REVIEW ARTICLE

Application of Rapid Prototyping in Prosthodontics

Shubhaani Singh *, Pankaj Dhawan, Mansi Nautiyal

Department of Prosthodontics & Crown and Bridge, Manav Rachna Dental College, Faridabad, Haryana, India

*Corresponding Author: Shubhaani Singh
Email: shubhaanisingh24@gmail.com

Received: 11 August 2021/ Accepted: 30 September 2021

Abstract

Purpose: Rapid Prototyping (RP) methods have for quite some time been utilized to construct complex 3-Dimensional (3D) models in the field of medicine since the 1900s. This paper intends to offer a thorough audit of different RP strategies, especially in Prosthodontics that are relied upon to carry numerous enhancements to this field.

Materials and Methods: A pursuit was made using the Google scholar web and the PubMed database as a search engine. The keywords; 'RP', 'rapid prototyping', '3D printing', 'dentistry' and 'prosthodontics', 'stereolithography', 'selective laser sintering', 'fused deposition method', and 'inkjet-based system' were looked at in the title/abstract of distributions. References of selected articles were additionally looked into for conceivable incorporation in the study. The selected articles utilized RP procedures in different fields of dentistry through various methods. Nonetheless, distributions concerning the dental utilization of RP advancements are as yet uncommon.

Results: Although the concept of layering 3D objects is almost as old as human civilization, this technology has only lately been applied to the construction of 3D complex models in dentistry. Many additional methods appear to be on the horizon that could alter standard dentistry practises in the near future. More unit hours should be included in dentistry curriculums to familiarise dental professionals with the various advantages of this unique technology.

Conclusion: Lately, RP using the property of adding substances or layering strategies have advanced quickly in different fields of dentistry as they can overcome known disadvantages of subtractive and regular procedures. RP has as of late proposed effective uses in different fields of dentistry, like fabrication of implant surgical guides, structures for Removable Partial Dentures (RPDs), Fixed Partial Dentures (FPDs), wax designs for the dental prosthesis, maxillofacial prosthesis, zirconia prosthesis, and molds for metal castings now as well for complete dentures.

Keywords: Rapid Prototyping; 3Dimentional Printing; Stereolithography; Selective Laser Sintering; Fused Deposition Method; Inkjet-Based System.

DOI: https://doi.org/10.18502/fbt.v9i3.9651

1. Introduction

Rapid Prototyping (RP) techniques, also termed Solid Freeform Fabrication (SFF) or layered manufacturing, have been employed to build complex 3-dimensional (3D) models in medicine since the 1990s [1]. The principle benefit of RP methods is that clinical models can be made to have undercuts, voids, and complex internal anatomy, for example, neurovascular channels or sinuses. The RP model is presently utilized predominantly for improved financial practicality, clinical analysis, and diagnosis, and precise surgical planning also abbreviates the activity period and altogether lessens hazard to the patient [2]. RP refers to the formation of 3D actual models directly from a computer-aided configuration model. The model is built by the process of layering according to 3D data. Conversely, with subtractive development, the additional substance advances can deliver complex build-ups and cavities assertively. Common RP progressions used in this field are explicit Fused Deposition Modeling (FDM), inkjet-based framework, Stereolithography (SLA), and Laser Sintering (SLS). RP procedures are presently viewed as an encouraging option for the production of dental prostheses [3].

A search was made using the Google scholar web and the PubMed database for the keywords; ‘RP’, ‘rapid prototyping’, ‘3D printing’, ‘dentistry’ and ‘prosthodontics’, ‘stereolithography’, ‘selective laser sintering’, ‘fused deposition method’, ‘inkjet-based system’, were looked at in the title/abstract of distributions. References of chosen articles were additionally looked into for conceivable incorporation in the study. The selected articles utilized RP procedures in different fields of dentistry through various methods.

1.1. New Frontier in Advanced Technology of Dentistry

Internet of Dental Things (IoDT) has reformed the dental care area radically since the last ten years. Ongoing advances in the computerized world have assisted with accomplishing the prevention and management of chronic diseases by innovation-based gadgets in the clinical field. Progressed science, cloud innovation, and a new generation of smartphones, in addition to tablets with incorporated applications, have assisted patients with following their sicknesses constantly on a consistent schedule. Dentistry has additionally changed totally because of the foundation of computer-based cutting edge innovations, new preventive infection measures, and worked on demonstrative and diagnostic strategies in the most recent couple of years. IoDT is an inventive way to deal with avoidance and the beginning of dental caries, periodontal illnesses, oral malignant growths, and other dental infections. IoDT could assume a crucial part in the assortment and observing of patients' information for oral medical services, additionally this information could be utilized in eventual risk evaluation and further research [4]. Over the past twenty years, CAD/CAM acronym for Computer-Aided Designing and Computer-Aided Manufacturing has become extremely popular. It has helped to revolutionize treatment concepts and the fabrication of prosthesis. It helps to improve the design as well as the function of the prosthesis [5].

