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Rapid Prototyping - An Engineering Tool in Dentistry.

Dr. Mohit Kamra
Professor, M.M Dental Institute Mullana . Haryana

Abstract: *Rapid prototyping, is a computer assisted designing and manufacturing technology that automatically constructs physical models from computerized three-dimensional data . This technology has recently been successfully applied in medical fields such as implant surgical guides, maxillofacial prosthesis, frameworks of removable dentures, wax patterns for dental prosthesis, zirconia prosthesis and moulds for metal castings and complete dentures. This technique of printing can reduce the time of surgery for giving a better understanding of the real-time surgery operation over the human body and these free accessible applications can increase design accuracy with possible minimal expense.*

Keyword: *Rapid Prototyping, Stereolithography, Dental prosthesis .*

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I. INTRODUCTION

Engineering is the process of designing, manufacturing, assembling, and maintaining products and systems. There are two types of engineering, forward engineering and reverse engineering. Forward engineering is the traditional process of moving from high-level abstractions and logical designs to the physical implementation of a system.

The process of duplicating an existing part, subassembly, or product, without drawings, documentation, or a computer model is known as reverse engineering. Reverse engineering is also defined as the process of obtaining a geometric CAD [Computer assisted designing] model from three-dimensional points acquired by scanning/digitizing existing parts/products. The first three-dimensional object was printed by *Charles Hull* in 1983 using stereolithography . Digital dentistry was introduced by *Francois Duret* in 1970s. Three-dimensional Printing is an additive process, also referred to as rapid prototyping.

II. APPLIATION OF PROTOTYPING SYSTEM

Medical Applications: Rapid Prototyping is used to build solid replicas of all human organs and parts. Components like stretchers, broken limbs, prosthetics are fabricated for bio-medical applications.

Engineering Applications: The Rapid prototyping systems helps in fabricating parts to required scales, to determine form and fit sizes, prototypes to perform flow analysis in various fields such as aerospace, automotive, bio-medical , ship-building industries.

Aerospace And Automotive Applications: The rapid prototyping process has wide applications in aerospace and automotive fields; for design, visual verification, assembly, form, fit, limits, tolerances, clearances, inspection, testing, prosthetics, [3D] three-dimensional casts , metal casting .

Manufacturing Applications: Tools and parts such as moulds, castings-metal or sand, master pattern making using materials such as resins, rubbers, metals and ceramics can be fabricated .

Rapid prototyping process shows its technological growth in textile industry, furniture design, electrical appliances, and architectural interior design and design of special and complicated contour objects. [1]

There are 3 basic steps in three-dimensional printing technique -.

The *first* step is to design a three-dimensional file of the object by using a CAD software, with a three-dimensional scanner.

The *second* step is the actual printing process. The material that will be used for printing is chosen according to requirement.

A variety of materials used in dentistry include plastics, ceramics, resins and metals . The *third* and final finishing process requires specific skills and materials. [2]

3D printing is very often used rapid prototyping method . 3D printing has the ability to fabricate geometrically complex shapes in a range of materials across different scales. It has various applications in medicine, art, manufacturing and engineering. 3D scanning is a process of collecting digital data on the shape and appearance of a real object, creating a digital model based on it.

III. BASIC PRINCIPLES OF RAPID PROTOTYPING -

Rapid prototyping can be of two types:
The parts obtained by RP technology can form the prototype directly without requiring any further processing.
The parts obtained by RP technology can be used to make moulds for casting the prototype component.
This technology is called as *Generative manufacturing Process (GMP)* as the shape of the work piece is not obtained by removal of chips or forming or casting. It is achieved by addition of material without any prior recognizable form or shape and no tool is necessary.

