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Rapid Prototyping: A Future of Modern Dentistry

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Abstract: *Emergence of advanced digital technology has opened up new perspectives for design and production in the field of dentistry. Rapid prototyping (RP) is the name given to the host of related techniques that are used to fabricate the physical models based on computer aided design and manufacturing. RP technology allows building of a three-dimensional (3D) model layer by layer, by additive process, reproducing almost every form of the external and internal anatomical structure by using 3D printers or stereolithography machines. RP is used in dentistry for a range of dental specialties including orthodontics, oral surgery, operative dentistry, prosthodontics etc. It has advantages of simplicity, flexibility, reliability, accuracy, better visualization and time saving. In this world of digitalization, rapid prototyping provides fascinating opportunities and can act as efficient auxiliary for diagnosis, treatment planning and treatment of patients as well. RP technologies are playing an imperative role in dentistry and will soon become one of the mainstream digital technologies holding the potential to change the conventional dentistry.*

Keyword: *Rapid prototyping, orthodontics, oral surgery, operative dentistry, prosthodontics*

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I. Introduction

In this era of virtual imaging, recent advancements in technology and digital solutions have modified diagnosis and treatment planning in dentistry leading to change in vision, from a conventional two dimensional(2D) into an advanced three dimensional(3D)technique."Rapid prototyping" is one such recent advancement in modern dentistry which constructs a 3D model by layer-by-layer additive process from three dimensional computer-aided design (CAD) data. Initially slicing of digital models is done, then through automated process of layer by layer construction, transverse sections are produced and these 3D physical structures are known as rapid prototypes. It is also known as "layered manufacturing", "solid free form manufacturing" or "3D printing"[1].This concept was first introduced in the field of engineering in 1980s for fabrication of solid models from computed files and day by day it is slowly becoming an integral part of dentistry as well. It provides fascinating opportunities in various aspects of dentistry like orthodontics, prosthodontics, oral surgery, implantology and operative dentistry etc. The key objective of this review is to focus on recent advancements of RP technology and its applications in the field of dentistry.

Classification of Rapid Prototyping Method

Broadly it can be categorized into:-

Subtractive method-involves lathing, grinding or milling. Less effective in dentistry because it captures only the external surface data of the object not the complex internal geometry.

Additive method-widely used in dentistry. Achieved by layered manufacturing and can produce complex shapes with cavities which are similar to human anatomy structures [2].

Process of Fabrication Of Rapid Prototypes

Fabrication of 3D model is preceded by a number of steps before 3D model is formed. Following are the steps involved:-[3]

1) Data acquisition-Data is obtained from CT/MRI scan slice images. Most of the MRI/CT scans software's produce output data in DIACOM (Digital Imaging and Communication in Medicine) image format which is

further converted into STL (Structured triangular language) file format. This is followed by slicing of virtual model after which it is transferred to the RP system for careful evaluation. [4]

2) Evaluation of design-unnecessary data is discarded and area of interest is retained.

3) Fabrication process-generation of physical model by layering method- The four most widely used techniques are:-[5]

- Stereolithography
- Fused deposition modeling
- Selective laser sintering
- Inkjet printing
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Stereolithography (SLA):-Chuck Hall in 1894 first introduced the concept of 3D printing, it was described as stereolithography (SLA)[6].In this technique, photosensitive liquid resin is exposed to ultraviolet(UV) laser leading to solidification of resin and thus construction of a 3D polymer occur. Solid object is formed by sequential curing of layers beginning from bottom of model.SLA is now one of the most popular RP technologies currently available.SLA can build the parts with complex geometries with high accuracy, good surface finish and fine building detail[4].But the method is quite expensive, labor intensive and time consuming.

Fused deposition modeling (FDM): It is the second most common method after SLA. In this technique, extrusion head deposits a thin bead of thermoplastic material onto build a platform which is maintained at low temperature. Layer by layer deposition occurs and hardening takes place to form the object. Though it is quite speedy and cheap method, the limitations include that only thermoplastic materials can be used; rough surface finish and not 100% dense.

Selective laser sintering(SLS):-In this process, carbon dioxide laser beam is used for fusing the layers of thermoplastic powdered material spread over a surface of cylinder to form a 3D model. The temperature of chamber is maintained below the melting point of the powder to minimize thermal distortion and for proper sintering of subsequent layers. After layer by layer building of model is complete, the piston of cylinder is raised and the object is removed. It can fabricate multiple units simultaneously and gives nearly 100% densities [7].

Inkjet printing :-First developed at Massachusetts Institute of Technology in 1993[8].In this technique, plastic materials supported by wax materials are ejected from jet heads which move in X-Y plane to form a layer of specific design. Subsequent layers are added which bond with each other to form a 3D model. After completion of this process the wax support is removed and the desired model is ready. Though the process is slow, it gives a smooth surface finish and fine resolution.

