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RAPID PROTOTYPING IN PROSTHODONTICS- A REVIEW

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ABSTRACT

The goal of rapid mechanical prototyping is to be able to quickly fabricate complex-shaped, 3D parts directly from computer-aided design models. The key idea of this novel technology is based upon decomposition of 3D computer models data into thin cross-sectional layers, followed by physically forming the layers and stacking them up; “layer by layer technique.” This new method of modeling has raised many attentions in dentistry especially in the field of surgery and implantology. The purpose of this review study is to represent the historical development and various methods currently used for building dental appliances. It is also aimed to show the many benefits which can be achieved by using this new technology in various branches of dentistry.

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]

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.[3] 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:- [4,5]

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.

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: The first process of this type of RP was patented by Hull (1984), for the production of 3D models from photopolymer resins (Hull, 1984). This technology today is capable of producing highly complex 3D geometries with little or no human intervention (Hildebolt et al., 1990). Practically, SLA method is best for educational purposes and rehearsing the best possible surgical planning before surgery. This capability has been fully demonstrated from many studies (Bajura et al., 1992; European Commission, 2002; Wouters, 1998). There is also some, who clearly demonstrated the possibility to use these systems for impression purposes in reconstructive surgeries and sub-periosteal dental implant surgery (Gateno et al., 2000; Sailer et al., 1998; Golec, 1986; Truitt et al., 1988; D'Urso et al., 2000; Klein et al., 1992; James et al., 1998). Nowadays, the main objective for using SLA models in dentistry is fabrication of surgical drilling templates during dental implant insertion. The high accuracy of SLA-made surgical drill guides has been proved by several welldocumented studies (van Steenberghe et al., 2002; Sarment et al., 2003; Chen et al., 2004). Furthermore, the transparency of the model and the recent development of color resins allow distinct visualization of anatomical structures (Lightman, 1997).

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. Unreacted powder undergoes the heating process, leaving the fabricated part sound and intact.

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.[6,7] 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. 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.

Fused deposition modeling: The FDM is a RP system in which a temperaturecontrolled head extrudes thermoplastic material layer by layer. The FDM process allows a variety of modeling materials and colors, such as medical grade ABS, polycarbonates and investment casting wax (Chua, 1994). FDM can produce models, as well as surgical guides and templates, out of medical grade ABS, which is gamma-sterilizable and translucent. ABS offers good strength, and more recently polycarbonate and poly (phenyl) sulfone materials have been introduced which extend the capabilities of the method further in terms of strength and temperature range. Superior visualization by highlighting selected features in a different color is another prominent feature of this technology (Lightman, 1997; Chua et al., 1998). The mean accuracy of this technique is about ^0.127 mm and currently FDM is the second most widely used RP technology. Support structures are fabricated for overhanging geometries and are later removed by breaking them away from the object. A watersoluble support material which can simply be washed away is also available .The method is office-friendly and quiet so some manufactures produced systems exclusively for use in dentistry. In one of them, the wax modeling process made completely automated and the system can easily produce over 150 units per hours.

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 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[8] fabricated plastic shells of the dentition and record base by using 3D laser lithography. Wu[9] designed and fabricated denture record base and a titanium record base of a complete denture by using a laser rapid forming system. Busch[10] formulate an automatic arrangement of artificial teeth by taking anatomic structures such as alveolar ridge center lines and the interalveolar 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.

Implantology: Rapid prototyping in Implantology involves 3D imaging using 3D software for treatment planning. In it, a laserdriven 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:-

- 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:

- 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.

FURTHER DEVELOPMENTS AND FUTURE OUTCOMES

It is noteworthy that working with RP technologies in the medical/dental field differs considerably from using them in the industrial environment. In manufacturing, only nonexisting models are usually virtually designed on the computer screen and then converted to physical models. In medical applications, the object or part to be modeled often, but not always, exists physically (anatomical structures of the patients body) and building medical models essentially starts with acquiring data such as CT cross-sectional images, preprocessing of collected data to provide a format that a CAD package or a RP system can recognize and finally linking with RP technologies to obtain the desired physical models. Although several attempts have been made to further customize the technique described above for using in dentistry but it seems that in near future many other methods will developed which could change the traditional dental practices. Some of the shortcomings which must be fully revolutionized in future are the delivery time which must be further shortened if RP and resin manufacturers can develop direct prototyping biomedical material, and the total cost of the finished product must be lowered in order to be used in everyday practice. Moreover, it is a necessity to educate the dental team (dentists and dental laboratory technicians) with this new technology and including further unit hours in dental curriculums. Currently, a new project; under the name of RP4 Baghdad was announced by European Community which is targeted the possible usefulness of RP in the field of medical/dental with the aim of further develop the technology and overcome the insufficiencies in RP technology. RP4Baghdad, launched in May 2005 by coordination of Materialise, has focused on serious cases involving head injuries among civilians in Iraq. Many medical models have been produced and shipped to Baghdad to support teams of doctors with complex reconstructive surgeries of the head and face.

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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