10.5005/jp-journals-10051-0068

REVIEW ARTICLE

Rapid Prototyping: A New Chapter in Dentistry

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ABSTRACT

With the introduction of three-dimensional (3D) imaging and advanced engineering techniques, a dental prosthesis can now be fabricated with more accuracy and speed. This can be achieved by rapid prototyping (RP), which is a layer-by-layer additive process to form a 3D model or prototype. This article will discuss various techniques of RP, viz. stereolithography, selective laser sintering, fused deposition modeling, inkjet printing, 3D printing, solid ground curing, and laminated object manufacturing. Rapid prototyping can be used for the fabrication of surgical templates, wax patterns, crowns and bridges, removable partial denture frameworks, maxillofacial prosthesis, orthodontics brackets, etc.

Keywords: Inkjet printing, Rapid prototyping, Selective laser sintering, Stereolithography.

How to cite this article: Jain N, Pathak C, Manisha, Kaur H, Kundra S, Ritu. Rapid Prototyping: A New Chapter in Dentistry. Int J Oral Care Res 2016;4(4):301-304.

Source of support: Nil

Conflict of interest: None

INTRODUCTION

A prototype is often used as a part of the product design in order to assess and confirm the performance before introduction of a new product. Prototypes or models can be fabricated by two techniques, viz. additive or subtractive. Rapid prototyping (RP) is a layer-by-layer additive process of producing models or prototypes from three-dimensional (3D) computer-aided design (CAD) data without involving any conventional manufacturing or tooling processes. It has found various applications in dentistry, i.e., fabrication of wax patterns for dental prosthesis, models, maxillofacial prosthesis, surgical template for implant placement, fixed partial denture prosthesis, tissue engineering, etc. The RP technology has already been used in building medical models representing a new approach for surgical planning and simulation and is now being explored in the field of dentistry.[1]

The subtractive technique is achieved by lathing, milling, or grinding, whereas the additive technique is achieved by layered manufacturing or solid free form manufacturing. The subtractive technique is able to capture only the external surface data of the proposed object and not the internal complex shapes, which can be captured by the additive techniques.[2] In all commercial RP processes, the model is fabricated by deposition of layers along the x–y plane two dimensionally, and all the single layers are stacked up on top of each other along the *z*-axis.

BASIC STEPS IN RAPID PROTOTYPING

The starting point of RP process is forming a 3D CAD model from a 3D digital image obtained from computed tomography (CT) scan or magnetic resonance imaging data or laser scanning (Fig. 1). The data are reformatted in STL file format, which is a triangular representation of a 3D surface geometry also called as tessellation and is a universally accepted RP file format.[3] After this orientation of part deposition is decided, it is followed by slicing of the virtual model horizontally in accordance with it. A suitable part deposition orientation can improve part accuracy and surface finish and reduce the cost, production time, and support structures needed for building the part.[4] After slicing, the data are transferred to the RP system and after careful evaluation of the design, a corresponding physical model is generated by layering method. Finally, the resultant prototype is cleaned, finished, and sent for evaluation (Flow Chart 1).

Various RP Technologies

- Stereolithography
- Selective laser sintering

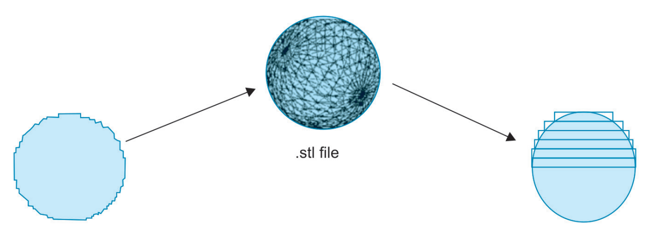

Fig. 1: Formation of 3D CAD model

Source: Upcraft S, Fletcher R. The rapid prototyping technologies. Assembly Autom 2003 Dec;23(4):318-330

