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Prosthodontic using Rapid Prototyping

Raja'a M. Albuha Al- Mussawi[a], Farzaneh Farid[b*], Mohammed T. Alkhafagy[c], Farhad Shafiei[d]

[a]*B.Sc, Tech. Master, PhD Student, Department of Prosthodontic Technology, School of Dentistry, International Campus, Tehran University of Medical Sciences, Tehran, IRAN.*

[a]*Assistant Professor, Prosthodontic Department, College of Dentistry, University of Kufa, Najaf, IRAQ.*

[b]*Assistant Professor, Department of Prosthodontic, School of Dentistry, Tehran University of Medical Sciences, Tehran, IRAN.*

[c]*Assistant Professor, Head of Prosthodontic Department, College of Dentistry, University of Kufa,, Najaf, IRAQ.*

[d]*Assistant professor, Department of Dental Materials, School of Dentistry, Tehran University of Medical Sciences, Tehran, IRAN.*

Abstract

Rapid prototyping is a set of technicality which applied to create a scale model of a physical part or assembly rapidly utilizing three-dimensional computer aided design (CAD) data. 3D printing or "additive layer manufacturing" technology was used to Develop the part or assembly. It is a CAD/CAM technology which was created initially to manufacture prototypes for industrial purposes. RP technology encouraged the configuration and quick generation of mass quantities of precise parts by the industrial manufacturing in a convenient time with exactness and pace. In the previous two decades this technology was utilized efficiently in the medical field with a promising results. In this review the technique, methods and various uses of this fast emerging technology regarding prosthodontic will be discussed.

Keywords: Dentistry; Prosthodontics; Rapid prototyping; Computer-aided design.

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* Corresponding author.

1. Introduction

In the past two decades, an improvement in medicinal science has been noticed clearly, different engineering applications can be the cause of this improvement . dentistry is the branch of medicine which has the longest imitation of fusing engineering solutions. As a part of dentistry, dental prosthetics which manages the substitution of missing teeth and surrounding tissue in the mouth by fixed and removable partial denture or any other artificial devices - has constantly connected with engineering disciplines, mostly depending on production engineering. a clear mark has been left on dental prosthetics with the Consistent and quick improvement of computer-aided technologies, which made a complete changing in the production engineering. Concerning dental prosthetics various technologies and methods has been presented which permit production of exactness, specially designed, ideal dental substitution [1,2].

Currently, computer-aided design (CAD) and computer-aided manufacture (CAM) were used widely in dental applications. Most of the advanced employed CAD/CAM systems are based on a milling procedure, by which a desired forms, such as full anatomical crowns or frameworks, are manufactured from a block of milling material. On the other hand the using of a revolutionary layering additive technique (Additive manufacturing/ AM), make the production of a complicated customized forms such as removable partial denture (RPD) frameworks is possible. Recently, “additive manufacture” (AM) was employed to describe the manufacturing of functional, end use components in a layer-by-layer manner. It facilitate the manufacturing of geometries that cannot be made with another methods, also it is suitable for low volume or forms which products one off. Particularly in medical applications [3]. Concerning dental technology, research has shown that laboratory crafting techniques can be replaced with a combination of CAD and AM [4,5].

Rapid prototyping (RP) technologies mostly used manufacturing methods which depended on the manufacturing basics [6] to create a custom made style and precise physical form in a short time [1,3,6]. ″It is a promising powerful technology that has the potential to revolutionise certain spheres in the ever changing and challenging field of medical and dental science″. The procedure aims to build prototypes (working models) within a short time to product and test different design features, thought, theories, functionality as well as results and performance in special cases [7].

2. Rapid Prototyping (Definition and Concept)

Computers are becoming an integral part of dental education and dental practice. Rapid prototyping is a technique for the production of solid objects from computer models. an assortment of rapid prototyping machines and materials that can be treated is always increasing [8]. The creation of parts in an additive, layer-by-layer method is the main idea of this innovative technology. It is a specific type of machine technology that rapidly creates parts and prototype models from 3D computer-aided design (CAD) model data, CT and MRI scan data, and data produced by 3D digitizing systems. RP systems connect liquid, powder, or sheet materials with additive approach to building shapes, in order to form models. These machines creates plastic, wood, ceramic, and metal parts in layer by layer manner, using thin, horizontal cross sections of the computer model [9,10].

