Concept of Rapid Prototyping in Dentistry

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ABSTRACT
Rapid prototyping is a potential tool in modern technology, facilitating automate design and production, improving productivity and quality. The use of advanced computers allows precise design of elements produced by specialized computer equipment. CAD-CAM techniques have been successfully introduced in the field of dentistry particularly in fixed partial dentures, maxillofacial prosthesis and implant dentistry.

Many of the manufacturing process are subtractive, in that they modify the geometry of a mass of material by removing parts of the material until final shape is achieved. Conventional and CNC milling procedures are examples of subtractive process. By contrast, additive procedures in rapid prototyping (RP) techniques build up a model gradually in layers until the final geometry is obtained.

Key Words: Not available

INTRODUCTION
Prosthetic dentistry is a branch of dentistry that unites scientific knowledge and artistic skill of the prosthodontist, in fabricating prosthesis successfully, that is acceptable by the patient.

Everyday prosthodontics involves cascade of steps. Each and every step is important, and has to be carried out with high level of accuracy to avoid failure of prosthesis because of technical error. All such procedures can hence be considered as highly technique sensitive and time consuming.

A revolution has happened in the field of manufacturing technology. With the introduction of laser technology, 3D Computer Aided Designing (3D-CAD), and Computer Aided Manufacturing (CAM) also known as Rapid prototyping or Free Form Fabrication (FFF).

The goal is to create products within shorter time, which are more individually styled and highly accurate.1,2

WHAT IS RAPID PROTOTYPING (RP)
Rapid prototyping is the process of producing physical prototype in a layer by layer manner from their CAD models without any human intervention or any tools, dies or fixtures specific to the geometry of the object being produced. Rapid prototyping although initially developed for engineering, product development environment has found its place in almost all areas of our lives. One of the most exciting applications of RP is in medical field often referred as rapid biomodelling or rapid bioprototyping. Using data from conventional medical scan technologies like Computer Tomography (CT) and Magnetic Resonance Imaging (MRI), quick and accurate rapid prototypes can be produced for a variety of purposes. RP is a type of computer-aided manufacturing that refers to automatic construction of mechanical models from graphical computer data.2 The two main methods of RP are as follows firstly, additive which is widely used and secondly, subtractive which is less effective.
SCOPE OF RAPID PROTOTYPING TECHNOLOGIES

1. Dental applications:
   RP technology is used to make a series of essentially invisible orthodontic prosthesis for straightening teeth. “Invisalign” is a company that uses this technology to produce aligners. Maxillofacial surgeons use stereolithography to produce 3-D representations of focal bony structures using data from CT or MRI. For correction of post traumatic or developmental facial asymmetry, great accuracy is required for successful surgical results, the surgeon can practice surgery on the models allowing full appreciation of osteotomy required to achieve the desired results. It can be helpful in orbital reconstruction following ablative surgery for malignancy, for fabrication of maxillofacial prosthesis. Additionally, it can be used for presurgical planning of implant placement (intraoral and extraoral). In restorative dentistry for fabrication inlays, onlays crowns.

2. Medical applications (Rapid Biomodelling):
   It provides an visualization aid for diagnostic and surgical applications. Surgeons can use rapid prototypes to improve their understanding of abnormal anatomy, so complex surgical procedures can be more effectively planned. Physical models can help make the assessment whether the surgery is necessary at all. Surgical procedures can be realistically simulated and practiced or could be taught. Custom implants can be designed for perfect fit since they can be tested using an exact replica of patient’s anatomy. Bioengineers are growing living artificial tissues to repair the damage from burns and chronic wounds, using laser based rapid prototyping technologies to render the biomimetic material designs in solid form.

Rapid Prototyping Technologies
A survey in 1999 identified some 40 different rapid prototyping manufacturing approaches. RP technologies may be divided broadly into those involving the addition of material and those involving its removal. The liquid based technologies may involve the solidification of a resin on contact with a laser or electrosetting of the fluid or melting and subsequent solidification of the prototype material. The processes using powders can be compounded using laser or by binding agents. Those processes using solid sheets are classified according to whether the sheets are bounded with a laser or with an adhesive.

