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Rapid Prototyping: A Modernistic Era in Prosthodontics

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Abstract: ***Rapid prototyping is a branch of technicality, significantly to form a scale model of a physical part or assembly rapidly by making use of three-dimensional computer aided design (CAD) data. 3D printing or additive layer manufacturing technology is used to create the part or assembly rapidly in a precise form. CAD/CAM technology was created initially to manufacture prototypes for industrial purposes. Rapid Prototyping technology persuades the configuration and quick generation of large quantities of precise parts by the industrial manufacturing within a specific time with accuracy and pace. In the previous two decades this technology was utilized efficiently in the medical field with promising results. Rapid prototyping has various dental applications as well, such as fabrication of implant surgical guides, zirconia prosthesis and molds for metal castings, maxillofacial prosthesis and frameworks for fixed and removable partial dentures, wax patterns for dental prosthesis and complete denture. In this review the technique, methods and various implications of this emerging technology regarding prosthodontic will be discussed.***

Keywords: CAD/CAM, Rapid Prototyping, 3D Printing, Stereolithography

1. Introduction

Nowadays, Computer aided design/Computer aided manufacturing technology (CAD/CAM) is being widely used in many dental applications. Recent approaching CAD/CAM systems are mainly based on a milling procedure, from which a specific carved form e.g. full anatomical crowns or frameworks, can be processed from a block of milling material.[1] Whereas, on another scale due to profound layering additive technique, the processing of a complex customized structures such as removable partial denture (RPD) frameworks get ease in production.[2]

For fabrication of a physical prototype (model) in dentistry/or medicine; two different propositions are used: subtractive and additive. The subtractive technique is generally achieved by the conventional numerical control machining (CNC). CNC machining data are obtained from an optical or contact probe surface digitizer that can reproduced the external structural data but not the internal tissue data of the preferable anatomical object. Therefore, CNC machining is generally used for fabrication of typically small prototypes; example metallic and/or ceramic crowns in dentistry.

Whereas, the additive technologies, can fabricate any complicated structures or internal geometries with minor details. This revolutionary method is called the "Layered manufacturing", in which a solid 3D CAD design of an object mould into cross-sectional layer depiction from the bottom up, bonding one on other and then the numerical files get transform into virtual trajectories controlling the material additive processes for rapid production of layers in an automated fabrication machine to produce the entity called "prototype".[4, 5]

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.[6] 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:-[7, 8]

1) First prototyping phase: in this period, manual prototyping have been created by efficient craftsman.
2) Second prototyping phase: in the mid of 1970s, a soft prototype model was stressed virtually, with precise material using 3D curves.
3) Third prototyping phase: begun in 1980s. In this era, layer by layer technique have been taken into consideration to create a prototype. Application of rapid prototyping begun together with the vast evolution of CAD/CAM technologies.

Several techniques were formed since the first trade implementation of RP technology. Currently, many types of materials are being used with this system such as ceramics, sand, metals, polymers and metal-polymer composites.

"Skills and desire revolutionise the better innovative outcome". So, with the arrival of the RP technology into dentistry and prosthodontics, various clinical and laboratory procedures have been innovated by obliterating some intermediate stages and also based on the quality of the outcomes from the practitioners' skills. RP technology represents the enhanced new methods, by which it has become possible to replace the traditional "impression-taking and waxing" procedure.[7, 9] RP methods also substantially helps to shorten the time for developing patterns, molds, and prototypes. This technology is widely used in fabrication of crowns, inlays, onlays, invisible orthodontic prosthesis teeth and implant pre-surgical planning placement, enabling the surgeons practicing surgery on models to have an estimation of osteotomy.[9] Basic steps of fabricating a prototype using rapid prototyping is depicted in Flow chart. (Fig. 1).

Various types of RP technology

The frequently adopted RP technologies are stereolithography (SLA), inkjet-based system (3D printing - 3DP), selective laser sintering (SLS) and fused deposition modeling (FDM). The used materials are completely different; however wax, plastics, ceramics and metals are mostly used for dental application.