Rapid prototyping process has two phases namely virtual phase and physical phase.
Virtual Phase is for designing the required component using CAD software i.e., a 3D CAD is built in this phase.
Physical Phase is for building the component. The 3D CAD model is sliced into thin layers and the part is built as per the sliced layers. Thus, Rapid prototyping is known as Additive process and Layer based fabrication. [1]

Advantages of Rapid prototyping**:** Fast and inexpensive method of prototyping design ideas.
Physical validation of design.
Reduced product development time .
Disadvantages:
Resolution not as fine as traditional machining.
Surface flatness is rough .
Building part layer by layer,
Limited range of material variety.

The basic methodology for all current RP techniques can be summarized as follows:
• A CAD model is constructed and then converted to STL (standard triangular language) format;
• The RP device processes the STL file by creating sliced layers of the model .
The first layer of the physical model is created, the model is then lowered by one layer thickness, and the process is repeated until completion of the model .
• Supports will be added for any layers that are not directly supported by the previous solidified layer which needs to be removed later.
• The model and any supports are removed; the surface of the model is then finished and cleaned.
A large number of RP techniques have been in use such as:
• Stereolithography (SLA)
• Selective Laser Sintering (SLS)
• Laminated Object Manufacturing (LOM)
• Fused Deposition Modeling (FDM)
• Solid Imaging (SI) or Multi-jet Modeling
• 3D Printing (3DP) or Selective Binding. [3]

A. Stereolithography:

This system consists of a bath of photosensitive liquid resin, a model-building platform, and an ultraviolet (UV) laser for curing the resin. The layers are cured sequentially and bond together to form a solid object beginning from the bottom of the model and building up.

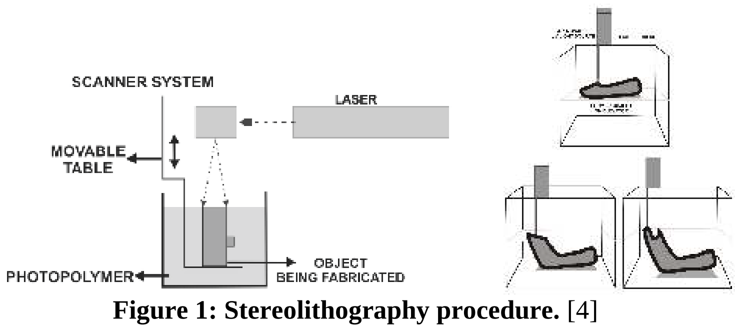


Figure 1: Stereolithography procedure. [4]

Stereolithography is a Rapid prototyping system designed to create solid and detailed, three-dimensional (3D) physical models that can accurately replicate complex anatomical structures directly from computer data . Combining the scanned information of reconstructed Computed tomography (CT) images with an ultraviolet (UV) laser beam sequentially passed over a photosensitive resin, it is possible to produce, from a two-dimensional (2D) image, a dimensionally accurate 3D anatomical model, as a complete replica of the external surface and internal structures (including soft tissues) in a layer-by-layer fashion . This process is accomplished with predictable results quickly, and cost effectively . The stereolithographic apparatus consists of a container or bath with a liquid photosensitive resin, a model-building platform, and a curing ultraviolet laser. The laser beam moves in sequential cross-sectional increments of 1 mm or less, corresponding to the slice intervals previously specified during the CT formatting procedure. The model is initially designed through a CAD (Computer Assisted Design) software; the CAD data file is converted into slices of known dimensions and transferred to the stereolithographic apparatus for building.

Technique of color stereolithography, a recent, improved method, allows for the selective coloring of determined anatomical structures in solid 3D models.

Stereolithography, also denominated laser lithography, is one of the most popular groups of techniques called modern Additive Manufacturing (AM) systems; additive means that the systems build objects in a layer-by-layer manner. Additive Manufacturing systems were initially developed and patented by *Swainson* in 1971 under the name of Photochemical Machining. Later, the first commercial CT device was introduced. In 1981, *Kodama* described an automatic technique for fabricating 3D models in layered, stepped stages employing a photosensitive polymer. *Herbert* designed the layer by layer method for replicating solid objects. [5]

Figure 2: ***StereolithographyE procedure.*** [4] Three-dimensional (3D) Computerized axial tomography (CAT) of a pediatric patient (A), stereolithography models of the same patient made with C. Acrylic (B, C). [5]

B **Selective lasering sintering**

It is a process of fusing together layers of specified powder material into a 3D model by a computer-directed laser. Thermoplastic powder is spread by a roller over the surface of a build cylinder. The piston in the cylinder moves down one object layer thickness to accommodate the new layer of powder.

