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Rapid Prototyping in Dentistry – An Update

Pratik Bhatnagar, Jaspreet Kaur, Pooja Arora, Vipin Arora

Department of Prosthodontics, Subharti Dental College, Swami VivekanandSubharti University, NH-58, Meerut-250 005, India

Corresponding Author: Pratik Bhatnagar

Abstract

Curiosity is the mother of 'innovation'. Manual prototyping by skilled craftsmen was an age old practice and a paradigm shift came from invention of computers. From then till now this manufacturing technology has developed from prototyping to rapid prototyping (RP). RP is two decade old technology to quickly produce prototypes directly from a 3D CAD (computer aided design) model and involves adding material successively, in layers, to create a solid of a predefined shape. It is being used to shorten and simplify, product development cycle for many applications - aerospace, automobile, home appliances etc. Advent of RP technology also has opened up new perspectives for design & production in the field of dentistry. Over the years, RP has evolved from producing prototypes for form, fit and functional testing to producing final end products for functional use. Since the presentation of first commercial application in last decade, a large number of processes have been developed. Present day commercial systems use various materials that range from polymers, metals, metal-polymer composites, ceramics and sand. This technique is widely used in dentistry, for e.g. in the fabrication of inlays, onlays, crowns, invisible orthodontic prosthesis for straightening teeth, pre-surgical planning of implant placement, surgeons can practice surgery on models allowing appreciation of osteotomy, and so on. Limitations to use of RP technology include high cost of equipment, complicated machinery, and reliance on special expertise to run the machinery during production .The expense could be justified in light of many other applications that could benefit from the RP which includes construction of surgical and burn stents, without subjecting sensitive tissues to impression making procedures. This article reviews the development of current technology available of rapid prototyping and its application in the field of dentistry.

Key Words: *Rapid Prototyping, Dentistry, Curing, Selective Laser Sintering, Tessellation*

Introduction

Prototyping or model making is one of the important steps to finalize a product design. It helps in conceptualization of a design. Before the start of full production a prototype is usually fabricated and tested. (Bagaria 2014). A prototype is an early sample, model or release of a product built to test a concept or process or to act as a thing to be replicated or learned from. There are three phases of prototyping as follows.

- First phase of prototyping

During this phase, Manual prototyping used to be done by skilled craftsman. It was an age-old practice for many centuries.

- Second phase of prototyping (Started around mid-1970s)

A soft prototype modeled by 3D curves and surfaces could be stressed in virtual environment, simulated and tested with exact material and other properties.

- Third phase of prototyping (Started during early 1980s)

The 3rd and the latest phase of prototyping came in which layer by layer deposition is done to make a prototype which is then later tested. Rapid prototyping (RP) started with the enormous growth in CAD/CAM technologies.

Historical Development of Rapid Prototyping (Chua and Leong 2000).

Table 1 depicts the historical development of rapid prototyping and other related technologies.

Table 1. Historical development of rapid prototyping and other related technologies

Year of inception	Technology
1770	Mechanization
1946	First computer
1952	First Numerical Control (NC) machine tool
1960	First commercial laser
1961	First commercial Robot
1963	First interactive graphics system (early version of Computer Aided Design)
1988	First commercial Rapid Prototyping system

Rapid Prototyping

It is the automatic construction of physical objects using additive manufacturing technology or it is is a group of techniques used to quickly fabricate a scale model of a physical part or assembly using 3-D CAD data.Construction of the part or assembly is usually done using 3D printing or "additive layer manufacturing" technology.

In all commercial RP processes, the part is fabricated by deposition of layers contoured in a (x-y) plane two dimensionally. The third dimension (z) results from single layers being stacked up on top of each other, but not as a continuous z-coordinate. Therefore, the prototypes are very exact on the x-y plane but have stair-stepping effect in z-direction.If model is deposited with very fine layers, i.e., smaller z-stepping, model looks like original (Pandey 2014).

In computer graphics, the term "tessellation" is used to describe the organization of information needed to render to give the appearance of the surfaces of realistic three-dimensional objects.

A **tessellation** is the tiling of a plane using one or more geometric shapes, called tiles, with no overlaps and no gaps. In mathematics, tessellations can be generalized to higher dimensions (Pandey et al 2004). Therefore to summarize, there are three steps in rapid prototyping-

1. Generation of mathematical layer information
2. Generation of physical layer model
3. Post- processing phase

Various Rapid prototyping techniques important in the field of dentistry are as follows:-

- Stereo-lithography (SL)
- 3-D Printing
- Fused Deposition Modeling (FDM)
- Solid Ground Curing
- Laminated Object Manufacturing (LOM)
- Selective Laser Sintering (SLS),

Stereo-lithography (Optical fabrication, Photo-solidification, Solid free-form fabrication and Solid imaging)

It is a technique or process for creating three-dimensional objects, in which a computer-controlled moving laser beam is used to build up the required structure, layer by layer, from a liquid. It is an additive manufacturing or 3D printing technology used for producing models, prototypes, patterns, and production parts.