Clinical dentistry has extraordinarily arisen since the last decade because of advances in computerization, rapid change in dental materials further developed clinical patient-administration procedures, and presentation of patient-driven preventive treatment measures. Computerized upheaval emphatically affects the present clinical dentistry, and this will doubtlessly proceed in the following coming years [6].

2. Rapid Prototyping (RP)

RP is the supposed "generative fabrication method", which displays a possibility to beat nearly all portrayed shortcomings. RP just comprises of two stages: virtual stage (modeling and stimulating) and actual stage (fabrication). The course which frames the actual model is the development of a 3D physical model made by CAD. A few qualities which describe the process are: Without involving the setup of whole machinery or final assembly the objects can be produced with different geometrical intricacies. Articles are created using various materials like composites. Besides, various materials can be used at better places for an object because of controlled conduction. By additive fabrication systems, the development of complex items is quick, helpful, and less complicated [7].

Benefits of RP:

• Speed is a clear advantage of RP.

• RP rapidly conveys superior designing specialized apparatus, the physical model rapidly and unmistakably imparts all the parts of the design and quality.

• RP helps with the identification of anatomical mistakes and adjustment of configuration defects at the earliest.

• In the elementary structure, one main advantage of RP is trust in the reliability of the design and approval of the fit by the patient [8].

Classification of RP Technologies in Dentistry:

1. It is broadly categorized into [9]:

- Additive method: which is commonly used
- Subtractive method: less frequent

2. The most frequently and commonly adapted technologies in dentistry are:

- SLA
- Inkjet-based system (3DP)
- Laminate Object Manufacturing (LOM)
- FDM
- SLS

2.1. Stereolithography (SLA)

The primary cycle of this sort of RP was licensed by Hull (1984), for the production of 3D models from photopolymer resins. This framework comprises a shower of photosensitive fluid resin, a model-building stage, and a bright (UV) laser for curing the resin as shown in Figure 1. The layers are relieved successively and bonded together to shape a strong object starting from the lower part of the model and building upwards. As the resin is exposed to UV light, a dainty distinct layer thickness becomes hardened. The resin stage is then brought down

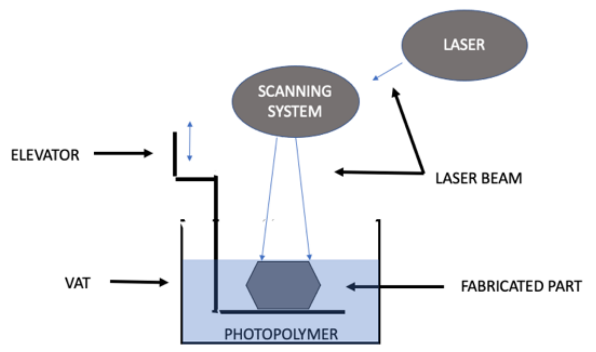

Figure 1. Schematic of Stereolithography (SLA). Reprinted with permission from [8]

inside the group by an insignificant distance solely after the layer of resin is cured. A wiper blade is used to clean another resin layer that is present outside the preceding layer, followed by consequent exposure and curing of the succeeding layer. The method of curing and dropping down the stand in the resin bath is rehashed until the entire model is complete. The property of self-adhesiveness of the material makes the layering attach in the end to form a complete structure of a 3D object. After taking out the model from the bath, it is cured inside an ultraviolet chamber for a specific period [8,10].

2.2. Inkjet Based System (3DP)

The working principle is like the traditional inkjet framework and deals with thermal stage changes. A single jet is used in this machine which comprises a plastic core material and a supporting wax-like material that is put together inside a reservoir in a liquefied state. The movement of separate jetting heads is in a particular pattern, resulting in the spraying of small droplets of materials that are poured into it to form a layer of the object as seen in Figure 2. As they are deposited, the material starts to solidify by rapidly dropping the temperature. A uniform thickness is attained by passing it over a milling

