

Review article:

Rapid prototyping: changing face of orthodontics

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ABSTRACT:

Amalgamation of recent advancements in technology and digital solutions have reformed diagnosis and treatment planning in dentistry leading to the change in approach, from a traditional two-dimensional (2D) into an advanced three-dimensional (3D) technique. Rapid prototyping (RP) is one of such advanced techniques which is considered as group of related techniques that are used to build physical 3D models layer by layer based on CAD-CAM (computer-aided design and computer-aided manufacturing). It accurately reproduces almost all forms of shapes including complex external and internal anatomic structures. Its orthodontic application includes digitization of models used for diagnosis and treatment planning, fabrication of orthodontic removable appliances, impression trays for indirect bonding, surgical stent for implant placement and customized lingual brackets. Rapid prototyping also helps us in making orthognathic surgical procedure more refined and predictable. Prototype models can also be used for education and training purposes or while explaining the treatment procedures to patients and their families for better understanding. This article presents a review of the present literatures on rapid prototyping technique, with particular reference to its orthodontic applications.

It has advantages of simplicity, flexibility, reliability, accuracy, better visualization and time saving, but still the clinical judgement remains vital.

INTRODUCTION:

In this era of virtual imaging, orthodontics is making the fully equipped 3D orthodontic office a reality, by embracing newer materials and advanced technologies. Rapid prototyping is a revolutionary concept that can affect various spheres in the ever

changing and always challenging field of dental science. It basically indicates the fabrication of a three-dimensional (3D) model, traditionally built by sequential addition or subtraction of materials according to the 3D input from a computer-aided design (CAD) (Laoui& Shaik, 2003)⁽¹⁾. Rapid

prototyping is also known as “layered manufacturing”, “solid free form fabrication” or “3 D printing”. The use of this technique has become possible in the clinical scenario due to simultaneous advancements in all its three fundamental steps namely

- Medical imaging (data acquisition – 3 D approach)⁽¹⁾
- Image processing (development of software for image slicing and its reconstruction)⁽¹⁾

HISTORY:

Rapid prototyping, an innovative concept was actually theorized from engineering methods. Prototypes were originally made for evaluating ease of assembly and manufacturing of design ahead of actual production. First significant work associated with modern photolithography (AM system) emerged during 1970's. In 1971 a system for patent was presented by Swainson, in which 2 intersecting beam of radiation produced a phase change to build 3D object. But due to certain drawbacks in proposed system and financial issues the idea was dropped in 1980's.⁽³¹⁾ Method for fabrication of 3D models by using photosensitive polymer was described by Kodama and Herbert in 1981 and 1982 respectively.⁽³¹⁾ Chuck Hull was the first person to develop the concept of 3D printing in 1984. In 1986, 3D Systems Company was established by Hull to market the first machine for rapid prototyping, stereo lithography (SLA)⁽⁶⁾. In 1988, fused deposition modeling (FDM), was developed by Scott Crump x which was later

- Rapid prototyping (3 D printers)⁽¹⁾

Clinically, a prototype or 3D model of anatomical structure can serve a range of significant functions. Like it can address visualization issues that virtual examination cannot always resolve. Also, it can be used as a simulation tool or a teaching device. Moreover, it helps medical practitioners and researchers to formulate a treatment plan according to “patient-specific” concept. Finally, it facilitates the Communication between the clinician and the patient.

commercialized by Stratasys in 1990⁽⁶⁾. In 1998, the developer of Poly Jet photopolymer (PPP) printing Objet Geometries was found⁽⁶⁾.

In this present world of digitalization dozens of 3D printers are available employing variations of SLA, FDM, and PolyJet technologies.

CLASSIFICATION:

Literature contains many different ways of classifying rapid prototyping process. Classification by German standard of production process which is based on state of aggregation of their original material is shown in fig2.

STEPS IN FABRICATION OF RAPID PROTOTYPES:

Fabrication of 3D model is preceded by number of steps before 3D model is formed (fig1). Following are the steps involved⁽⁶⁾.