Piston moves upward incrementally to supply a measured quantity of powder for each layer. A laser beam is then traced over the surface of this tightly compacted powder to selectively melt and bond it to form a layer of the object. The process is repeated until the entire object is fabricated.

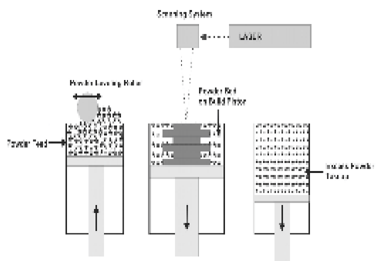


Figure 3 - Selective lasering sintering [4]

C. **Fused deposition modeling-** A plastic / wax filament is unwound from a coil and supplies material to an extrusion nozzle. The nozzle is heated to melt the plastic, nozzle is moved over the table in the required geometry, it deposits a thin bead of extruded plastic/wax to form each layer. The plastic/wax hardens immediately after being squirted from the nozzle and bonds to the layer below.

The supporting structures are contrived for overhanging geometries and later removed by cutting them out from the object. The model is printed in form of layers from down to up direction.

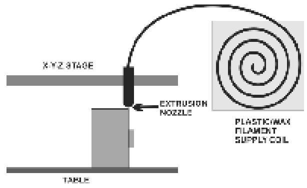


Figure 4 - Fused deposition modeling [4]

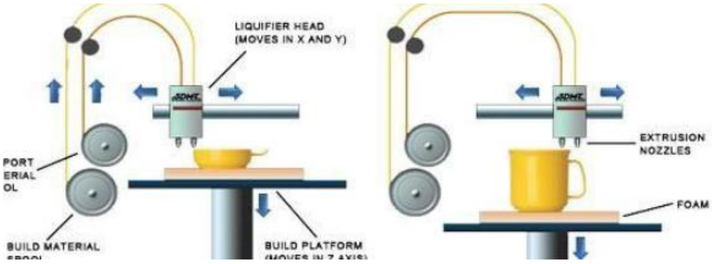


Figure 5 - Fused Deposition Modeling process . [6]

D. Inkjet (thermal Phase Change):

The working principle of this RP system is basically similar to the conventional 2D inkjet printer. This machine uses a single jet each for a plastic build material and a wax-like support material, which are held in a melted liquid state in reservoirs. The liquids are fed to individual jetting heads which squirt tiny droplets of the in the required pattern to form a layer of the object. The materials harden by rapidly dropping in temperature as they are deposited. After an entire layer of the object is formed by jetting, a milling head is passed over the layer to make it a uniform thickness. The process is repeated to form the entire object. [4]

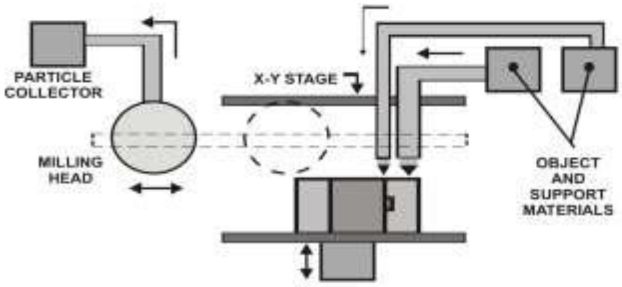


Figure 6 - Inkjet (Thermal phase change) procedure

IV. APPLICATION OF RAPID PROTOTYPING [RP] IN METAL CASTING.

A major application of RP technologies in industrial manufacturing is Rapid Tooling in metal casting.
Methods can be classified into the following three categories:

- *Direct tooling* - use of RP-generated model as a substitution for a traditional tooling means;
- Indirect tooling - use of RP-generated models as means for production of an actual tooling;
- *Tool-less processes* - technological processes in which actual cores or moulds are made without traditional tooling, directly by an RP-system.