All of the processes reviewed require input from a 3D solid CAD model. The designer, first uses a CAD package to design the product which he wishes to manufacture. This model is then exported as an STL file, which is the current industry standard for faceted models. It is then sliced and the slices sent to the RP machine for the production of final physical part.

Sterolithography (SLA)
It is one of the oldest, dating back to the mid 1980s, and the most popular among currently available RP technologies. It relies on a photosensitive monomer resin, which forms a polymer and solidifies when exposed to laser light.

Fused Deposition Modelling
This belongs to a class of RP technologies that are collectively known as ‘concept modelers’ because the models created are nonfunctional in terms of strength and surface finish is poor. Concept modelers are intended to provide a fast route to create a part that can be checked for any gross errors and usually used as a communication tool between the product development team.

Solid Ground Curing
It is a combination of stereo-lithography, fused deposition and CNC milling. Instead of solidifying the polymers fluid with a laser dot, a mask of the whole section is placed over the fluid. The exposed fluid is then flooded with UV light to cure and solidify the liquid. The remaining fluid is wiped off by a special vacuum cleaner and molten wax poured around the solid polymer.

When the wax is set, a milling cutter removes the excess wax and mills the section to the correct thickness. This leaves the solid section of polymer surrounded by wax to provide support. A further film of polymer fluid is placed on the top and a new mask used and so on. When all the slices have been completed, the wax is melted off leaving the completed polymer part.
Selective Laser Sintering (SLS)
Using SLS, any material which are convertible to powder form, can be used to build up rapid prototypes. SLS uses fine powder which is heated with a CO$_2$ laser of power range of 25-50W such that the surface tensions of the grains are overcome and they fuse together. Before the powder is sintered, the entire bed is heated to just below the melting point of the material in order to minimize thermal distortion and facilitate fusion to the previous layer.

Laminate Object Manufacturing (LOM)
LOM is one of the cheapest RP technologies and is excellent for making larger parts. Parts can be made using paper, plastics and fibre reinforced glass ceramics. The system employs 25 or 50W CO$_2$ laser to cut the material.

Multi Jet Modelling (MJM)
MJM also belongs to the class on “concept modeler”. This technique has been linked to printing in three dimension and geometrically acceptable models can be obtained in a material that would not, normally be used for final part.

Steps in Fabrication of Models
Any CAD-CAM technology, depends upon obtaining a CAD model of the part or object that is to be built up. Model processing using CAD/CAM technologies involves three basic steps that includes. Data acquisition, image processing to obtain a CAD model, followed by model production.

Dental CAD/CAM systems, are developed to produce dental as well as maxillofacial prosthesis. Dental prosthesis designed, whether with lost wax casting technique or a CAD-CAM system, has three functional components.

1. Data acquisition:
   a) Extraoral
   The aim of data acquisition is to gather topographic data on site of deformity where the prosthesis is to be secured. A healthy ‘donor’ organ on which the design of the prosthesis will be based. Although, conventional impression techniques have proved suitable for the fabrication of facial prosthesis, there are some disadvantages.
   - Impression materials put weight on the tissues, compressing the poorly supported soft tissues by underlying skeleton.
   - Materials may cause reflexes of periorbital, perinasal, perioral structures.
   - It should be ensured that respiration is not disturbed.

To capture anatomic details and profiles, two non invasive, non contact computer aided techniques can be employed.

b) Medical imaging system
   - Computerized Tomography (CT)
   - Magnetic Resonance Imaging (MRI)

Medical Imaging System: Data is obtained as series of equally spaced axial 2-D transverse tomographic image slices. CT or MRI scanners have been employed successfully for capturing the external profile of human anatomy.

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<th>CAD-CAM system</th>
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<td>Optical modelling, laser scanning, CT, MRI, digital photographs</td>
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<td>Investing and casting techniques</td>
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Limitations of Medical Imaging Systems:
Limitations of CT are that the patients are exposed to larger doses of harmful radiation and resolution encountered in soft tissue imaging is poor.
Limitations of MRI are that powerful magnetic fields generated make it unsafe for patients with implanted ferromagnetic devices (ex-pacemakers). Larger amounts of data generated of both internal and external structures, with the imaging system demands higher, computing resources to manage and manipulate therefore increasing cost.
c) Laser surface digitizers