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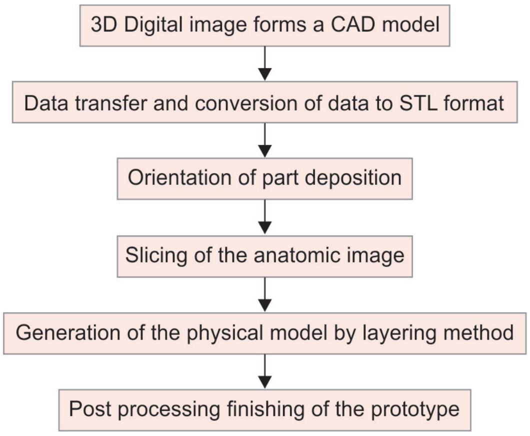
Flow Chart 1: Basic steps of rapid prototyping



- Fused deposition modeling
- Inkjet printing
- 3D printing
- Solid ground curing
- Laminated object manufacturing.

Stereolithography

In this process, the model is made using a photosensitive liquid resin, which is cured on a platform by exposing it to ultraviolet laser. After the first layer is cured, the platform is lowered into the bath containing the photosensitive resin, and a new layer of a specific thickness is added. It is then cured and gets bonded to the previous layer due to its self-adhesive property. The layers are sequentially added until the building up of the model is complete. After that, the model is removed from the platform and kept for further curing in a chamber using ultraviolet laser. It can be used for surgical template fabrication for implant placement.[5] It provides high accuracy, high strength, and good surface finish.

Selective Laser Sintering

In this process, a thermoplastic powder material (polymers, metals with binder, metals, ceramics) is spread over a surface of a cylinder and is sintered or fused together using a CO_2 laser. A new layer of powder of specific thickness is next added as the piston of the cylinder gets lowered down by that specific distance. This layer is sintered by melting and bonding to the previous layer. The temperature of the chamber is maintained just below the melting point of the powder in order to minimize thermal distortion and for the bonding of the subsequent layers. After sequential building up of the model is complete, the piston of the cylinder is raised and the model is removed. This technique can be used for the fabrication of removable partial denture frameworks, crowns, and bridges. It can be used to fabricate multiple units at the same time and give nearly 100% density.[6]

Fused Deposition Modeling

In this process, the material is supplied by a plastic or wax coil, which is attached to an extrusion nozzle. The coil is unwound, and the nozzle is heated in a controlled manner. The nozzle moves to supply the material in a specific thickness and design on a mechanical stage. The subsequent layers are added, which will bond to the previous layer on solidifying. The temperature of the chamber is maintained below the melting temperature of the material for better bonding and speed. It can be used for fabrication of surgical templates and wax patterns. The product is not 100% dense and has the limitation of using only thermoplastic materials. It is a time-consuming process and has low resolution.[7]

Inkjet Printing

In this process, the model is fabricated from plastic material supported by wax material. These materials are released from individual jet heads, which move in a X–Y plane to supply a layer of specific design. A milling head subsequently moves over this layer to make it to a uniform thickness. Subsequent layers are then added, which bond to each other. After completion of the model, the wax support is removed, and the finishing of the model is done. Though it is a slow process, it gives a good surface finish and fine resolution. It is used for fabrication of all ceramic prosthesis.

Three-dimensional Printing

This process involves two chambers, i.e., feed chamber and build chamber, both of which contain a piston. A feed roller overlying the feed chamber spreads a layer of the feed material (ceramic, polymer, and metal powders with binder) on the surface of the build chamber. A binder cartridge will travel over this layer to deposit binder solution. The binder piston will then move down by a specific distance to provide space for the deposition of the next layer. This process is repeated until the completion of the desired model followed by its removal from the build chamber. It is a quick procedure and gives high resolution, but the surface finish is poor.[8] It can be used for the fabrication of crowns, bridges, stone models, and orthodontic appliances.

