Rapid Prototyping: A Revolutionary Technique in Dentistry: A Review

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Abstract
Rapid prototyping is a CAD/CAM technology introduced in 1980s is a branch of engineering used to fabricate scale model based on three-dimensional computer aided design (CAD) data. In the past two decades RP was utilized in medical and field and has given promising results. RP has many dental applications such as preparing implant surgical guides, mould for metal castings, zirconia prosthesis and framework for fixed and removable partial dentures, wax patterns fabrication of dental prosthesis and complete denture.
Keywords: Rapid Prototyping, Stereolithography, Inkjet Based System, Selective Laser Sintering, Laminated Object Manufacturing

Introduction
Rapid prototyping systems also known as solid freeform fabrication (SFF) or layered assembling, or generative manufacturing enables quick and automatic construction of a 3D model of a part/product. Rapid prototyping (RP) is a technique for the fabrication of solid objects from computer design; and can be defined as a process of producing physical prototype in a layer by layer manner from their CAD model data, CT and MRI scan data, and any 3D digitised data without the involvement of any fixtures particular to the geometry of the model being processed.[1,2] RP technology subjoins liquid, powder, or sheet materials with additive ways to build shapes, in order to create models. RP technology was developed in three phases; as:-First prototyping phase: in this period, manual prototyping have been created by efficient craftsman. Second prototyping phase: in the mid of 1970s, a soft prototype model was stressed virtually, with precise material using 3D curves.Third prototyping phase: begun in 1980s. In this era, layer by layer technique have been taken into consideration to create a prototype. Applications of rapid prototyping had begun together with the vast evolution of CAD/CAM technologies.

History
Innovation is a product of curiosity. Manual prototyping which done by skilled craftsmen considered as an outdated practice and a model shift came from innovation of computers. Since that time until now this technology has advanced from prototyping to rapid prototyping (RP). 1894 - Chuck Hull first introduced the concept of 3DP described it as stereolithography (SLA). 1957 - World’s first CAM software program using a numerical control programming tool named PRONTO by Dr Patrick J. Hanratty. 1971 - Computer-assisted production of dental restorations by Duret. 1988 - Hull and the company 3D system developed the first 3D printer termed "SLA apparatus". 1990 - Scott Crump engineered a technique called "FDM". 1992 - Introduction of SLS. To fabricate a physical prototype or a scale model through digital technology, two different approaches can be used: Subtractive approach and Additive

approach. Subtractive approach is usually facilitated using computer numerical control machining (CNC milling). The data principally obtained from an optical or contact probe surface digitizer captures the external surface data of the prescribed anatomy and not the internal tissue surface, hence less effective. This approach relies on milling an available larger blank using a CNC machine.The CAM software automatically translates the designed CAD model into a tool path for the CNC machine. This involves series of procedures, including sequencing, milling tools, and tool motion direction and magnitude. The dental CNC machines are composed of multi-axis milling devices facilitating 3D milling of dental prosthesis. 3-Axis Milling Devices: These are the most commonly used. The milling burs move in three axes (x-, y- and z- axes) according to calculated path values. Therefore, 3-axis milling has the advantage of having minimal calculation and cumulative milling time. 4-Axis Milling Devices: These machines allow for blank movements in an additional axis, which helps mill larger blank producing long-span frameworks. 5-Axis Milling Devices: The 5th axis in this machine provides a rotating path of the milling tool or the blank. This facilitates the production of very complex geometries and smooth external surfaces such as acrylic denture bases.[3,4,5,6] The Additive approach, on the other hand, can produce arbitrarily complex shapes with cavities such as human anatomical structures with the use of rapid prototyping. Additive manufacturing is defined as joining materials to make objects from 3D model data, usually layer upon layer. Once the CAD design is finalized, it is segmented into multislice images. The machine lays down 5–20 layers for each millimetre of material successively with liquid and powder that fuses to create the final shape. This is followed by workpiece refinement to remove the excess materials and supporting arms.