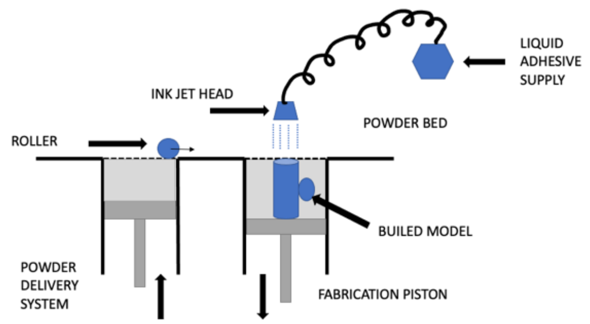

Figure 2. Schematic representation of Inkjet-based system (3DP). Reprinted with permission from [8]

head after an entire layer is formed by using a jetting head. The particles that are released during milling are vacuumed and are caught in the filter. The object is fully formed by repeating the cycle and the supporting wax material melts and is subsequently dissolved. The characteristic of the inkjet framework that is of paramount importance is its capacity of delivering incredible resolutions and a smooth finish [8,11].

2.3. Laminate Object Manufacturing (LOM)

It is one of the RP methods given by Helisys [12]. In this system, layers of adhesive-coated materials like paper, plastic or metal laminates are glued together and cut the desired shape with the help of a knife. It can also be further modified after printing by the method of drilling. Using a Carbon-dioxide laser (CO_2 laser), LOM cuts the thin layers of material mounted on a Two-Dimensional (2D) plotter. The materials commonly used are sheets of paper stacked over and bonded with an adhesive. The parts of the sheet present outside the model help to provide support and the unwanted areas are marked with intersecting lines and cut off after the model is complete. The main advantage for this system is that only the circumference of the part is processed while in other RP systems the entire area needs to be processed [12].

2.4. Fused Deposition Modeling (FDM)

In comparison with SLA, the use of FDM is ranked second among various RP tools. The material is supplied into an extrusion nozzle by a filament made of either plastic or wax which has been separated from a coil. The nozzle is equipped with a mechanism that can both liquefy the plastic and allow for this liquefied plastic to flow as necessary. This is followed by mounting the nozzle onto a mechanical platform at a height that can be shifted both horizontally and vertically as seen in Figure 3. Each layer is formed by deposition of a thin sheet of plastic or wax which has been extruded through the nozzle as it is moved over the table. Bonding to the subsequent layer is facilitated by immediate hardening of plastic or wax as released from the nozzle. The whole framework is enclosed inside a cabinet maintained at a temperature lower than what is required for the used material to melt [2,13].

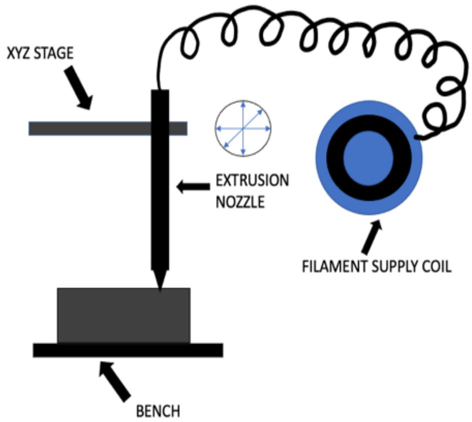

Figure 3. Schematic representation of Fused Deposition Modeling (FDM). Reprinted with permission from [8]

2.5. Selective Laser Sintering (SLS)

SLS is a process wherein a computer-aided laser is used to fuse layers of quantified material into a 3D model. This system consists of a cylinder filled with thermoplastic powder which is spread on the outer surface. The piston present inside the cylinder moves down by a thickness of one object layer to contain the new layer. To oblige the new layer, the piston in the cylinder drops down one object layer thickness. A piston moves up gradually to supply a deliberate amount of powder for each layer as shown in Figure 4. A laser shaft is then followed over the surface of this firmly compacted powder to selectively melt and bond it to form a layer of the object. The fabrication chamber is kept up at a temperature just below the melting point of the powder. To cause sintering, the heat from the laser raises the temperature. The cycle is repeated until the whole article is created. After the item has been completely fabricated the piston is lifted away. Excess powder is essentially brushed away and completion is done manually. The pioneer advantage of SLS is to create functional parts in basic definitive constituents. In any case, the frameworks are precisely extra complicated than other different advances of RP [12,14].