Use a laser projector and detector system to accurately capture 3-D topographic data of external surface of physical objects. Data produced are 3-D point cloud. These point clouds are merged together to obtain the recorded image. With the limitation that only surface data within the line of sight of the scanner can be captured. Scanning of complex facial organs such as folds of ears, nose, will result in missing data patches or blind spots. Regions that are dark because of skin colour or hair may cause similar error.9

OPTICAL MODELING OF EXTRAORAL DEFECTS

In order to reduce the stress caused to patients by conventional methods of modeling using CT and MRI, this optical modeling process has been developed for extraoral defects and body areas7. The scanning unit provides a point cloud or virtual model of face. The primary principle used to obtain digitized data for extraoral areas is the method of structured light illumination with a digital light projection unit.18

Data acquisition from casts and Dies (Indirect Method)

CAD/CAM technology is proved be beneficially used in the field of fixed partial dentures. It has shows promising application in fabrication of crown, inlays, onlays, and bridges.

Application of CAD CAM technology in the production of metal framework or pattern for framework of removable partial denture has remained only a theoretical possibility.8

Use of electronic surveying or digitized surveying of a 3-dimensional (3-D) scanned dental cast is described. The scanner used to scan the cast was an optical system that used projected light and digital camera technology to capture approximately 140,000 points in 3-D on the surface of the object, termed as “point cloud”. The scanner can collect data on surface that are obscured or at too great an angle to the line of sight will not appear in the scan data, so for a cast of a patient several scans are necessary. By electronic surveying of the scanned cast, a pattern of metal framework can be designed on computer screen.

Various CAD/CAM system (Procera, DentiCAD, CICERO, DUX System) have been described to be used in fabrication of ceramic crowns, inlays, onlays.

A rough overall scan of the total arch, using steps of 0.2mm between consecutive scan lines is made and converted to gray scale z-chart. After this, the computer generated surface of prepared tooth is extracted from the scan data. The total area to be digitized is first marked by tracing the finish line of the die and then divided into 2000mm x 2000mm squares each of which is digitized at least twice. Because the finish line is the most critical part, the data on the line and adjacent 1mm are recorded first.8

Data recording directly from prepared tooth

The three systems involves in applying CAD/CAM technology for dental prosthesis fabrication have been mentioned.

The French system

This system utilizes a hand held optical probe to measure the 3-D coordinates of the tooth prepared for a restoration and of the adjacent teeth. The probe consist of a laser diode source and a charge-coupled device (CCD) photoreceptors. The scanner probe has a resolution of 20mm. After a non-reflective substance is applied to the patients teeth to eliminate spurious reflections, the probe is passed over the teeth. The signals created by the laser light reflected by the teeth is picked up by CCD arrays, converted to a digital signal and relayed to the computer.5

The Swiss system

A non-contacting head of the scanner is positioned over the prepared tooth. The scanner incorporates a light entitling diode and lense system to illuminate the prepared tooth. Light is reflected back to the scan head where it is sensed by the CCD sensor. The intensity of light reflected is recorded as voltage values proportional to the intensity of light reflected back to the CCD chip.

The voltage values are recorded in digital form and are transmitted to the computer for subsequent analysis. The readings obtained by the scan head can be improved by coating the cavity
Comparative study of various CAD software's

<table>
<thead>
<tr>
<th>Software</th>
<th>Able to view and edit STL file</th>
<th>Support STL file conversion</th>
<th>Able to read in surface date</th>
<th>Support CAD-operation</th>
<th>PC based</th>
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<tbody>
<tr>
<td>Duct (Delcam)</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
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<tr>
<td>3-D eye Trispective(3D-eye)</td>
<td>Yes</td>
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<tr>
<td>Solid works</td>
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<tr>
<td>Solid edge (electronic data system)</td>
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<tr>
<td>Solid view (solid concepts)</td>
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<td>Proengineer (PTC)</td>
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<td>Yes</td>
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<td>Surfacer</td>
<td>Yes</td>
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with a layer of white, glare-free substance (CAVISON, Svedia, Dental Industry Sweden).5

The Minnesota system
Data are acquired by photographic based system. Data acquired include the surface of prepared tooth, adjacent and opposing teeth, the position of cusp tips of opposing teeth in relation to prepared tooth, in centric occlusion, working and balancing positions and protrusion.