Methods have been used for a number of metal casting processes, which are detailed below.-

Sand Casting

It is one of the major processes used to manufacture cast parts. In this process, molten metal is poured into a disposable mold formed out of foundry sand containing binder.

Investment casting process

This process utilizes disposable shell molds made using a wax pattern or some other material that can be melted or burned away. The tooling in this process is reusable mold for lost pattern pouring. These molds can be made from metal (usually aluminum) in case of high-production runs, or from epoxy, or even rubber in case of medium and low-runs productions.

Permanent Mould Casting

This process utilizes reusable (permanent) molds made of a metal. Cores, used in permanent mould casting may also be made from metal (reusable cores) or sand (disposable cores). Since metallic moulds and cores are reusable, they are the immediate tooling in permanent mould casting. RP technologies can be utilized in the process of permanent mold making as direct or indirect implements. Besides metallic cores, sand cores made by RP methods may also be used in permanent mould casting. [3]

V. RAPID PROTOTYPING TECHNOLOGY IN MAXILLOFACIAL PROSTHESIS .

Application in Maxillofacial Prosthesis:

Rapid prototyping has been applied in the following aspects of maxillofacial prosthodontics -:
Production of auricular and nasal prosthesis .
Obturators .
Duplication of existing maxillary and mandibular prosthesis .
Manufacturing of surgical stents for patients with large tumors which require excision.
Manufacturing of lead shields to protect healthy tissue during radiotherapy treatment.
Fabrication of burn stents. [7]

Sculpting software is primarily used to create a basic *nose* prosthetic model. This basic model of nose is superimposed on an STL file converted from patients head soft tissue CT scan to create a matching prosthesis. The final model is then converted into 3-matic Medical for analysis and making the model air tight. Then the model sends to software for slicing and G-Code [Geometric code] production in order to make RP.

The final model of the nose is printed by using the 3D printer ,then finished by sand paper . Try in procedure is performed, and any pressure area is relieved. The 3D printed model is invested into a mold using investment material and the material is burned out in the oven. Maxillofacial silicone elastomer is chosen to reproduce the qualities of skin. [8]

VI. APPLICATION IN COMPLETE DENTURE

The manual method or conventional style takes a long period of time to produce.The manual method involves too many steps, such as making an impression, master model, wax up, mould casting, divesting, preparation and veneering.

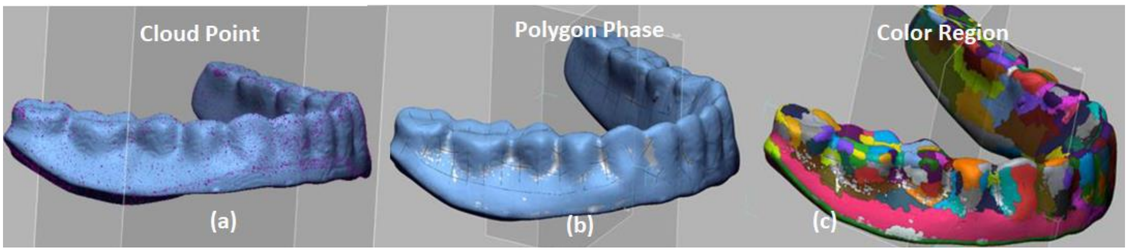
The complete denture undergoes the reverse engineering method before fabricating it with the help of 3D printing technology. Methodology can be divided into five levels which are identify product, 3-D scanning (digitizing), 3D model editing, 3D printing, and fabricate it completely with flashing technique of manufacturing denture.

a. Scanning Process

In the 3D scanning method, there are two types of method classification which are contact method and non-contact method.

b. 3D Editing Process

Software that is used is specialized in editing wrap file or point cloud file before converting it into STL [standard triangulated language] or IGES [Initial Graphic Exchange Specification] format. The editing software has three stages, which are *point phase, polygon phase, and shape face.* . All of these phase needs to be completed to accomplish a better part that been covert into STL format.