Types of Rapid Prototyping Technology

Stereolithography (SLA), Selective laser sintering (SLS), Direct metal laser sintering (DMLS), Fused deposition modelling (FDM), Polyjet 3D printing (PJP), Laminated Object Manufacturing (LOM), Inkjet 3D printing (IJP), Colour-Jet-Printing (CJP), Multi-Jet-Printing (MJP), Electron Beam Melting (EBM), The common technologies being used are stereolithography (SLA), inkjet-based system (3DP), selective laser sintering (SLS), and fused deposition modelling (FDM).[7,8]

Stereolithography

Stereolithography is in use since the mid1980s, although it is an old age system, it is found to be the most favoured advanced RP technology. It uses computer-controlled moving laser beam to build up the required objects from a liquid in a layer by layer manner through additive manufacturing or 3D printing data. A bath of photosensitive liquid resin, a model-building platform, and an ultraviolet (UV) or lasers for curing the resin are its main components. It processes the layers sequentially and bind them together forming the solid structure starting from the bottom of the model to upwards. By exposing the resin to an UV light, hardening of a thin defined layer gets done. Once the resin layer is cured, its platform is lowered within the bath in a definite distance, and then the process is being repeated till the full object is achieved. And at last the object is being removed from the bath and will be cured for more time in a UV cabinet. Currently, selectively colour-changing materials are available for SLA/biomedical applications, having accentuated properties with a various colour providing distinct visualization of anatomical structures. SLA is mainly used to create the impression for reconstructive surgeries and sub-periosteal dental implant surgery and to fabricate surgical drilling templates during the insertion of dental implant.[9,10,11,12]

Inkjet-Based System OR 3DP

In 3Dimensional Printing system, measured amount of the raw powder is dispersed from the container by a moving piston. Then, a roller suppresses the powder located at the top of the fabrication chamber. Following this the multi-channel jetting head will deposit the liquid adhesive in a 2dimensional pattern onto the powder, bonding and forming a layer of object. Next, the piston will distribute and join a layer of powder. This layer by layer adding process will continue till the development of a complete prototype. The unreacted powder which remains at the end undergoes heating process with the fabricated part sound and intact.[1,7,11,13,14]

Selective Laser Sintering

Selective laser sintering (SLS) discovered by Dr. Carl Deckard and Dr. Joe Beaman in 1980. In this layers of powder material selected were fused into a 3D model by appropriating a computer-directed laser. A roller distributes the powdered material over a cylindrical surface which is built and is spread on top layer wise fashion of the preceding hardened layer and repeated sintering is done.To support the newly added layer of powder, the supporting platform maintains one object layer thickness. The surface of this firmly compressed powder is then exposed to a beam of laser.Especially in prosthodontics, thermoplastic materials commonly employed in this method includes nylon composite, metallic materials, ceramics, investment casting wax and thermoplastic composites.[3,6,1015,16]

Fused Deposition Modelling (FDM)

In FDM method, thermoplastic material is used for the fabrication purpose.Temperature-controlled FDM extrusion nozzle dome is used in delivering the thermoplastic polymer which is then heated to form a free-flowing semi-liquid. The processor controls the motion of the nozzle head which leads the material into place with an ample precision to trace and deposits the raw material in very thin layers onto a subsidiary platform. Layer by layer built up of the subject is done and the underlying material solidifies in less than 0.1s after being emitted from the nozzle. The supporting structures in the process are used for projecting geometries and are later removed from the completed object.[5,7,11,17,18]

Direct Metal Laser Sintering (DMLS)

DMLS technique is used in the fabrication of metal parts with high precisionand mechanical strength.The metal material is added layer by layer and to fuse powder. From a definite point laser beam is used in the fabrication of prosthesis.[1,8,13]

Laminated Object Manufacturing (LOM)

Defined sheets of materials were used forfabrication in this method.As per the desired cross-section lasers are used to cut the sheet material and adhesives are used to conjoin the layers and created by repeating the steps again.

Biomedical materials used in RP technology

Varieties of materials are available to be used in medical applications of RP. And their selection is mainly based on the purpose of resultant object (planning procedures, implants, prostheses, surgical tools, and tissue scaffold) and the chosen RP technique. These Materials must exhibit biological compatibility. RP bio-medical materials mainly includes: Photosensitive resins, Metals (stainless steel, titanium alloys, Cobalt Chromium alloys, other), Advanced bio-ceramic materials (Alumina, Zirconia, Calcium phosphate-based bio-ceramics, porous ceramics), Polycaprolactone (PCL) scaffolds, polymer-ceramic composite scaffold made of polypropylene-tricalcium phosphate (PP-TCP). PCL and PCLhydroxyapatite (HA) for FDM, PLGA, starch-based polymer for 3DP, polyetheretherketone-hydroxyapatite (PEEK-HA), PCL scaffolds in tissue engineering for (SLS), Bone cement: new calcium phosphate powder binders (mixture of tetracalcium phosphate (TTCP) and beta – tricalcium phosphate (TCP)), Polimethyl methacrylate (PMMA) material, other polymer calcium phosphate cement composites for bone substitutes and implants. RP technology is attaining geographical popularity too. The main savings are in costs as it minimizes the tooling, designing procedures ultimately reducing the labour cost. Part-specific settings up and programming are also reduced; thereby minimizing the assembly, purchasing and inventory expenses. Thereof, providing greater diversity of offerings to choose from.[19,20,21]