1. Anatomical data acquisition
 - a. Imaging using CT scan or MRI scan
 - b. Acquisition of DIACOM files.

- c. Conversion of DIACOM into STL files.
2. Evaluation of the design
3. Surgical planning and superimposition (if required)
4. Process of fabrication
5. Validation of the model

1) ANATOMICAL DATA ACQUISITION

Magnetic Resonance (MRI) and computerized tomography (CT) imaging are commonly used for this purpose. Other sources such as Laser surface digitizing, ultrasound and Mammography can also be used. Laser surface digitizing allows acquisition of external data only, while MRI AND CT includes both internal and external data, therefore it reduces scanning time and file Size (Liu et al., 2006).

Most of the MRI AND CT Scan software produces output data in .DIACOM (Digital Imaging and Communication in Medicine) image format. ⁽⁸⁾Further, .DIACOM data is converted into .STL (structured triangular language) file format. Specialized software is required for this conversion.

⁽⁸⁾

2) EVALUATION OF THE DESIGN AND SURGICAL PLANNING

In this step unnecessary data is discarded and useful data (area of interest) is retained. We can skip this step if model is to be made for educational purposes ⁽⁸⁾.

3) PROCESS OF FABRICATION

Can be generally divided into two major categories: “additive” and “subtractive” ^(4,5). Additive process involves the fabrication of 3D model by sequential addition of materials to a substrate. On the Other

hand, a subtractive process involves sequential removal of materials from the substrate to form the object. Depending on the evaluation of parameters such as manufacturing speed, desired accuracy and budget the additive or subtractive method is chosen (Mishek, 2009). In the clinical scenario, additive techniques are more commonly employed. With changing trends and recent advances there are over 30 different techniques available, some of which are commercially available and rest underdeveloped. The four most widely used techniques ⁽⁴⁾ are:

- Stereo lithography
- Fused deposition modelling
- Selective laser sintering
- Inkjet printing

Stereo lithography (SLA):

This system includes photosensitive liquid resin bath, a model-building platform and an ultraviolet laser for curing the resin which is guided by PC controlled mirror (Winder & Bibb, 2005). Here, in this technique first the input image is divided into multiple sections and fed to the SL machine. Solid object is formed by sequential curing of layers beginning from the bottom of the model. After curing of layer the resin platform is lowered by same distance as the thickness of layer. The process of curing and lowering of platform is reiterated until desired 3D object is formed. The removal of model from the resin bath is followed by further curing in an opposite cabinet. Support structures are added to the model in order to aid layers adhesion and then removed once the model is printed ⁽³¹⁾. (Fig 3, table 1) This technology accurately produces highly complex 3D geometries which can be used

for various purposes and also for performing mock surgery (Bajura et al., 1992; European Commission, 2002; Wouters, 1998).

Fused deposition modelling (FDM):

FDM also works on the same principle as stereolithography. In this system thermoplastic material is extruded by a temperature controlled head in a layer by layer fashion. Variety of modeling material and colors can be used in this system. (fig: 4 , table 2)

Selective laser sintering (SLS):

It also works on the principle of additive manufacturing. It uses computer directed laser for fusing the layers of specified powder material to form 3D model. The selective nature of laser helps in fabricating complex geometries without compromising functionality. (Lightman, 1997) (fig:5)

Ink jet printing or 3DP:

It has been developed at the Massachusetts Institute of Technology in 1993. It is also a layered manufacturing technique in which an inkjet print head moves across a bed of powder in X and Y plane, selectively depositing a liquid binding material. The process is repeated until desired 3D model is fabricated. Once the model is complete, unbound powder removed in a process called "de-powdering". (fig: 6 , table 3)

4) VALIDATION OF THE MODEL

Fabricated model is evaluated and validated by team ⁽³²⁾.