Rapid prototyping can be defined as that procedure in which a physical prototype is fabricates in a layer by layer manner from their CAD models and there is no any human interference or any tools, dies or fixtures specific to the geometry of the model being fabricated. Although it is developed for engineering purposes at the beginning, product development environment has found its place in all fields of human lives.

Rapid biomodelling or rapid bioprototyping is one of the most exciting applications of RP in medical field. fast and precise rapid prototypes can be manufactured for a different purposes by using data from conventional medical scan technologies such as Computer Tomography (CT) and Magnetic Resonance Imaging (MRI). It is a kind of computer-aided manufacturing which indicates the automatic texture of mechanical models from graphical computer data [11].

3. History of Rapid Prototyping

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).

RP technology firstly produced before two decade to create prototypes in short time from 3D CAD (computer aided design) model by adding material in layers, to manufacture a solid from predefined format. Product development cycle became faster and easier in many of industrial applications such as aerospace, cars, home appliances etc by using this technology. In dentistry, appearance of RP technology shows a new perspectives for design & manufacturing. Over time, RP has developed from prototypes for shapes production convenient and practical testing to definitive products for practical use production. Many of processes were developed since the display of first trade implementation in the latest decade. Now a days, there are many types of materials which used with this system such as ceramics, sand, metals, polymers and metal-polymer composites.

In Dentistry, this technology used widely in fabrication of crowns, inlays, onlays, invisible orthodontic prosthesis(for proper aliment of) teeth and implant pre-surgical planning placement, it enabled the surgeons practicing surgery on models permitting estimation of osteotomy [12].

Progress and development always produce a new terms, “Medical rapid prototyping (MRP)’’ was used in the late 1990s It is used in medicine as well as in dentistry fields like oral and maxillofacial prosthodontics and surgery [13,14]. Implant (surgical guide or physical model [15,16,17], and prosthodontics appliances [18,19].

There are three phases of prototyping as follows:

- First prototyping phase: within this period, skilled craftsman used prototyping manually.
- Second prototyping phase: begun within the mid of 1970s.By using 3D curves and surfaces a soft prototype modeled could be stressed in virtual environment, with precise material and other properties, it was simulated and tested.
- Third prototyping phase: begun within 1980s. In this period, adding layer by layer was used to create a prototype that was tested later. Using of rapid prototyping begun together with the huge development

of CAD/CAM technologies [12].

Many RP technologies were used since its initiation to create medical prototypes in medicine and dentistry.

Table 1: Historical development of rapid prototyping and other related technologies [12].

Year of inception	Technology
1770	Mechanization
1946	Early computer
1952	Early Numerical Control (NC) machine tool
1960	Early commercial laser
1961	Early commercial Robot
1963	Early interactive graphics system (early version of Computer Aided Design)
1988	Early commercial Rapid Prototyping system

4. Types of Rapid Prototyping Technology

The most common types of Rapid Prototyping system technologies in dentistry are stereolithography (SLA), inkjet-based system (3D printing - 3DP), selective laser sintering (SLS) and fused deposition modeling (FDM). The used materials are completely varied, however wax, plastics, ceramics and metals are used for dental purposes by many teams [9,20,21,22]. The chosen material which is in powder, liquid, or solid state added inside the machine in a progression of thin layers, it can be used depending on the quality of the intended form and the type of machine. Each process works in a slightly various method, Although the general basics remain the same [23].

4.1. Stereolithography

This technology used since the mid 1980s,Although it is an old age system, Stereolithography considered to be the most popular from the advanced RP technologies [11]. It creates three dimensional model by using a computer-controlled moving laser beam in order to build up the required objects from a liquid in a layer by layer manner. Additive manufacturing or 3D printing technology employed to fabricate prototypes, models, patterns, as well as production parts [9,12] a bath of photosensitive liquid resin, a model-building platform, and an ultraviolet (UV) or laser for curing the resin are the components of this system. Which process the layers sequentially and bind them together forming the solid form starting from the bottom of the model then building up. By displaying the resin to an UV light, hardening of a thin well-defined layer thickness will be done. After curing of resin layer, its platform is lowered within the bath into a little specific distance, and repeating this process until completing the full objective. then repeating this process until completing the full objective. And finally removing the objective from the bath and curing it for another period of time in a UV cabinet [9,22,23], other post-processing steps such as cleaning and post cure are needed.