4) Validation of model-Finally the resultant prototype is cleaned, finished, evaluated and validated.

II. Dental applications of rapid prototyping

Application in orthodontics

1) Diagnosis and treatment planning;-

3D RP model can be used as an effective diagnostic tool in orthodontia. The correct identification of the position of the impacted tooth plays an important role in determining the treatment. Faber et al [9] used a RP model in identifying the exact position of impacted canine, and also locating the exact anatomical relationship between the impacted tooth and other surrounding teeth. Model also acts as a guide during intraopertive navigation of the surgical site. Above all it can act as a mode of communication with the patients and also for fabrication of metal attachment for canine retraction. Pessa first demonstrated the use of high resolution SLA for studying facial aging [10].

2) Fabrication of impression trays for indirect bonding and removable orthodontic appliances;-

Ciufollo et al introduced a new method of preparing trays for indirect bracket bonding wherein a silicone impression was first taken and the casts thus obtained were used to prepare the initial model of malocclusion [11]. Scanning of the model was done to create a 3D presentation and the data was processed in computer with dedicated software. After virtual positioning of brackets was done, the fabrication of RP trays was begun. These custom made trays help in accurate bracket placement and also saves clinical time.

Invisalign or clear braces are gaining popularity as an alternative to conventional metal braces. RP manufacturing of Invisalign is time saving and gives high accuracy. Lee et al first used a polyvinyl chloride

impression and generated a computerized 3D model in STL file format [12].Unlike previous attempts that used an expensive laser scanner for digitization of patients dental tissues, the recent technique uses CBCT data and is thus reasonably cheap, provides consistency and speedy over manual methods.

CAD and CAM techniques are used nowadays in fabrication of removable orthodontic appliances. A new method of incorporating wire into a single build was first introduced by Al Mortadi et al with the help of SLA [13].

3) Lingual orthodontics:-

Individualization of customized bracket allows clear cut and easy positioning on the tooth surface which can be directly bonded by the orthodontist. Arch wire geometry is produced by 3D location of bracket slots and the prototyping technology allows any clinical shortcomings to be rectified on spot. Wiechmann et al attached Herbst appliance to a lingual orthodontic [14].

Appliance using RP technology and it ensured an optimal 3D tube and plunger position for smooth functioning of the telescopic mechanism.

4) Orthognathic surgery:-

OPG, facial photos, dental study casts and cephalograms are used as conventional diagnostic tools before any orthognathic surgery. However the spatial relationship of bony structures cannot be accurately analyzed with these diagnostic aids specially in case of facial asymmetry. Surgeons also have to mostly rely on their personal experience and subjective visual estimation which might not be that accurate.3D RP models help to overcome these limitations by providing an accurate understanding of anatomical relationships and exact nature of malocclusion. Mock surgeries can be performed on the models which help to achieve better post operative results. Discrepancies due to asymmetry can be directly measured on models which help the surgeons to plan and perform the surgery more efficiently.

5) Fabrication of surgical stents for implant placement:-

Use of mini screws for skeletal anchorage is becoming popular day by day. For success of any implant one of the key factors that play an important role is its accurate positioning. Kim et al first fabricated a surgical template for mini implant using RP technology [15].This method is specially helpful in cases where there is not enough space for free hand insertion like where there is multiple impacted teeth or reduced interradicular space due to extension of maxillary sinus.

6) Distraction osteogenesis:-

Salles et al produced a case report of a patient with agglosia who had dentofacial abnormalities mandible particularly [16].3D RP models of jaws were constructed and used as guide for fabrication of a distracter to perform osteogenic distraction of mandibular symphysis.

III. Application In Endodontics

1)Guiding canals:-

A thorough knowledge of root canal anatomy and its variations is very important for successful endodontic therapy. Locating and accessing the canals in case of complex root canal system becomes quite challenging. RP plays an imperative role in these cases by providing a 3D visualization of canals through digital reconstruction. Lee et al used RP technology to demonstrate the unusual anatomy of 3 distal roots of a right mandibular first molar with the aid of 3D digital reconstruction and computer-aided rapid prototyping (CARP) model [17].

2) Accurate Diagnosis of lesion:-

Diagnosis of resorption is mostly made by clinical and radiographic examination. On an intraoral radiograph the lesion usually shows a rough outline, which may or may not be continuous with the pulpal cavity. Different angled radiographs can be useful to determine which surface is involved but they still do not provide a three-dimensional idea of what the resorption really looks like. But with RP technology, size of apical lesion and as well as resorption can be accurately diagnosed. Kim et al reported a case of multiple extracanal invasive resorption in which the exact size and location of resorption area was visualized utilizing 3D RP models [18].