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.[10-12] (Fig. 2).

Currently, selectively colour-changing materials are available for SLA/biomedical applications, having accentuated properties with a various colour providing distinct visualization of anatomical structures.[4] 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.[15]

Selective laser sintering

Selective laser sintering (SLS) discovered in the middle of 1980s by Dr. Carl Deckard and Dr. Joe Beaman. It forms the acquired three dimensional structures by fusing small powdered particle materials like plastic, metal, ceramic or glass powders with a high power laser (CO2 laser). The particles have many higher properties than resin-based technologies with higher yields. Laser fuses the materials specifically after scanning the cross- sections which are created from a 3-D digital interpretation of the model on the surface of a powder bed.[12, 13]

The diffusion system of powder is like the action of the build cylinder, in which a piston moves upward to distribute a proper amount of powder for each layer further getting exposed to laser beam. Subjoining of the laser beam and the powder will increase the temperature to the melting point, causing the fusion of powder particles forming solid structure. (Fig. 3). SLS machine maintains temperature in the powder bed less than its melting point by infrared heating, causing depletion of thermal deformation and binding the layers. After finishing of the first layer, extra powder layer will be added by a roller technique over the layer which is scanned previously. This process is repeated until the whole object is formed, then the object is removed from the building chamber and the powder which is not scanned and fused can be reused. Post-processing may be needed, depending on the desired application. SLS technology can be utilised to fabricate removable partial denture (RPD) frameworks with cobalt-chromium alloy spherical powder that has maximum particle size of 0.045mm (particle size range 0.005- 0.045mm), the mean particle size approximately 0.030mm.[11-13]

Inkjet-based system or 3DP

In 3DP system, a steady measured quantity of the raw powder-form get transfer from a container by a moving piston. Then, a roller suppresses the powder at the top of the fabrication chamber. Then, the multi-channel jetting head will deposit the liquid adhesive in a 2D pattern onto the powder, bonding and forming a layer of the object. When a layer is formed, the piston will distribute and join the next powder layer. This process will continue till a complete prototype is developed. (Fig. 4). Unreacted powder undergoes the heating process, leaving the fabricated part sound and intact.[16]

Fused deposition modeling

FDM is the second most commonly used RP technology. In FDM, a thermoplastic material is used in a layer by layer manner through a temperature-controlled head. Supplied material is then liberated from a coil with a plastic filament into an extrusion nozzle head. The heated nozzle, then melt the plastic into semi liquid form permitting its flow in order to be turned on and off.[6-9]

FDM works in three axes, drawing the model one layer at the same time. When the machine nozzle is moved over the stand table in specific manner, it drops a thin bead of plastic forming the first layer. After its release from the nozzle, the plastic will solidifies and bonds to the layer below.[6-9] (Fig. 5).

FDM is useful for forming appropriate bone models. It can deliver the excellent visualization of an object form by highlighting specific features with different color. The system works slowly in case of fabricating models having wide cross sections, whereas, in fabricating small models having tall, thin form-factors, it works faster.[17]

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:-[18]

- 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 PCL-hydroxyapatite (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.

Prosthodontic implication of RP technology

Complete denture fabrication

Very few literatures are available for complete dentures enhanced by advanced technologies. **Maeda**[19] fabricated plastic shells of the dentition and record base by using 3D laser lithography. **Wu** [20] designed and fabricated denture record base and a titanium record base of a complete denture by using a laser rapid forming system. **Busch**[21] formulate an automatic arrangement of artificial teeth by taking anatomic structures such as alveolar ridge center lines and the inter-alveolar relations between alveolar ridges as guidance.

Regards to complete denture cases using RP technology, dentures in clinical use are altered to cope the proper occlusal relation and the mucosal surfaces, scanned through cone beam computed tomography (CBCT) and then merge as STL data. A 3D measurement device is used to scan the participant's face and then the positional relationship between the face and the dentures in 3D harmony are recreated via data integration by using CAD software. Afterward, the positions of the artificial teeth get arrange correlating the corresponding face simulation. The polished denture surfaces are also created on the basis of arrangement of the artificial teeth. Trial dentures can also get fabricated from the denture data by applying RP technology.