APPLICATIONS IN ORTHODONTICS:

1.) Diagnosis and treatment planning

The most common clinical problem an orthodontist comes across in day to day life is impacted maxillary canine. It is equally challenging for an orthodontist to diagnose and bring it into alignment. Diagnosis and treatment planning of the impacted maxillary canine has become easier by the introduction of rapid prototyping models. A digitalized 3 D model can be fabricated showing anatomical relationship between the impacted tooth and other teeth and its relationship with respect to maxillary and mandibular arch (if position is favourable or unfavourable). Model will also act as an aid while navigating intraoperatively during surgical exposure of impacted canine. Apart from above mentioned uses model can be used to communicate with patients, his parents and fabrication of metal attachment for canine retraction ⁽¹⁴⁾.

2.) Fabrication of impression trays for indirect bonding and removable orthodontic appliances:

Rapid prototyping combined with CAD-CAM are also used for fabrication of template for indirect bonding, and also for orthodontic removable appliance fabrication. While preparing **trays for indirect bracket bonding**, first a silicone impression is taken, and the casts produced from these impressions are used to prepare the initial model of malocclusion. After virtually accurate positioning of bracket, the fabrication of the RP trays begins ⁽²⁰⁾.

Invisalign or clear braces are highly popularized as an alternative to metal braces in the recent times. 3 D manufacturing of invisalign is highly accurate and saves time. Same set of poly vinyl chloride impressions can be used for fabrication of models and clear aligners ⁽¹⁶⁾.

The digital splints are obtained by vacuum pressure thermoforming process. Al Mortadiet al developed a newer technique for incorporation of wire in a single build with help of stereolithography because it allows build to be paused and insertion of prefabricated pieces and built around ⁽¹⁹⁾. Stereolithography plays a vital role in the preoperative planning of complex dentoskeletal anomalies. It can also be used in study of facial aging by measuring changes in various angular readings, height, width and depth of maxilla with aging ⁽¹⁵⁾.

Advantages of this technique is that it uses CBCT data unlike previously when laser scanners were used for digitization of patient's dental tissues. It also provides consistency, accuracy, fine quantitative control, and less time taking compared to manual methods.

3.) Orthognathic Surgery:

Dental study casts, Cephalogram, OPG and facial photos are regularly used as aids for planning orthognathic surgery. Spatial relationship of bony structure is difficult to analyse accurately with the help of above mentioned tools especially in case of facial asymmetry. In comparison to conventional radiography and CT scans RP has significant advantages in diagnosis, treatment planning and communication with patients ^(21, 22).

In case of conventional radiographs 3D image is formed in clinician's mind which is difficult to explain to the patients. Earlier surgeons used to rely on their personal experience and subjective visual examination. 3D RP models provides an accurate understanding of anatomic relationship and exact nature of malocclusion. It helps surgeons to achieve better operative results by providing an easy and convenient way to measure discrepancy directly on the model. Models can also be used to study the bony the structure of patient on which Mock surgery can be performed ⁽²³⁾.

Digitized Surgical splints can be accurately fabricated from the models for use in orthognathic surgery.

4.) Fabrication of Surgical stent for Implant Placement:

Use of miniscrews for skeletal anchorage has gained popularity in recent years. One of the most important factors which affects the success of implants is its position.

Anatomy, limitations and treatment goals has to be considered while planning the position of implants for accurate placement and better results. Stereolithographic surgical stent can be fabricated on RP models which can be used as surgical guide for precise and accurate placement of implants ⁽²⁴⁾. This method is especially helpful in cases where there is less space for free hand insertion like in cases of multiple impacted teeth or in cases where there is limited interradicular space due to extension of maxillary sinus ⁽²⁴⁾.

5.) Lingual Orthodontics:

In spite of aesthetic advantages of lingual orthodontics over labial orthodontics former has lost its demand in dentistry due to various disadvantages. The main disadvantages includes:

- a. rate of debonding of brackets is higher in comparison to labial appliances
- b. complex indirect bonding
- c. Finishing process is more time consuming and tedious,
- d. Difficulty in speaking and irritation to tongue patients faces problem in adapting to appliance.

These drawbacks can be solved by customization of individual bracket components.