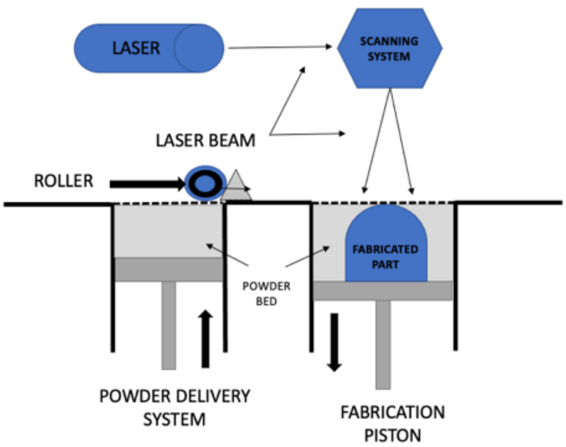

Figure 4. Schematic representation of Selective Laser Sintering (SLS). Reprinted with permission from [8]

3. Application of RP in Prosthodontics

During the ebb and flow years, RP method research has immensely advanced in the molding and processing of the material. Although this innovation can be utilized to produce real functional parts, it is not only used for prototyping. Therefore, RP has begun holding more value in dental purposes. Likewise, RP strategies are used for designing, creating, and manufacturing dental prostheses like Fixed Partial Dentures (FPDs), copings, and crowns. By conventional methods, dental prostheses require a lot of arduous and tedious hands-on work by the technicians or the dental specialists themselves. In comparison to conventional procedures, the advantage of the RP procedure lies in utilizing a computer model to fabricate a new dental prosthesis without human mediation and part-explicit tooling. The cost of the labor is viably decreased; more dental restorations can be accomplished at a quick pace. Presently, RP procedures are viewed as a hopeful option for the fabrication of dental prostheses [2, 14].

It has been noticed by many researchers that there is a rising focus on the usage of various 3D scanning devices and CAD elaboration on data acquisition for the design of the dental prosthesis. However, there is a gap in the literature when it comes to the use of RP technology in the fabrication of prosthesis patterns.

3.1. Dental Prosthesis Wax Pattern Fabrication

Conventionally, including all means in making an Removable Partial Denture (RPD) framework, porcelain-fused to metal crown, pressed ceramic crown, and wax design fabrication is very basic and quite strenuous. The nature of wax-up additionally relies upon the abilities of the technician. With the beginning and appreciation of RP innovation, another methodology is feasible for programmed wax-up creation. This methodology improves on the traditional fabrication measure and speeds up the production by utilizing 3D imaging, CAD, and RP. The new interaction includes the accompanying three stages [15, 16]:

1. Digitizing the master models with a 3D optical scanner (the full arch and opposing dentition digitization can be performed).

2. Designing the wax pattern with specific CAD programming.

3. Fabricating the wax-up with RP procedures, for example, FDM and 3D printing.

The framework required for computerized dental wax-up-making frameworks is created by the manufacturers. For the fabrication of dental wax-ups having intense velocity, large-scale manufacturing, and mechanical quality, the WaxPro system (Cynovad, Montreal, Canada) is used which incorporates a CAD/CAM having a powerful design station and a rapid 3D scanner. By utilizing WaxPro, just the accompanying two stages are required: (1) synchronous examining and planning with Cynovad's Pro 50 and (2) creating the wax-ups with 3D printing. After the wax design is manufactured by RP, the customary lost-wax process is as yet required. This cycle is less expensive in comparison with sintering direct manufacturing or laser liquefying processes. The significant benefits with RP procedures are:

- The rate of production is higher. With RP procedures, prosthodontic labs can improve productivity.

- The finish of the wax copings details the most accurate fit and constant wall thickness.

- Helps to lessen the time of spring for fabrication.

- The irregularities in wax adapting thickness can be avoided, as they sometimes make additional work for finishing the metal after the cast. Subsequently, it decreases the completing work required on the cast copings [8, 17].

3.2. All Ceramic Restoration Fabrication

Restorations by all-ceramic have recently been made by the frameworks of CAD/CAM. Fixed dental restorations, which use zirconia as the standard material, are manufactured by milling systems. Significant inconveniences of this system include the generation of the sizeable amount of waste of raw material as the unused parts of mono-blocks are cast off after milling and recycling are not viable. Another disadvantage is the presence of minute cracks on the surface of the ceramic formed due to the tooling cycle [18, 19].

Rapid prototyping strategies could help and conquer these disadvantages. A proposal has been put forward wherein fabrication using direct inkjet technique can be used to make green-zirconia all-ceramic dental restoration utilizing a slurry miniature expulsion process. Following this process, the final restoration is completed by a laser-assisted or sintering process. This novel approach is a promising CAD/RP framework concerning its high precision, least material utilization, and economy.