Solid Ground Curing

In this process, a photomask of a section of the model is placed over a photosensitive fluid. The exposed fluid is then flooded with ultraviolet light to cure and solidify the liquid. After the layer is cured, the machine vacuums up the excess liquid resin and sprays wax in its place to support the model during the build. The top surface is milled flat, and then the process is repeated to build the next layer. When the model is complete, the wax is removed by immersing it in a solvent bath. This technique can build multiple parts rapidly due to the large surface area that can be cured at the same time.[9]

Laminated Object Manufacturing

Profiles of object cross sections are cut from roll of paper or other web material using a laser. A new slice is bonded to the previous layer using a heated roller, which melts an adhesive coating on the bottom side of the paper. The profiles are then traced by an optics system that is mounted to an X–Y stage. The excess paper is cut away and is wound on a take-up roll. Areas of cross sections that are to be removed in the final object are heavily cross-hatched with the laser to facilitate removal. After completion of the model, all the slices are sealed with a urethane lacquer, silicone fluid, or epoxy resin to prevent distortion and water sorption.[10] The finish, accuracy, and dimensional stability of paper objects are not as good as for materials used with other RP methods.

DISCUSSION

Zhao et al[11] studied the accuracy of CAD/computer-aided manufacturing (CAM) and laser sintering technique for implant surgery and found that they aid in better preoperative planning and more precise implant insertion as compared with conventional techniques. Scott Ganz[12] has described the use of stereolithography technique in predictable placement and immediate loading of implants through use of CT imaging, stereolithographic models, and CT-derived surgical templates. The RP can be used for the fabrication of dental implants, which otherwise is difficult due to overhangs, sharp corners, and undercuts. It can also aid in the fabrication of mandibular titanium trays, which are implanted to replace the bone lost or removed due to tumor.

The RP and manufacturing technologies are of great assistance in developing novel biodevices, since they have to be carefully tested and evaluated as they come in direct contact with the biological systems.[13] The RP technology is being used by bioengineers to grow scaffolds of living artificial tissues in order to repair burns and chronic wounds.[14]

The RP technology has gained importance in oral and maxillofacial surgery.[15] It can be used as diagnostic tool in orthognathic surgery, predicts surgical results with simulation models, enables reconstruction of resected mandibular section, and aids in placement of implants.

The RP can effectively reduce the extraoral time of tooth during tooth transplantation procedure.[16] This can be achieved with the simulation model, which aids in the precontouring of the recipient bone and quicker tooth transplantation. It also maintains the integrity of the periodontal cells of the tooth in question.

Sykes et al[17] compared the accuracy, time required, and potential advantages of RP over the traditional methods in the production of wax patterns for auricular prosthesis and found that wax patterns produced by RP were better than that of conventional methods. Wu et al[18] have described a method combining laser sintering with RP in the fabrication of porosity-free and smooth titanium castings without making use of the traditional impression-making technique.

Kwon et al[19] described CAD/CAM fabrication of the complex anteroposterior lingual bonded retraction appliance for intrusive retraction of the maxillary anterior dentition. The RP has also been found to be useful in lingual orthodontic technique to fabricate custom-made brackets and series of prebent wires.[20]

Stanek et al[21] compared the mechanical properties, i.e., tensile strength and impact strength, surface quality of prototypes, and final cost, with time of part building for fused deposition modeling and 3D printing. The results were found to be better for 3D printing because of better mechanical properties, shorter time, lower costs, and better surface quality.

Despite so many advantages and its various applications, one of the main disadvantages of RP is the failure of reproducing a real product or a system. It heavily relies on working with models and prototypes that may just be a replica and short of the characteristic of the real products. The virtue of only producing small applications is in itself a disadvantage, since the process cannot be used in large applications. The RP is also limited by the materials that can be used and involves high cost.

CONCLUSION

Rapid prototyping is an emerging technology of designing, creating, and applying the use of working models or prototypes to test on a product's features, which include the design, the performance, and the output. Its rapidness in production makes this process a very effective way of designing and developing such models. It can be used for surgery planning and simulation, improvement of diagnostic quality, fabrication of implants, providing information about the surgery to the patient, orientation during surgery, and fabrication of maxillofacial prostheses with higher precision and quality in a shorter period. Rapid prototyping will soon replace the conventional dentistry and make it quicker, more accurate, and more predictable.

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