Removable partial denture clasps fabrication

Based on the former studies; making use of rapid prototyping and computer aided design (CAD), the framework is fabricated by scanning and digitally reconstructing the patients cast. The wax framework is then directly printed. **Han** combines 3D imaging and CAD with direct metal fabrication through Selective Laser Melting (SLM), allowing one-step fabrication of the final metallic framework. It is also expertise in creating fully dense metal parts having mechanical properties, equivalent to those of cast or wrought material.

All-ceramic restoration fabrication

Green– zirconia, all-ceramic dental restoration can be created by direct inkjet fabrication technique making use of slurry micro extrusion process. This leads to produce all-ceramic dental restorations with high precision along with cost competence and minimum material requirement.[6, 11, 12]

Implantology

Rapid prototyping in Implantology involves 3D imaging using 3D software for treatment planning. In it, a laser-driven polymerisation process fabricates an anatomic model and surgical templates allowing the precise translation of the treatment plan at the surgical field.

RP technology formulates a new way of translating a surgery planned on the computer to the operation itself. Thereby, the 3D data obtained can be filed into a computer, which further helps in fulfilling the following primary objectives of implant planning:-[23]

- Detailing of available bone quantity and quality,
- Recognition of any critical anatomic structures,
- Choosing authentic implants from software-based libraries and catalogues, and
- Simulation of the surgical implants placement that have been overlying on 3D images, at their defined host sites.

Maxillofacial prosthetics

RP technology roped the formulation of customized 3-D anatomic models exhibiting a level of complexity at ease, as it is based on an additive process of forming an object in layers demarcated by a computer model that has been virtually sliced. This also helps in detailed production of complex shapes with internal features and undercut areas. Through 3-D scanning as a modeling technique, it provides a digital model of the proposed anatomic part. Then, which can be digitally manipulated to form unacquainted reproduction of facial surface features, mirror anatomic parts, and formulating models in many scales. In maxillofacial prosthetics, RP are being used for[24]:

- Fabrication of obturator
- Fabrication of auricular, nasal prosthesis
- Forming surgical stents for patients having large tumours scheduled for excision.
- For radiotherapy treatment, it forms lead shields protecting healthy tissue.
- Formation of burn stents, so that only burned area can be scanned rather than subjecting other delicate, sensitive burn tissue to impression taking procedures.

2. Conclusion

It should be noted that RP technologies differs considerably both in dental/medical field and 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 data enabling 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. Whereas, it also has certain limitations such as excessive cost of equipments, 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.