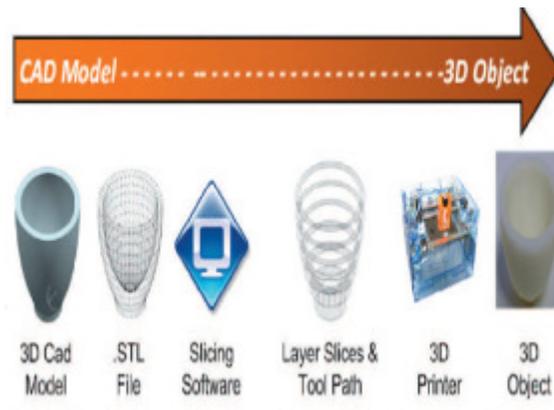
CAD-CAM software along with high end RP techniques is used to customize brackets for each tooth. Customization of base permits easy and accurate placements of brackets on the tooth, which

can be directly bonded by the orthodontist. Archwire geometry is yielded by the 3D location of the bracket slots. The prototyping method used here allows any clinical shortcomings to be rectified immediately ^(25, 26).

6.) Distraction Osteogenesis: Prototypes of the jaws can be used as an aid for the fabrication and placement of a distractor for distraction osteogenesis process ⁽²⁸⁾.

CONCLUSION:

In this world of digitalization, rapid prototyping can act as an efficient auxiliary for diagnosis, treatment planning and management of patients with malocclusions. No one technique is ever efficient to fulfill all the patient's needs. So rapid prototyping along with CAD CAM, 3 D imaging and digital scanning has potential to change the conventional methods of managing patients in dental offices.



1: Steps involved in rapid prototyping processFig

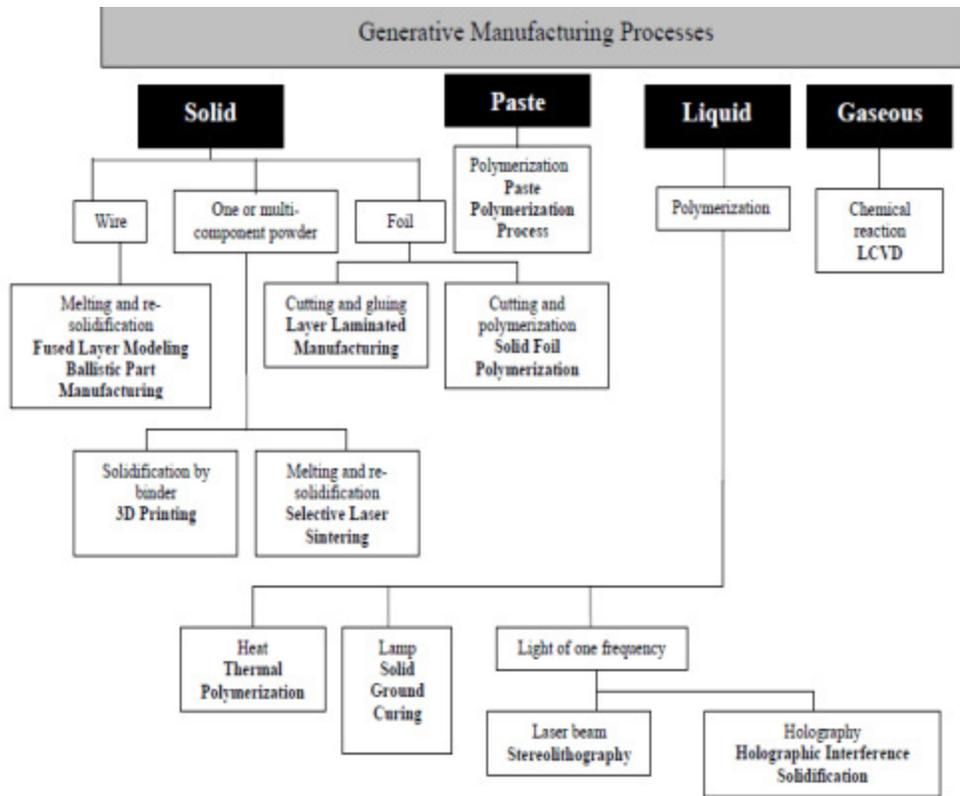
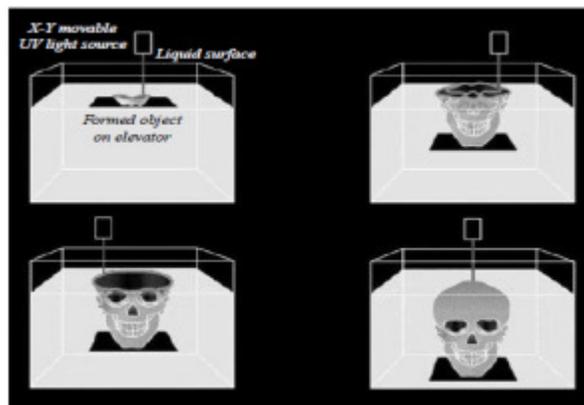