The direct inkjet framework is capable of printing a suspension of zirconia powder having a high solid substance. The properties of the ideal pseudoplastic zirconia powder slurry are determined by the solid loading, pH value, and drying speed after delivery. This helps in the extrusion of the slurry at a low pressing factor and acceptable dimensional capacities. Following the slurry expulsion, the furnace is set to a temperature of around 900°C to 950°C for sintering a small green piece of the dental restoration for 5 to 8 minutes. Post the sintering process there is shrinkage in the crown for about 27% and 25% in height and width, respectively. With a slurry extrusion, the dental zirconia restoration is produced which is then continued by densification of the expulsed slurry by laser. This method makes it possible to print a suspension with a strong zirconia powder content. To develop dental prosthetic restorations which are made up of high-strength zirconia ceramics, the cycle enables the utilization of direct inkjet 3D printing innovation with the conventional drop-on-demand inkjet printhead. However, to fabricate a dental all-ceramic restoration by CAD/ RP is still at an experimental phase [20, 21].

3.3. Rapid Prototyping of Prosthesis Mold (Shell)

3.3.1. Mold for Metal Casting

The molds made of ceramic can be created by metal parts straight by CAD models contrasted with customary strategies for projecting which incorporate development and poring of the cast. These molds can be ready by utilizing RP procedures directly on a computer screen. 3-DP, for example, the casting process that uses direct shell production, produces fired projecting molds for metal projecting utilizing a printing process that is done layer by layer. The interaction includes the deposition of a liquid binder onto the layers of ceramic powder by a multi-stream print head. After the printing is completed, the firing is done on the rigid ceramic mold. Then the liquid metal is poured into the mold to deliver a useful metal cast part. RP procedures are more ideal as they take out the tedious and strenuous steps of the conventional projecting cycle. They likewise sidestep the requirement for wax and core molding, wax assembly, wax removal, design and manufacturing of wax and core tooling, and shell dipping and drying [22, 23].

3.3.2. Mold for Facial Prosthesis

The computer-aided designing and RP technology are used to design and produce a negative form of the facial prosthesis with silicon directly. The CAD model is generated by the prosthesis computer model as opposed to manufacturing a rapid-prototyped design of the prosthesis. A negative profile of the real prosthesis is then framed from the mold's cavity. The manufactured shape is utilized to project the real prosthesis in silastic materials, clinical-elastomer, or polyurethane. The mold formed helps us to eliminate the process of prosthesis making and the procedure of conventional flasking and investing [24].

3.3.3. Mold for Complete Denture

A novel computer-aided designing and RP framework were fostered by researchers at Peking University to design personalized molds for a total teeth replacement. The interaction incorporates building up a 3D database for parameterization of artificial teeth positioning, getting edentulous rims in centric relation by the similar database, fabricating physical molds or flasks by 3D printing, and completing the total dental replacement utilizing a customary lab procedure. The dentures are in centric balanced occlusion with precise fitting placed over the edentulous models. The following step ought to be more clinical investigations and quantitative tests by the lab to better the procedure. The absence of research articles uncovers that the cutting-edge innovation in this field of prosthodontics actually should be explored [14, 25, 26].

3.4. Direct Dental Metal Prosthesis Fabrication

The traditional technique incorporates numerous manual steps such as embedding, fabricating, burning out the wax pattern, post-processing, and metal casting. This is a labour-intensive and lengthy procedure. A metal prosthesis is created which is additionally tedious and prompts misuse of the majority of the material with the help of CAD/CAM processing [27].

Thus, RP innovation, particularly Specific Laser Melting (SLM) and Specific Laser Sintering innovation, has drawn in incredible consideration among specialists for its fabrication with great accuracy of metal parts with various shapes and materials. SLM/SLS is a strategy that expands the material layer by layer that permits the formation of complicated 3D parts by specifically merging layers on top of each other with the powder material, utilizing thermal energy provided by a laser beam which is controlled by a computer. Also, the powder, which is left during the process, can be used again. Dental prostheses are truly appropriate for handling through SLS/SLM because of their intricate geometry and their capacity to be redone without long manual pre-or post-processing. The principle 3 stages are as per the following:

1. The computerized geometry is captured and the dental cast is processed;
2. The outline of the framework is modelled digitally;
3. The system is created through a computer through SLM/SLS.

This interaction works on the customary system manufacture measure and speeds up the production period for about 1.5 hours by utilizing CAD, RP, and 3D imaging. In this entire process, the structure is built with the CAD packages to fabricate a designed metal removable partial denture framework. This proposed RP/CAD technique gives a proficient and quick strategy to carefully design and fabricate biocompatible metal systems for complex dental prostheses [28].