Nowadays, restricted selectively colour-changing materials are obtainable for biomedical and other applications, which highlighting a selected properties with a various colour and providing superior visualization [20]. Moreover, with the transparency of the model and the current development of color resins, a distinct visualization of anatomical structures will be allowed. European Commission considered SLA as the best method for educational purposes and it preferable for exercising on surgical planning before surgery [22]. It is used also to produce the impression for reconstructive surgeries and sub-periosteal dental implant surgery [13,24]. Currently, the main purpose for using its models is to fabricate surgical drilling templates during the insertion of dental implant [23,25,26].

4.1.1. Advantages [9,12,20,22]

- Good speed.
- The needed time is depend on the model volume and complexity.
- High accuracy in producing the details.
- Close tolerance.
- Good finished surface and smooth.
- It is possible to make it transparent.
- The possible density is 100percent.
- High mechanical strength, its Prototypes are used as master models for injection molding, thermoforming, blow molding.

4.1.2. Disadvantages

- The equipments and materials are highly Expensive.
- It used with polymers only.
- Handling of wet materials.
- It need Post- processing procedure.

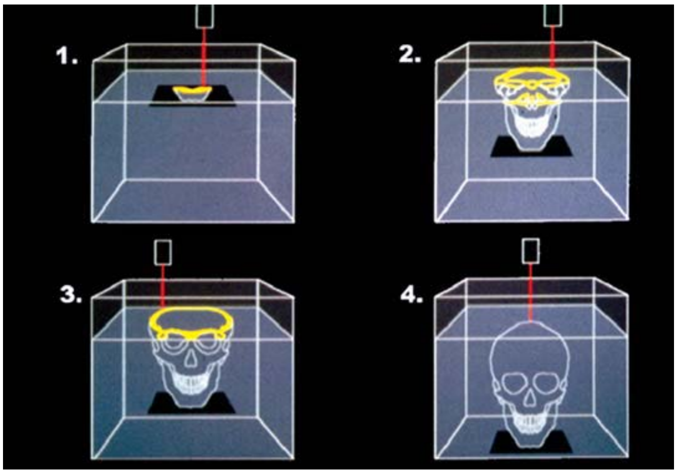

Figure 1: Principle of stereolithography (Medical Modeling Corp., Golden, CO).

4.2. Inkjet-based system (3D printing - 3DP)

Because it is precise, cost effective and speedy, 3DP technique got a great importance. It is an additive rapid prototyping technique that differ in duration of design and print a wax pattern of a restoration. The machine builds wax patterns of full crowns and frameworks in a manner similar to that of manual waxed restorations [12,20].

The pattern fabricated by spraying binder materials on a thin distribution of powder which spread over the surface of a powder bed in a similar manner to that of ink-jet printing [20] at the beginning, a measured amount of powder is added from a supply chamber by moving a piston upward gradually, then a roller spreads and compresses the powder at the top of the manufacturing chamber. After that a head of multi- channel jetting will deposit a liquid adhesive in a 2D pattern on to the layer of powder, which becomes joined in the areas where the adhesive is deposited, to form a layer of the object. After a finishing of a layer, the piston which supports the powder bed and the part is lowers and the next powder layer can be spread and bind selectively. 3DP is a layer-by- layer technique which continued progressively till the prototype is totally manufactured. After heat-treating, unbounded powder is swept up and leave the created part intact [22].

The powder bed supports overhangs, so there is no need for external supports during creation process [20]. Due to its high tolerance, 3DP technology is not useful for impression purposes as SLA, this tolerance considers as a problem during creating delicate dental models such as casting patterns while during creating educational models it does not matter. Moreover, it seems that due to this high tolerance, 3DP technology is not as useful for impression purposes as SLA is. 3DP is inaccurate technology because it may break off easily which lead to additional time for precise fitting of medical implant during surgery, However, it can be helpful for exercising the surgical procedures [27].

4.2.1. Advantages

- Short manufacturing time.
- Inexpensive used material.
- Coloring ability.
- Models can be manufactured to be used in casting purposes with low ash burnout.
- Toxicity is Low.
- Variety of used material.

4.2.2. Disadvantages

- High tolerance.
- Models with low strength.
- Surface finish is rough.
- Resolutions are Limited.