Post-processing phase of a denture scanned data (a) cloud point (b) polygon phase (c) color region. [9]

The first step in the 3D editing process is the *point phase*. In this phase, the noise reduction process needs to be done to reduce the point of scanned data. The step in the point phase began with reduction of noise of the uniform sample and lastly compute the wrap process. In the *polygon phase*, the polygon models are constructed. The *first* process is the open manifold process. *Second* is filling the hole process which fills the gap hole on the surface and checks the triangle of the surface. The *last process* is repaired intersection and relax polygon. After completing this phase, the NURBS [Non uniform Rational basis Spline] surface can be exported to STL, IGES or STEP [Standard for the Exchange of Product model data] file based on the application. The reverse engineering method offers a faster way of producing complete denture replacement. It saves about 30% of the time from the conventional method. [9]

VII. APPLICATION IN IMPLANT

Computer-aided designing and fabrication techniques, employing any available implant simulation software, provide a pre-operative view of anatomical structures and restorative information for achieving the ideal implant position. Subsequently, this clinical evidence can be accurately transferred to the patient and guide the pre-prosthetic surgical procedure. In the clinical setting, guided implant surgery applies these digital techniques using drill guides processed by *stereolithographic rapid prototyping*, on which implants are positioned, with minimal surgical exposure of bone, or even with a flapless approach. The advantages of the less invasive flapless surgical procedure include . • Shorter duration and facilitation of the surgical procedure • Faster and less complicated recovery.

• Enhanced esthetic results. • Bone grafting procedures are unnecessary.

A guided surgery system essentially consists of a stereolithographic guide with implant mounts for fixture installation, additional guide sleeves for fixation screw installation, drill keys of different heights, and depth-calibrated drills to prepare osteotomies.

In conjunction with conventional periapical and panoramic imaging techniques, visual inspection, and clinical palpation, this approach offers significant benefits over traditional procedures, providing more accurate and consistent results . [5]

There are four steps used in the fabrication of the dental implant . The received data of CT [Computed tomography] or MRI [Magnetic resonance imaging] is converted into an STL file i.e. stereolithographic file. The 3D structure obtained from the CT/MRI images is meshed in form of triangles. The received data of CT or MRI is converted into an STL file i.e. stereolithographic file. This STL file is used in some designing application in order to make an accurate and customized design. The number of triangles in order to make the design printable, is adjusted. The design is then sliced into layers with is interpreted and understood by the 3D printer by the same application or any slicing application. The 3D printer takes the directions of the nozzle from the sliced data. The completion of the process results into the manufacturing of a physical model. The material used in the printing of the dental implant prototype is PLA (Polylactic Acid).

The *first step* is to take the CT Scan data. For the selection of maxilla and the mandible region, a mask is created. In creating the mask, the range is selected to define the type of tissues being hard or soft. After calculating the mask region and setting the masking threshold, the mask is applied. A 3D structure of the selected threshold tissues is obtained. This 3D model is moved to the *second* step as a STL. The STL file is opened for the second step of analyzing the problem, and printing the implant. The *third* step involved the conversion of set parameters in printer. Then the slicing is done automatically by the software according to the given parameters. The *fourth step* is to transfer the sliced design data to the 3D printer. It takes 25-30 minutes in the printing of these dental implant prototype. The model is compared to the virtual design. The design results in high precision and a good fit to the printed maxilla.. [6]

CAD and Rapid prototyping technologies are being used in various fields of medicine. and dentistry for the rehabilitation of patients with head and neck defects. These systems are also being used for presurgical planning in dentistry , treatment planning and placement of implants, fabrication of facial prosthesis , this method accelerates the manufacturing field, reducing the manufacturing cost and time. It offers opportunities to make the production faster at lower costs, with high dimensional accuracy influenced by machine parameters.

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