Advantages-

- Speed- good
- The length of time - depends on the size and complexity of the project.
- Maximum size of approximately 50×50×60 cm (20"×20"×24")
- Prototypes made by stereo-lithography are strong enough to be machined and can be used as master patterns for injection molding, thermoforming, blow molding, and various metal casting processes.

Disadvantages-

- Very Expensive
- The cost of photo-curable resin ranges from $80 to $210(Rs. 5100- Rs. 13500) per liter, and
- Cost of stereo-lithography machines ranges from $100,000 to more than $500,000. (Rs. 64 Lac- Rs 3.1 Cr).

Selective Laser Sintering (SLS)

Selective laser sintering (SLS) is an additive manufacturing technique used for the low volume production of prototype models and functional components. It was developed and patented by Dr. Carl Deckard and Dr. Joe Beaman in the mid-1980s. It involves the use of a high power laser to fuse small particles of plastic, metal, ceramic or glass powders into a mass that has a desired three-dimensional Shape.

The Laser selectively fuses powdered material by scanning cross-sections generated from a 3-D digital description of the part on surface of a powder bed. After each cross-section is scanned, powder bed is lowered by one layer thickness, a new layer of material is applied on top, and the process is repeated until the part is completed. SLS machine preheats the bulk powder material in powder bed below its melting point by infrared heating in order to minimize thermal distortion (curling) and facilitate fusion to the previous layer. Various materials can be used such as fine polymeric powder – polystyrene, polycarbonate or polyamide etc. within the range of 20 to 100 micrometer diameter. The laser is modulated in such away that only those grains, which are in direct contact with the beam, are affected (Pham and Dimov 2001).

Advantages

In this process support structures are not required as the un-sintered powder remains at the places of support structure. It is cleaned away and can be recycled once the model is complete.

3-D Printing

It is a different additive rapid prototyping technique in terms of design and print a wax pattern of a restoration. It operates like an inkjet printer, the machine builds wax patterns of frameworks and full crowns.The waxpattern subsequently is castor pressed in the same manner as manually waxed restorations would be.

Laminated Object Manufacturing

Laminated object manufacturing (LOM) is a rapid prototyping system developed by Helisysinc. in which, layers of adhesive coated paper or plastic are successively glued together and cut to shape with a knife or laser cutter. The slices are cut in required contour from roll of material by using a 25-50 Watt CO_2 laser beam. A new slice is bonded to previously deposited slice by using a hot roller, which activates a heat sensitive adhesive. Apart from the slice unwanted material is also hatched in rectangles to facilitate its later removal but remains in place during the build to act as supports. Once one slice is completed platform can be lowered and roll of material can be advanced by winding this excess onto a second roller until a fresh area of the sheet lies over the part. After completion of the part they are sealed with a urethane lacquer, silicone fluid or epoxy resin to prevent later distortion of the paper prototype through water absorption.

Advantages

- In this process, materials that are relatively cheaper like paper, plastic roll etc. Can be used.
- Parts of fiber-reinforced glass ceramics can be produced.
- Large models can be produced and
- The building speed is 5-10 times as compared to other RP processes.

Limitations

- The process included fabrication of hollow models with undercuts
- Large amount of scrap is formed.
- There remains danger of fire hazards and
- Drops of the molten materials formed during the cutting also need to be removed

Solid Ground Curing (SGC)

It is a type of additive technique in which laser polymerizes successive layers of resin through a stencil. They all use ultraviolet light to selectively harden photosensitive polymers. Unlike SLA, SGC cures an entire layer a time.

The photosensitive resin is sprayed on build platform. The machine develops a photomask (like a stencil) of layer to be built. The Photomask is printed on glass plate above build platform using an electrostatic process. Then the Mask is exposed to UV light, which only passes through transparent portions of mask to selectively harden shape of current layer. Later Machine vacuums up excess liquid resin and sprays wax in its place to support model. The top surface is milled flatand the process repeats to build next layer. When the part is complete, it must be de-waxed by immersing in solvent bath.

Applications (Joshi 2006)

1. Wax pattern fabrication
   - PFM crowns
   - Pressed ceramic crowns
   - RPD frameworks

2. Maxillofacial prosthodontics
3. Mold for metal casting
4. Mold for complete denture
5. Direct metal prosthesis fabrication

Conclusion

Rapid prototyping is an emerging field in the field of dentistry. Yet it had emerged a long ago but it will take time to hold its feet in the ground in dentistry. The engineering field has developed more than 30 rapid prototyping techniques but in dentistry less than 10 techniques have been used so far. So it is a long journey to take ….

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