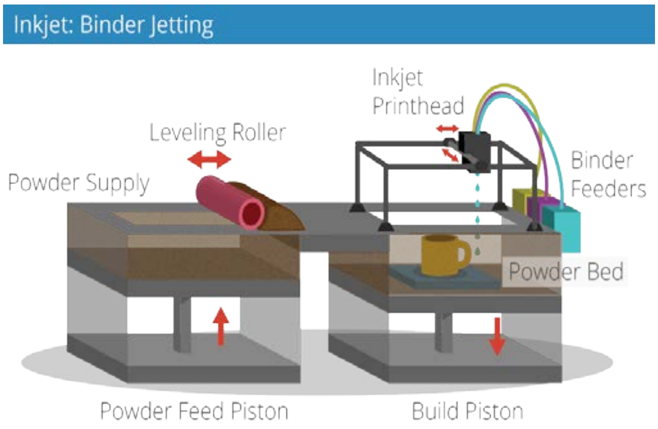

Figure 2: Inkjet-based system (3D printing - 3DP)

4.3. Selective laser sintering

Selective laser sintering (SLS) Firstly discovered and developed in the middle of 1980s by Dr. Carl Deckard and Dr. Joe Beaman, it is an additive manufacturing technique which employed to produce prototype models with low volume and functional components.

It creates the desired three dimensional Shape solid mass by fusing small particles powdered materials like plastic, metal, ceramic or glass powders with a high power laser(CO2 laser). A wide variety of materials can be used by coating particles with thermal binders. The powders have many higher properties than resin-based technologies with higher yields and faster post-finishing [12,20] Fusing of the material is done by the laser selectively after scanning of the cross- sections that created from a 3-D digital description of the model on surface of a powder bed [12].

By using a roller, the powdered material will spread on the surface of a build cylinder. Then moving the piston in the cylinder down just one layer thickness to give sufficient space to the new layer of powder. The distribution system of powder is similar in action to the build cylinder, in which a piston moves upward gradually to give a measured amount of powder for each layer. Then the surface of this tightly compacted powder is exposed to laser beam. An interaction will occur between laser beam and the powder which elevates its temperature to the melting point, leading to fusing of the powder particles and solid mass forming. Laser beam energy is adjusted to melt only the powder in areas which determined by the object's form over that cross section. The temperature of manufacturing chamber is kept lower than powder's melting point and the laser heat will raised the temperature a little only to cause sintering. SLS machine keeps the bulk powder material temperature in the powder bed less than its melting point by using infrared heating to reduce thermal deformation ″curling″ and simplify binding to the prior layer. This will reduce a lot of processing time . After finishing of the first layer, extra powder layer will be added by a roller technique over the layer which scanned previously. This process is repeated until the whole object is finished, 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. This method not need for support because the solid powder bed supporting the overhangs and undercuts [12,20,21,22,27].

SLS technology can be used 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. A complete cobalt- chrome RPD framework was fabricated with a demonstrate successful [18,22].

4.3.1. Advantages [9,12,20,22]

- Wide range of materials can be used especially in dentistry.
- Excellent accuracy.
- Simple post- processing.
- Un-sintered powder remains at the sites of support structure. So support structures are not needed, after completing the model it can be recycled.

4.3.2. Disadvantages

- Material and equipment are costly.
- Large tolerance for dental uses (0.5± 0.2).

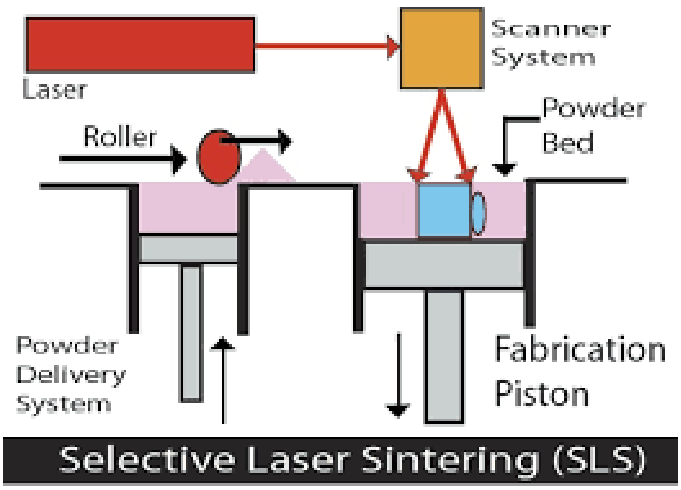

Figure 3: Selective laser sintering system.