Data are acquired with a standard 35mm camera through a 10mm diameter single rod lens magnifying laryngopharyngoscope, which attaches to a standard 55mm lens. An entire crown preparation can be viewed from a single position approximately 25mm above the surface of the tooth. A number of views are obtained, to overcome the blurring due to movement of patient.

To permit 3-D surface reconstruction and of movements of the jaw, stereo-pairs of images are made. The images are recorded on standard film (Ectachrome ASA 400). The exposed film is developed by commercial processors.

The colour slides are digitized by using a digitizing system (Eikonix Corp., Bedford, Mass) having a resolution of 4096 x 40960 pixels. The digitizer senses the intensity of light passing through each pixel and write this value along with the address to the computer.

The Duret system
This optical probe located near the dental chair. The operator holds the probe like a hand piece and places it in patients mouth to take pictures. The dentist moves the probe around the preparations, controls the positioning of the probe on a TV monitor facing him and activates a foot switch to record the picture. Several views are taken of the preparation. One final important view is the teeth in occlusion for recording dynamics of occlusion.6

IMAGE PROCESSING/DATA RECONSTRUCTION
After the image or data of the part to be constructed is obtained, the user can modify the image by separating the data of interest from general information available from the scanner.

Combining the data recorded with CAD software, 3-D design of a new part can be undertaken that is displayed on computer screen. This is the 3-D CAD model (virtual model). This 3-D model after completion of segmentation and visualization will command the manufacture of parts after by RP. “The standard interface from CAD to RP is the standard triangulation language (STL)”, though other transfer formats such as initial graphic exchange specification (IGES), standard for the exchange of product model data (STEP), common layer interface (CLI), and virtual reality modeling language (VRML) are also possible.6
Number of commercial softwares are available to edit and manipulate the point cloud data generated by the digitizer. The ability of the software to convert CAD models to STL data format is important as STL file format is the standard for data interfacing between CAD and RP systems.9

After pairs of scans are obtained by data recording. It is exported as “STL file” function to obtain a STL integrated 3D digital file.

Model/Prosthesis fabrication

Once the 3-dimensional CAD model (virtual model) is obtained, the actual model is fabricated either by commanding a CNC milling machine to mill, the model from solid blocks similar to the virtual model or programming a rapid prototyping unit to built up the model or the prosthesis by various technologies described earlier.

In maxillofacial prosthesis fabrication, preparing a mirror image wax pattern for the defect part by conventional method is a complicated, difficult and time consuming procedure. Using RP technologies, mirror image wax pattern for the maxillofacial prosthesis can be fabricated. For example, a definitive acrylic ear cast can be manufactured in on step using the STL file format and stereolithography. Once the acrylic resin sets, vinyl polysiloxane material is used to transform the acrylic resin cast into wax ear. A silicone mold is obtained with an opening at the base of prototyped ear. The mold is splitted to retrieve the acrylic ear cast. Recompose the mold with cyanoacrylate and pour the mold to obtain wax model of ear prosthesis.

Models can be obtained using numerically controlled milling procedure. The 3-D CAD data is displayed in on computer screen, the same manner as plaster would be prepared for laboratory manufacture. The interactive editing capability allows the clinician to design the restorative 3-D shape on the computer screen as desired. Once the computer designed shape of defect restoration has been completed, the CAD image files are processed to generate computer milling control data. The milling data is used to program a milling machine to mill the required wax model from wax block.10

CONCLUSION

Combining dental sciences and manufacturing technologies is the idea behind use of rapid prototyping in fabrication of dental prosthesis. Any prosthesis or restoration fabricated by conventional methods involves multiple steps in fabrication. Each step adding up to the chances of introducing manual errors, lot of time of dentist, laboratory technician and patient is spent in obtaining a good fitting prosthesis.

With computer control over prosthesis fabrication, the number of steps are reduced saving time and the task can be performed with high level of accuracy with RP technology, precise form and shape of any missing maxillofacial part on one side can be obtained simulating its counterpart on opposite side.

The only limitation to the use of RP technology, include the high cost of the equipment, complicated machinery needed and reliance on an expertise to run the machinery during production. Influence of CAD-CAM, is changing the practice of dentistry, mainly because of extraordinary speed and high degree of precision. Future evolution could be spectacular, considering its numerous possibilities.

REFERENCE