Applications of Rapid Prototyping Technology in Prosthodontic

Rapid prototyping is the technology which produce a solid objects of computer models. It can form functional structures in a direct way such as metal parts, as well it can used in nano-/micro- manufacturing and bio manufacturing, it is powerful manufacturing method. Like other medical branches, dentistry also used rapid prototyping in many of its fields such as surgery and maxillofacial prosthodontics surgical guide or physical model of dental implantology and Prosthodontics. From the definition, metal-free ceramic restorations that made by CAD/CAM system falls into this group of technology. One of the considerable other benefits of RP when used in dentistry is medical modelling fabrication, it is quite useful when used in mass production of patterns for casting purposes. In this method, it will be easy to create the difficult parts of restorations even without human involvement in a short time. Clinically, rapid prototyping technology can reduce the time and possible injury which may occur during implantation process. Although this technology was highly used in dentistry, however, its applications in prosthodontics are rare until now. By RP technology, dental prosthesis is constructed layer by layer directly from digital model simply and rapidly without special tooling and human interference, it makes a revolutionary progressing in the manufacturing of dental prosthesis. After the evolution of RP technologies and the materials which used with it, there is a possibility to create many types of dental prostheses for many various implementations, Such as dental prosthesis wax pattern, dental (facial) prosthesis mould (shell), dental metallic prosthesis, and zirconia prostheses. RP thought to play an important role in prosthodontics and it will be most acceptable technique for digital manufacturing of dental prostheses. Some of RP implementations are: crowns and RPD wax pattern manufacturing, complete dentures and casting moulds, maxillofacial prosthesis and dental metallic prosthesis manufacturing. RP technologies will be an alternative method instead of usual method which depends on the skills of dentists and technicians in the manufacturing of dental prosthesis.[2,6,7,11,22,23,24]

Advantages of RP Systems

RP is fast, it needs 1to 2 days to construction and insertion of the prosthesis. Physical prototype rapidly and clearly communicates all aspects of better design. Design defects can be detected and repaired with RP technique early. Confidence of the design integrity is one of the properties of RP technique. Good management for the tissues with fewer traumas. Accurate assessment of anatomical landmarks is important such as the size of the maxillary sinus in the upper jaw and location of the alveolar nerve in the lower jaw can be made with 3D technique like Accurate Osseous Topography analysis and precise location of implants. Data can be get without direct patient to avoid tissue tension. It can also be used with patients who can't cooperate when preparing usual full face moulage impression. CAD and RP technique can be reduce lab work due to creation of positive models which invested for casting later. Objects with definite accurate dimensions can be created by using RP approach of stereo lithography. If primary model is wasted or damaged during fabrication process, digital one can be used. The fabricated model will have the internal detail as well as outer surface.[17,19]

Disadvantages

More expensive materials and equipment is needed. Rp technique is contraindicated in case of unsupported soft tissue. A two-steps impression may be required to have proper orientation of the soft tissue. Undercuts that can't registered by the lenses will be lost, this can be minimized by positioning the patient correctly, also it will be helpful to create any additional undercuts by using digital manipulation of the STL file.Whereas, it also has certain limitations such as excessive cost of equipment, dependency on the user experience and complexity of the machines. However, several attempts have been made: amending its speed and accuracy, reducing the system and items cost rendering more use of RP fabricated models with continuous evolution of it.[14,18,24]

Conclusion

It should be noted that RP technologies differs considerably both in dental/medical fieldand in the industrial environment. Industrially, only non-existing models are planned virtually on the computer screen and then converted to physical prototype. Whereas in dental application, the object to be modelled often, exists physically (anatomical structures), whose creation involves acquiring data such as CT cross-sectional images, pre-processed collected dataenabling a format that a RP system can recognize, thereby leading to the formation of required physical prototype by linking with RP technology. RP system found to be an advanced and resilient fabrication technique. It made a rebellious alteration in the manufacturing of dental prosthesis.

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