3.5. Dental Implants

In implantology, RP is limited to 3D imaging and treatment planning. Additive RP is used to make the surgical guides whereas the subtractive is used to make the restorations mainly all-ceramic. Improper positioning of the implant is one of the most common reasons for the failure of implants. With the help of RP, we can create surgical guides which help to guide the implant insertion. 3D printers can print bone tissue tailored to the requirements of the patient and can act as biomimetic scaffolds for bone cell enhancement and tissular growth and differentiation. Even calcium phosphate powders mixed with printing powders based on calcium sulphate can be used as a bone augmentation material [29, 30].

3.6. RP for Maxillofacial Prosthetics

Traditional methods in maxillofacial reconstruction can't effectively handle the issues which are exact situating of the osteotomized bone sections, limitation of a surgical incision, distinguishing proof of fissure marks, and treatment of facial asymmetry. [31] These issues are significantly a result of trouble in recognizing the structure of patients inside tissues and organs in manufacturing adequately the complicated models and processing the certain accuracies of the guides [32]. It can likewise be used to navigate maxillofacial procedures by consolidating into a surgical. To work with maxillofacial recreation, RP innovations have been applied and it assists with deducting the issues by the CAD/CAM innovation by the brisk speed, generally, the production cost is low and precise fabrication can be done of solids of complex sizes and shapes utilizing a variety of materials. Because of the benefits, RP advancements have been effectively utilized for treating different congenital or acquired malformations, facial asymmetry, and deviation, and maxillofacial defects [33, 34]. Materials assisted for maxillofacial prosthetics are:

- Non-autologous bone grafts
- Alloplastic bone replacement material
- Autologous bone grafts

3.6.1. Restoration of Acquired Maxillofacial Defects and Deformities

Imaging devices like Magnetic Resonance Imaging (MRI), Computed Tomography (CT), and scanner are utilized to get information, with which natural or anatomical model is produced by RP advancements. The bio model further aids in planning, preoperative diagnosis, and surgical training. Likewise, it helps to improve the medical procedures and support the operating procedures or drug therapy. The fabrication of customized implants can be done by RP technology as well. This gives a precision of fit to the deformity and stays away from complexities like seroma in the follow-up period, extrusion and infection [35].

3.6.2. Reduction of Functional Bone Tissues

The 3D model of the skeleton created by RP innovation has ended up being fruitful in diagnosing the fracture structure, assessing the character of the fracture, and planning a surgery procedure plan. Additionally, it is easier to perform a surgery that is more accurate by simulating the surgery on a 3D model priorly. Increasing the accuracy of surgery, restoring maxillofacial fractures, and refining facial symmetry is easily done with the help of supplementary Computer-Assisted Surgical (CAS) methods including the mirror-imaging strategy [4, 31].

3.6.3. Fabrication of the Maxillofacial Prosthesis

In conventional strategies, moulage impression is normally used to re-establish extraoral maxillofacial deformities. However, it is time-consuming and in some cases causes inconvenience for the patient, distortion of the site due to the weight of the impression material, and disfigurement of the soft tissue because of the pressing factor of the impression material and changes in tissue area with alterations of the patient's position. To tackle this load of issues, various strategies which coordinate RP advances with cutting edge imaging procedures, for example, laser examination and 3D optical imaging, are projected to create a nasal, and auricular, or facial prosthesis for improving the aesthetics of a debilitated maxillofacial appearance. The consolidated strategies have uneasiness to a lesser extent for the patient and no contortion from regular impression materials or patient situation despite relatively expensive devices and conceivable confounded shadings among model and normal skin tones [36, 37].

4. Conclusion

With the progression in innovation, RP methods have been significantly utilized in dentistry, yet utilization of RP in prosthodontics is generally uncommon. Dental prostheses can be manufactured using a computer model effectively and quickly by different strategies of RP. This method is a progressive change for the fabrication of dental prostheses. Comparatively to the conventional methods, it helps to rule out the manual mistakes, saves time and energy of the dentist, the laboratory steps are reduced and the patient acquires prosthesis with an undeniable degree of accuracy.

The limitations of the RP innovation incorporate the significant expense of the instruments, complex and confusing machinery, and the dependency on an ability to run the machinery during production. The authors accept that RP strategies are progressively becoming a basic part of prosthodontics and will get one of the standard advances for computerized manufacture of dental prostheses in not so distant future.

References

1- R Petzold, H-F Zeilhofer, and WA Kalender, "Rapid prototyping technology in medicine—basics and applications." *Computerized Medical Imaging and Graphics,* Vol. 23 (No. 5), pp. 277-84, (1999).