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Figures

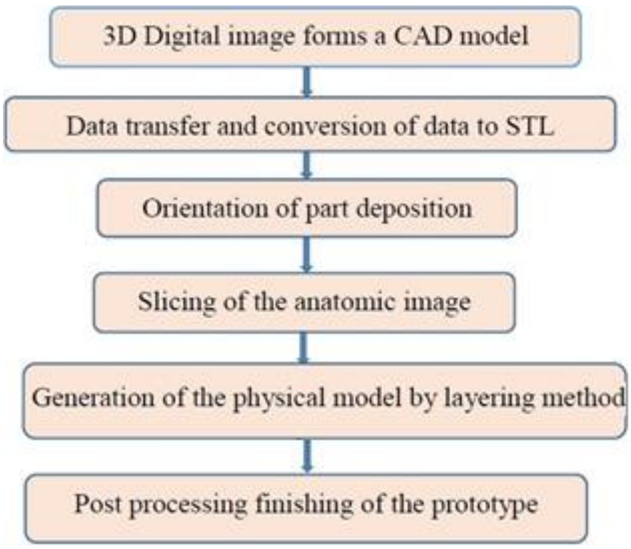

Figure 1: Flowchart depicting steps involved in rapid prototyping

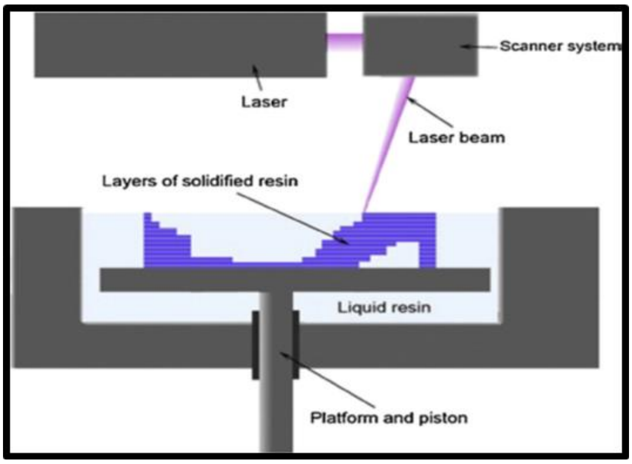

Figure 2: SLA Process

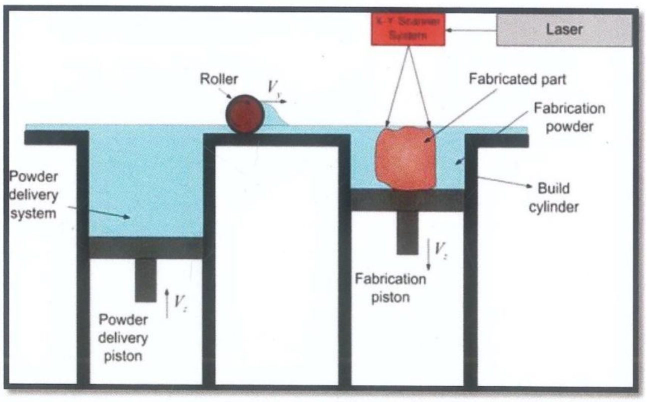

Figure 3: Schematic representation of 3DP technique

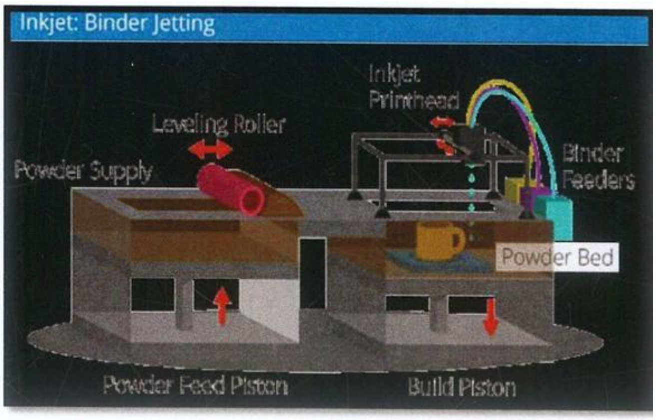

Figure 4: Inkjet-based system (3D printing - 3DP)

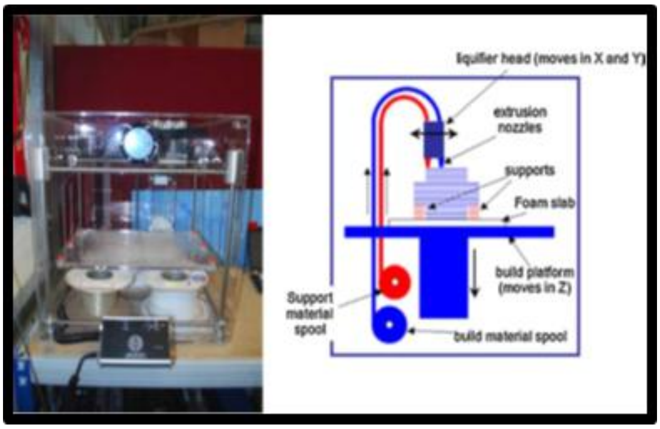

Figure 5: Fused filament fabrication apparatus and schematic