Endodontic treatment of tooth with anomalies is a challenge to clinicians and requires complete understanding of aberrant root canal anatomy. Byun et al reported a case of a dilacerated tooth in which a comprehensive 3D tooth model carrying information of internal root canal structures was digitally reconstructed and based on this tooth model a custom made jig was fabricated to achieve a safe and precise working path to the root canal [19].All the canals were assessed and treated without any complications.

3) Autotransplantation:-

One of the earlier techniques used in transplantation procedures was the use of an extracted donor tooth as a template for the preparation of the recipient site. Developments in cone beam computed tomography (CBCT) and rapid prototyping (RP) have permitted innovations such as the fabrication of accurate surgical templates to aid in recipient site preparation It has been established that the most important factor in the success of autogenous tooth transplantation is the vitality of the periodontal ligament attached to the donor tooth, and its viability decreases when it is exposed extra-orally. The efficient utilization of digital technology has helped to reduce surgical time as well as to avoid intraoperative errors. The decrease in extra-oral time has led to more predictable outcomes and improvements in success rate for autotransplanted teeth.

Park et al reported a case of autotransplantation with the help of rapid prototyped tooth model as an effective aid for critical time based procedure [20].

4) Endodontic training and research:-

Apart from clinical applications, RP techniques are also used in the field of training and research. A study was conducted by Ordinola Zapata R et al to compare the efficiency of two rotary systems in preparation of curved canals using 3DP tooth models [21].It was concluded that micro computed tomography(CT) based RP tooth models are effective tools to access endodontic procedures.

IV. Application In Prosthodontics

1)Dental prosthesis wax pattern fabrication:-

Traditionally, the fabrication of the wax pattern is the most critical and labor-intensive step in making the porcelain-fused-to-metal crown, pressed ceramic crown, and RPD framework.

In this time-consuming task, the wax-up's quality is dependent on the skilled labor of the individual. With the advent and popularity of RP technology, a new approach is possible for automatic wax-up fabrication which simplifies the traditional fabrication process and accelerates the production turn around period by using 3D imaging.

RP application has several advantages as follows-

- High production rate. With RP techniques, the dental laboratory can easily reach a production rate of over 150 units per hour.
- Quality control of wax copings, which results in a high precision fit and constant wall thickness.
- Reduced spruing time.
- Reduced finishing work needed on cast copings. The irregularities in wax coping thickness can be avoided, as they usually create extra work for finishing the metal after the cast.[22]

2) Direct metal prosthesis fabrication:-

The lost-wax casting method is the traditional way to fabricate a metal prosthesis. This method is a lengthy and labor-intensive process that comprises many manual steps such as fabricating,

Embedding and burning out the wax pattern, metal casting, and post processing. Recently, RP technology, especially selective laser melting (SLM) and selective laser sintering (SLS) technology, has attracted great attention among researchers for its brisk fabrication of high-precision metal parts.

SLS/SLM is layer-wise, material-addition techniques that allow generation of complex 3D parts by selectively consolidating successive layers of powder material on top of each other, using thermal energy supplied by a focused and computer-controlled laser beam. In addition, the remaining unprocessed powder can be reused. Dental prostheses are very suitable for processing by means of SLS/SLM due to their complex geometry and their ability to be customized without lengthy manual pre- or post processing.

In 2005, Eggbeer et al used CAD/CAM and RP technologies to manufacture metal RPD structures [23]. Williams et al[24],Bibb et al[25], and Han et al[26] all reported cases of a metal frame made directly by RP. In these cases, a mold was made in a patient with partial bilateral mandibular edentulism, the plaster model was scanned, and a 3D design was obtained. An RP machine of the SLM type was used, and the metal frame was constructed by direct deposition of Co–Cr.

3) All-ceramic restoration fabrication:-

For the fabrication of green-zirconia all-ceramic dental restoration, direct inkjet fabrication procedure has been proposed using a slurry microextrusion procedure. After fabrication of the green restoration, the definitive restoration is obtained by a sintering or laser-assisted densification process. This novel technique is a promising CAD/RP system with great potential to produce all-ceramic dental restorations with high accuracy, cost efficiency, and a minimum of material consumption. This technique is still in the experimental stage.

4) Mold for complete dentures:-

Very few publications in the field of designing and fabricating a complete denture with a computer are available which shows that advanced manufacturing technology has not been successfully applied in this field. Researchers at Peking University developed a novel computer aided design (CAD) and RP system to make individualized molds for a complete denture. The process includes:-

- Establishing a 3D graphic database of artificial teeth positioning
- Getting 3D data of edentulous models and rims in centric relation
- Exploring a CAD route and developing software for complete dentures
- Fabricating physical molds by 3DP
- Finishing the complete denture using laboratory procedure

Studies conducted by Khanazawa et al used the patients pre-existing denture to record the data on computer and fabricate a new denture using RP technology [27]. However the problem with this technique was difficulty during trial insertion. To overcome this obstacle, Inokoshi et al conducted another study in 2011 and the main objective of their study was to formulate new methods of fabricating trial dentures using RP and to compare this approach with the conventional method using wax dentures [28].However, prosthodontists gave ratings significantly higher for the conventional method in terms of esthetics and stability whereas RP method was significantly seen to reduce the chair side time and showed high degree of accuracy in the processing step. With the advent of newer technologies such as face stimulation, MRI and CBCT to directly scan the patient‘s ridge, rapid prototyping technology will prove to be a popular method for fabricating complete dentures in the future.