2- Chee Kai Chua, Siaw Meng Chou, Sing Ching Lin, Kee Hoe Eu, and Kok Fah Lew, "Rapid prototyping assisted surgery planning." *The International Journal of Advanced Manufacturing Technology,* Vol. 14 (No. 9), pp. 624-30, (1998).

3- Jian Sun and Fu-Qiang Zhang, "The application of rapid prototyping in prosthodontics." *Journal of Prosthodontics: Implant, Esthetic and Reconstructive Dentistry,* Vol. 21 (No. 8), pp. 641-44, (2012).

4- Smita Salagare and Ramjee Prasad, "An overview of internet of dental things: new frontier in advanced dentistry." *Wireless Personal Communications,* Vol. 110 (No. 3), pp. 1345-71, (2020).

5- Hussein Ali Al Essa, "CAD/CAM in prosthodontics: A gate to the future." *International Journal of Applied Dental Sciences,* Vol. 5 (No. 3), pp. 394-97, (2019).

6- Harry Dym and Orrett E Ogle, "Technological advances in dentistry and oral surgery. Preface." *Dental Clinics of North America,* Vol. 55 (No. 3), pp. xiii-xiv, (2011).

7- Kianoosh Torabi, Ehsan Farjood, and Shahram Hamedani, "Rapid prototyping technologies and their applications in prosthodontics, a review of literature." *Journal of Dentistry,* Vol. 16 (No. 1), p. 1, (2015).

8- Abbas Azari and Sakineh Nikzad, "The evolution of rapid prototyping in dentistry: a review." *Rapid Prototyping Journal,* (2009).

9- Shakeba Quadri, Bhumika Kapoor, Gaurav Singh, and Rajendra Kumar Tewari, "Rapid prototyping: an innovative technique in dentistry." *Journal of Oral Research and Review,* Vol. 9 (No. 2), p. 96, (2017).

10- Maria Eugenia Guerrero, Reinhilde Jacobs, Miet Loubele, Filip Schutyser, Paul Suetens, and Daniel van Steenberghe, "State-of-the-art on cone beam CT imaging for preoperative planning of implant placement." *Clinical oral investigations,* Vol. 10 (No. 1), pp. 1-7, (2006).

11- F Xu, YS Wong, and HT Loh, "Toward generic models for comparative evaluation and process selection in rapid prototyping and manufacturing." *Journal of manufacturing systems,* Vol. 19 (No. 5), pp. 283-96, (2001).

12- Ajay Pandey and Lily Tiwari, "3D-Printing-The New Frontier in Prosthodontics-A Review." *Journal of Advanced Medical and Dental Sciences Research,* Vol. 7 (No. 11), pp. 69-73, (2019).

13- Vladan Andonović and Gligorče Vrtanoski, "Growing rapid prototyping as a technology in dental medicine." *Mech Eng Sci J,* Vol. 29 (No. 1), pp. 31-39, (2010).

14- HM Klein, W Schneider, G Alzen, ED Voy, and RW Günther, "Pediatric craniofacial surgery: comparison of milling and stereolithography for 3D model manufacturing." *Pediatric radiology,* Vol. 22 (No. 6), pp. 458-60, (1992).

15- M Wu *et al.*, "Application of laser measuring, numerical simulation and rapid prototyping to titanium dental castings." *Dental Materials,* Vol. 17 (No. 2), pp. 102-08, (2001).

16- RJ Williams, Richard Bibb, Dominic Eggbeer, and John Collis, "Use of CAD/CAM technology to fabricate a removable partial denture framework." *The Journal of prosthetic dentistry,* Vol. 96 (No. 2), pp. 96-99, (2006).

17- Qingbin Liu, Ming C Leu, and Stephen M Schmitt, "Rapid prototyping in dentistry: technology and application." *The International Journal of Advanced Manufacturing Technology,* Vol. 29 (No. 3), pp. 317-35, (2006).

18- J Ebert *et al.*, "Direct inkjet printing of dental prostheses made of zirconia." *Journal of dental research,* Vol. 88 (No. 7), pp. 673-76, (2009).

19- J Davies and JGP Binner, "Coagulation of electrosterically dispersed concentrated alumina suspensions for paste production." *Journal of the European Ceramic Society,* Vol. 20 (No. 10), pp. 1555-67, (2000).

20- Xiaoxuan Li and Leon L Shaw, "Microstructure of dental porcelains in a laser-assisted rapid prototyping process." *Dental Materials,* Vol. 21 (No. 4), pp. 336-46, (2005).