4.4. Fused deposition modeling

FDM is the other vastly used rapid prototyping technology, following stereo lithography [13]. It is a technique in which a thermoplastic material was threw in a layer by layer manner through a temperature-controlled head. In this system, supplied materials is released from a coil with a plastic filament in to an extrusion nozzle head. The plastic melts in to a semi liquid form by the heated nozzle, the melted plastic then permitted to flow in order to be turned on and off.

This system operates in three axes, essentially, drawing the model one layer at the same time. As the machine nozzle is moved over the stand table in the required trajectory, it drops a thin bead of extruded plastic forming the first layer. After ejection of it from the nozzle, the plastic will solidifies directly and bonds to the layer below.

The system is composed of a chamber which is held at a temperature lower than temperature that melts the plastic. This technology permit designing of a wide range of materials and colors like wax of investment casting and medical grade ABS.

FDM is suitable for the fabrication of bone models .It use build materials which manufacture strong and tough models in one step. Furthermore , it can give excellent visualization by highlighting a chosen features with different color. For overhanging geometries, supporting material is required which can be broken away from the object after finishing it, or can be easily washed away when a water soluble support material is used. The system is slow in fabricating models have wide cross sections, while in fabricating small models that have tall, thin form-factors it will be faster [9,20,22].

4.4.1Advantages [9,20,22]

- Wax pattern is directly fabricated.
- Constructed in multi color.
- Relatively, fast and speed technique.

4.4.2. Disadvantages

- Removing the support structure after model fabrication is completed.
- Finishing surface is rough.
- Only thermoplastic material can be used.
- Its dense is less than 100 percent.

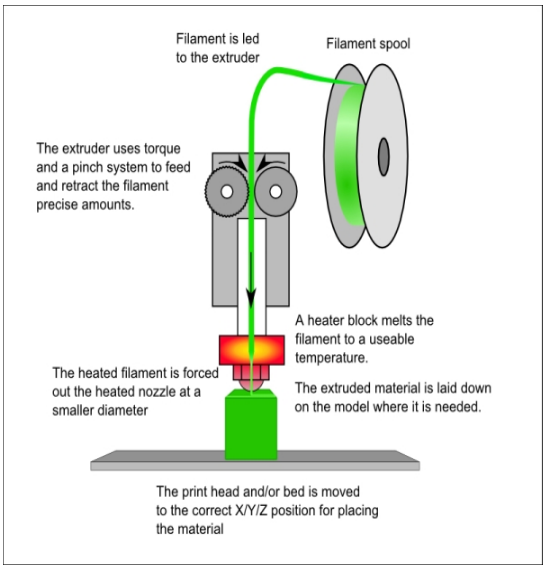

Figure 3: Fused deposition modeling.

5. Applications of Rapid Prototyping Technology in Prosthodontic

Rapid prototyping is the technology which produce a solid objects of computer models [8]. 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 [28].

Like other medical branches, dentistry also used rapid prototyping in many of its fields such as surgery and maxillofacial prosthodontics [1,2,3] surgical guide or physical model of dental implantology [17,18,28] and Prosthodontics [29,30,31,32,33,34]. From the definition, metal-free ceramic restorations that made by CAD/CAM system falls into this group of technology [8].

One of the considerable other benefits of RP when used in dentistry is medical modeling 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 [9]. Clinically, rapid prototyping technology can reduce the time and possible injury which may occur during implantation process [8]. 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 mold (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 [30]. Some of RP implementations are: crowns and RPD wax pattern manufacturing, complete dentures and casting molds , maxillofacial prosthesis and dental metallic prosthesis manufacturing [2].

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 [20].

6. Advantages of RP Systems

1. RP is fast, it need 1to 2 days to construction and insertion of the prosthesis.
2. physical prototype rapidly and clearly communicates all aspects of better design.
3. Design defects can be detected and repaired with RP technique early.
4. Confidence of the design integrity is one of the properties of RP technique.
5. Good management for the tissues with less trauma.
6. Accurate assessment of anatomical landmarks 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.
7. Accurate Osseous Topography analysis.
8. Precise location of implants.

9. Data can be get without direct patient to avoid tissue tension. Also can be used with patients who can't cooperate when preparing usual full face moulage impression.
10. CAD and RP technique can be reduce lab work due to creation of positive models which invested for casting later.
11. An objects with definite accurate dimensions can be created by using RP approach of stereo lithography.
12. If primary model is wasted or damaged during fabrication process, digital one can be used.
13. The fabricated model will has the internal detail as well as outer surface [9,23].

