT OF INTEREST

Nil.

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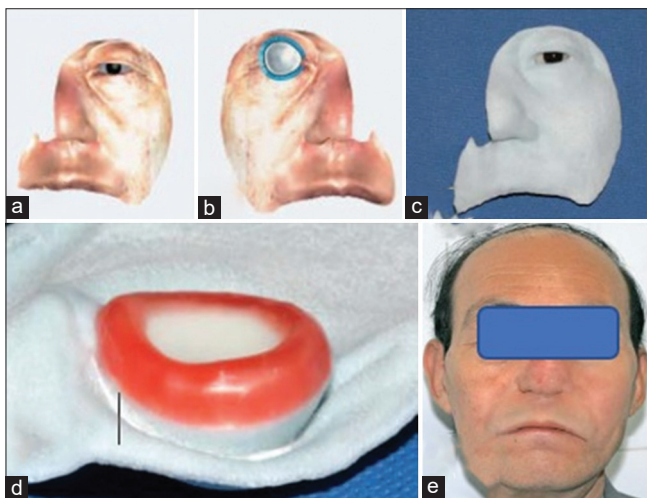


Figure 2: Fabrication of facial prosthesis with eye prosthesis using computer-aided design/computer aided manufacturing system

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