5) Maxillofacial prosthesis fabrication:-

Designing a prototype is essential prior to the making of the definitive facial prosthesis. To fabricate a real prototype, it is necessary to make a facial moulage with an impression material and then to pour it into a dental stone. Afterwards, a wax prototype is sculpted on the stone cast by using the free-hand technique. With this method, the success of the wax prototype depends on the artistic skills of the technician. At the same time, the impression materials may depress the thin and unsupported regions of the face and the stone cast may not be an identical copy of the patient's face. To overcome these hurdles, RP technologies are gaining popularity.
Applications in maxillofacial prosthodontics are as follows:[29]

- Obturators
- Production of auricular and nasal prosthesis
- Duplication of existing maxillary/ mandibular prosthesis especially crucial when an accurate fit to natural teeth or an osseointegrated implant is needed
- Manufacturing of surgical stents for patients with large tumors scheduled for excision
- Manufacturing of lead shields to protect healthy tissue during radiotherapy treatment
- Fabrications of burn stents, where burned area can be scanned rather than subjecting delicate, sensitive burn tissue to impression - taking procedures.

Qiu et al reported that a patient with a total rhinectomy was scheduled for a nasal prosthesis [30]. Based on the 3D model of the patient's face (reconstructed with the CT data), a four-piece mold for the nasal prosthesis was prototyped using a CAD and RP procedure.
Conventional silicone was processed with this physical mold to fabricate the definitive nasal prosthesis. Hamit Serdar Cotert reported a case of ear prosthesis fabrication in an anotia case with RP technology [31].

6) Fabrication of prosthetic implants:-

Implant placement has become a routine dental care modality. Detailed diagnosis and pre-surgical planning are always necessary and must include anatomical as well as prosthetic considerations in order to precisely position the implants that will enable the fabrication of esthetic and functional restorations. Computer-aided designing and fabrication techniques, employing any available implant simulation software, provide a pre-operative view of anatomical structures and restorative information for achieving the ideal implant position.

In the clinical setting, guided implant surgery applies these digital techniques using drill guides processed by stereolithographic rapid prototyping, on which implants are positioned, with minimal surgical exposure of bone, or even with a flapless approach. The advantages of the less invasive flapless surgical procedure include the following:

• Shorter duration and facilitation of the surgical procedure.
• Faster and less complicated recovery.
• Enhanced esthetic results.
• Bone grafting procedures are unnecessary

V. Application in Oral And Maxillofacial Surgery

In the craniomaxillofacial area, stereolithography has become a well-known technique in the processes of diagnosis, preoperative planning, and surgery simulation, primarily in cases of reconstructive and orthognathic surgery. Surgery simulation is helpful when grafts are positioned from a predetermined donor area, such as scapular bone, fibula, or iliac crest. The length and shape of the graft are estimated through a surgery model, and special plates can be pre-produced to hold the future bone graft, thus facilitating the surgical procedure and saving operating time. Likewise, by coloring tumors with stereolithography, it is possible to visually establish their extension and clarify their relationship to the alveolar nerve in the mandible and hard surrounding structures, such as paranasal sinuses, orbit etc

The use of prototypes in immediate trauma is not common, but it is rather frequent in trauma squeal. Prototypes are very useful in planning surgeries for facial reconstruction and are essential to reestablish symmetry for the patient. Models can be used for rehearsal and more accurate planning and bring reductions in surgical time.

Prototypes can and should be used in several situations [32], such as: -

- Evaluation of asymmetrical features
- Reconstruction of symmetrical structures using mirroring
- Fracture assessment
- Modeling rigid internal fixation plates and screw selection
- Modeling osteogenic distracters
- Calculation and adaptation of bone grafts
- Tumor assessment
- Fabrication of surgical guides

VI. Conclusion

Rapid protoyping presents fascinating opportunities in various streams of dentistry. Its advantages include rapid fabrication, minimal time consumption, easy handling, better visualization, reuse of design and repeated verification. However, the clinical judgment still remains vital. The process is difficult as well, as it demands high amount of artistic skill, complicated machinery and the high cost of the tools. But RP technologies are increasingly playing an imperative role in dentistry and in days to come it will become one of the mainstream digital technologies holding the potential to change the conventional dentistry.

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