7. Disadvantages

1. More expensive materials and equipments.
2. 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.
3. 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 [23].

8. RP models production

The conventional method for dental prosthesis fabrication includes many of manual laboratory processes, the quality of these restorations depends on the dentists and dental technicians skill and expertise. Because dental restorations is very individual and complex. computer aided manufacturing (CAM) is chosen for this purpose. Particularly , using of CAM for the processing procedure will highly rise the manufactured quality of dental restorations [1].

Dental restorations models' as well as, medical models', the manufacturing procedure includes: data acquisition, data processing and model fabrication [20].

Table 2: Steps of RP models production

CAD-CAM steps	**CAD-CAM system**
Data acquisition	Optical modeling, laser scanning, CT, MRI, digital photographs
Data processing	Digital data is process to obtain a CAD model
Model fabrication	Rapid prototyping, CNC milling

8.1. Data acquisition

Acquisition of the data for the required model with contact or non- contact method is the first step, the widely used technique for this purpose are: computerized tomography (CT), magnetic resonance imaging (MRI), and laser digitizing. Other techniques include ultrasound, mammography, and X-ray [20]

Optical technique which based on laser or white light is the widely used type in dentistry particularly in prosthodontics [32] after projection of laser or white light on the model, a digital camera will be used to obtain the reflected lights, then 3D data would be acquired. This type of dental scanner permits non-contact scanning of both soft and brittle materials however, precision of scanned data could be affected by the optical features of the model [31].

8.2. Data Processing

The quality of dental or medical model is depend on data processing which is very complex step [6]. Many types of procedures like noise filtering, data reduction, segmentation of the point cloud parts or assembling are used to convert the acquired data file format into a file format that can be treated for computing and manufacturing procedure [1]. Sterolithographic file format(STL) is suitable in most situations for Rapid manufacturing [6,20].

8.3. Model fabrication

Many types of RP technologies were used such as stereolithography, selective laser sintering, fused deposition modelling (FDM), and Ink Jet printing techniques to create dental models [23]. The type of dental restoration will determine the chosen technology, it depended on exacting precision, finishing surface , visible manifestation of inner structures, number of colors which needed for each model, strength and properties of the materials etc. The model is ready for implementation if the team decided that there are no errors after the RP medical model is created [6].

For designing frameworks of RPD, STL is the best choice. the STL model is used to identify the existing undercut areas on the virtual CAD model which prepared for the teeth and surrounding tissues of the patient. Undesirable undercuts should be blocked out to ensure a path way for replacement and removal of the RPD into the patient mouth. Soft tissues will be relieved, Then carving will done virtually with special software tools [1,33,34] making it similar to conventional carving by using haptic device which enabling models′ movement, rotation and translation in all axes, as well as hand moving.

The important property of haptic device that it makes the user feeling as contacting with the model. Using of modern software for virtual carving and haptic device will permit implementation of standard CAD parametric properties. This will make model more flexible and efficient [1].

9. Conclusion

In the last two decades, different technologies were developed, whereas other technologies are appears. Rapid prototyping manufacturing (RPM) is one of these technologies, it is known as a advanced and resilient fabrication technique. There were a continuous attempts to improve them by: amending its speed and accuracy , reducing the system and items cost , and developing more obtainable popular items . RP technologies plays a very important role in dental application and it is noticeable that using of its models in dentistry will be widened in the future with continuous evolution of it. It will be useful in many fields of dentistry such as planning for surgery and designing for prosthodontics .

Dental replacements can be manufactured in a layer by layer manner directly from a model created by the computer easily and quickly with different RP technologies without neither using special tools for each particular part nor involvement of the user. It made a rebellious alteration in the manufacturing of dental prosthesis. the evolution and research of the variety for RP techniques and materials which used with it make the creation of various types of dental prostheses for different implementation is possible. As in fabrication of wax pattern and molds for dental prosthesis, zirconia prostheses and metal prosthesis. Although the present limitations in using RP technique such as excessive cost of equipments, its depends on the user experience and complexity of the machines. But it thought to play an important role in dental prosthesis fabrication, it may become one of the most important techniques in digital prosthdontics. With time, more sophisticated implementations of RP will be available to be more benefit for more patients.

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