21- X Li, J Wang, and LL Shaw, "Optimization of the cross section geometry of laser-densified dental porcelain bodies for rapid prototyping processes." *Rapid Prototyping Journal,* (2005).

22- Elena Bassoli, Andrea Gatto, Luca Iuliano, and Maria Grazia Violante, "3D printing technique applied to rapid casting." *Rapid Prototyping Journal,* (2007).

23- Emanuel Sachs, "CAD-casting: the direct fabrication of ceramic shells and cores by three-dimensional printing." *Manuf Rev,* Vol. 5pp. 118-26, (1992).

24- Chi-Mun Cheah, Chee-Kai Chua, Kwang-Hui Tan, and Chung-Kiat Teo, "Integration of laser surface digitizing with CAD/CAM techniques for developing facial prostheses. Part 1: Design and fabrication of prosthesis replicas." *International Journal of prosthodontics,* Vol. 16 (No. 4), (2003).

25- Yuchun Sun, Peijun Lü, and Yong Wang, "Study on CAD&RP for removable complete denture." *computer methods and programs in biomedicine,* Vol. 93 (No. 3), pp. 266-72, (2009).

26- N Kawahata, H Ono, Y Nishi, T Hamano, and E Nagaoka, "Trial of duplication procedure for complete dentures by CAD/CAM." *Journal of oral rehabilitation,* Vol. 24 (No. 7), pp. 540-48, (1997).

27- J-P Kruth, Peter Mercelis, J Van Vaerenbergh, Ludo Froyen, and Marleen Rombouts, "Binding mechanisms in selective laser sintering and selective laser melting." *Rapid Prototyping Journal,* (2005).

28- Dominic Eggbeer, Richard Bibb, and R Williams, "The computer-aided design and rapid prototyping fabrication of removable partial denture frameworks." *Proceedings of the Institution of Mechanical Engineers, Part H: Journal of Engineering in Medicine,* Vol. 219 (No. 3), pp. 195-202, (2005).

29- Cristian Zaharia *et al.*, "Digital dentistry-3D printing applications." *Journal of Interdisciplinary Medicine,* Vol. 2 (No. 1), pp. 50-53, (2017).

30- D Rajesh, "Rapid prototyping in prosthodontics: Review of literature and implications for future research." *Journal of Advanced Medical and Dental Sciences Research,* Vol. 9 (No. 7), pp. 147-50, (2021).

31- Preeti Sagar, Sumver Jain, and Abhinav Agarwal, "RAPID PROTOTYPING TECHNOLOGY: AN INNOVATIVE TECHNIQUE IN PROSTHODONTIC DENTISTRY." *Guident,* Vol. 13 (No. 9), (2020).

32- Wei Zhong Li, Mei Chao Zhang, Shao Ping Li, Lei Tao Zhang, and Yu Huang, "Application of computer-aided three-dimensional skull model with rapid prototyping technique in repair of zygomatico-orbito-maxillary complex fracture." *The International Journal of Medical Robotics and Computer Assisted Surgery,* Vol. 5 (No. 2), pp. 158-63, (2009).

33- Sekou Singare, Liu Yaxiong, Li Dichen, Lu Bingheng, He Sanhu, and Li Gang, "Fabrication of customised maxillo-facial prosthesis using computer-aided design and rapid prototyping techniques." *Rapid Prototyping Journal,* (2006).

34- Adir Cohen, Amir Laviv, Phillip Berman, Rizan Nashef, and Jawad Abu-Tair, "Mandibular reconstruction using stereolithographic 3-dimensional printing modeling technology." *Oral Surgery, Oral Medicine, Oral Pathology, Oral Radiology, and Endodontology,* Vol. 108 (No. 5), pp. 661-66, (2009).

35- Nicolai Adolphs, Weichen Liu, Erwin Keeve, and Bodo Hoffmeister, "Craniomaxillofacial surgery planning based on 3D models derived from Cone-Beam CT data." *Computer Aided Surgery,* Vol. 18 (No. 5-6), pp. 101-08, (2013).

36- James J Xia, Jaime Gateno, and John F Teichgraeber, "New clinical protocol to evaluate craniomaxillofacial deformity and plan surgical correction." *Journal of Oral and Maxillofacial Surgery,* Vol. 67 (No. 10), pp. 2093-106, (2009).

37- Ho-Joong Jung, Young-Bok Jung, Kwang-Sup Song, Se-Jin Park, and Jong-Seok Lee, "Fractures associated with computer-navigated total knee arthroplasty: a report of two cases." *JBJS,* Vol. 89 (No. 10), pp. 2280-84, (2007).