Fig 2: Classification of RP process (after Gebhardt, 2003)



3: Principles of Stereolithography

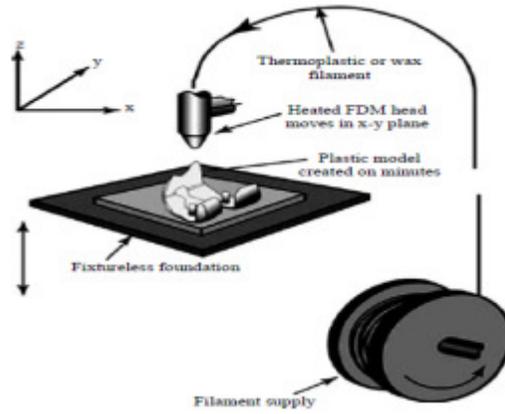
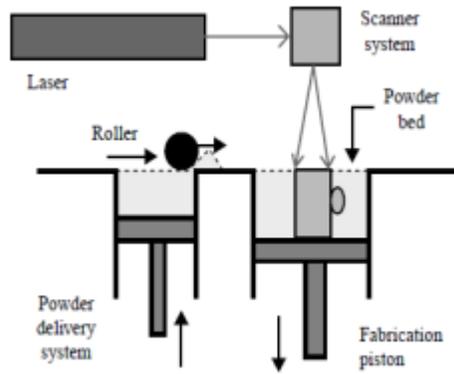


Fig 4: Schematic diagrams of FDM



5: Schematic diagram of SLS

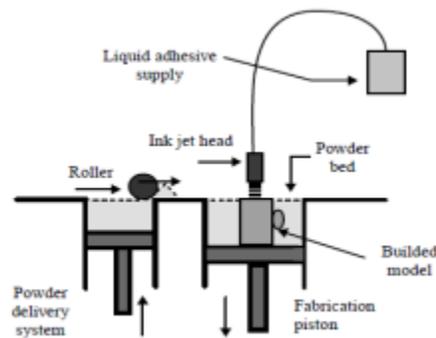


Fig 6: Inkjet 3D printers

Table 1: Advantages and disadvantages of SLA

Advantages	Disadvantages
High accuracy	Expensive equipment
Close tolerance	Material high cost
Good surface finish	Can be used only for polymers
Can be made transparent	Post-cured required
100 percent density possible	
High-mechanical strength	
Smooth surface finish	
Fine building detail	

Table 2: Advantages and disadvantages of FDM

Advantages	Disadvantages
Direct wax pattern	Support structure must be removed
Multi-color part	Rough surface finish
Fairly fast and speedy	Thermoplastic material only
	Not 100 percent dense

Table 3 : Advantages and disadvantages of 3DP system

Advantages	Disadvantages
Fast fabrication time	Large tolerance
Low material cost	Lower strength models
Capability of being colored	Rough surface finish
Build models can be used for casting purposes directly	
Low toxicity	
Relative material variety	

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