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APPLICATION OF RAPID PROTOTYPING TECHNOLOGY IN COMPLETE DENTURE FABRICATION - A REVIEW

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Abstract:

The aim of this article was to write a literature review on the application of rapid prototyping technologies in complete denture fabrication and to outline the principle, procedure, advantages and limitations of the same. Rapid prototyping refers to the automatic construction of mechanical models with 3D printers or stereo lithography machines. It is an innovative technique currently employed in dentistry. With the appropriate design software and hardware, it is possible to arrange the dentition, occlusion, shape, angulations, and even the flange itself with different colors. Application of this new technology has proved to be effective in reducing chair side time and producing high level of accuracy and aesthetic property. By understanding the principles and mechanisms, rapid prototyping can be efficiently used to fabricate accurate and aesthetic complete dentures.

Key Words: Complete Denture, Digital, Fabrication, Rapid Prototyping & Stereo Lithography

Introduction

Complete dentures are prosthetic devices used to replace the entire dentition of an edentulous patient, supported by the surrounding soft and hard tissues of the oral cavity. A successful prosthesis requires optimum support, stability, retention, fit and should restore masticatory, phonetic and aesthetic requirements. The conventional method of complete denture fabrication is cumbersome and is dependent on the professional skills of the dentist and the dental technician [1]. With the advent of modern computer aided technologies, more precise and systematic protocols can be applied to reduce the burdensome steps of both chair-side and laboratory work, thus saving vital time [2]. One such computer aided technology is Rapid prototyping. Rapid prototyping (RP), also termed as solid free form fabrication (SFF) or layered manufacturing is a CAD/CAM technology that automatically constructs physical models from computerized three-dimensional (3D) data [3]. This technology has recently been successfully applied in medical fields such as implant surgical guides, maxillofacial prosthesis, frameworks of removable dentures, wax patterns for dental prosthesis, zirconia prosthesis and moods for metal castings and complete dentures [4]. The RP model is now used for an improved, cost-effective medical diagnosis and accurate surgical planning, which shortens operation time and significantly reduces risk to the patient [5]. RP has gained popularity in dentistry after it has progressed from a prototyping method to a manufacturing aid. Dental prosthesis are fabricated layer by later directly from a computer model without part specific following and human intervention, thus reducing the labour cost and saving time[6]. As a result, RP techniques have emerged as a promising alternative for dental prosthesis production. However, the field of RP is relatively new and requires further expansion in terms of speed, accuracy and reliability. The cost efficiency of such systems also poses a problem to clinicians. Clinicians need to be aware of the possible flaws of such systems. This article reviews mainly the application of rapid prototyping technology in complete denture fabrication. By using the adequate software and hardware, it is possible to arrange the dentition, occlusion, angulations and aesthetics. This is an indication that in the future, complete denture fabrication will be successfully done using computer aided technologies without having to rely on laboratory technicians.

Rapid Prototyping:

A prototype is an early sample, model or release of a product built to test a concept or process or to act as a model to be replicated. Rapid prototyping designates a set of technologies that allow the realization of automatic physical models based on design models, all with the help of a computer.

There are three phases of prototyping as follows [7]:

- ✓ First phase of prototyping: This was the earliest phase where manual prototyping used to be done by a skilled craftsman.
- ✓ Second phase of prototyping: A soft prototype modeled by 3D curves and surfaces could be stressed in virtual environment, simulated and tested with exact material and other properties.
- ✓ Third phase of prototyping: The latest phase of prototyping introduced a layer by layer deposition to make a prototype which is later tested.

The evolution of this technology has occurred over the past few decades which has led to its integration into the field of medicine and dentistry. The geometrical complexity faced in dentistry has made the RP technology the next generation method for fabrication [8].

1. Basic Principle and Mechanism:

The basic principle is that three dimensional computer models are decomposed to form thin transverse sectional layers followed by reconstruction of these layers [9]. Two different approaches have been utilized to fabricate the physical prototype or model: subtractive and additive. The subtractive technique is accomplished by conventional machining such as milling. The inout data for this method are principally from an optical or contact probe surface digitizer which can only capture surface data of the anatomy and not the internal tissue structure of the proposed object [10]. Numeric control machining is typically used to fabricate metallic or ceramic crowns in dentistry [11].

The additive technologies can produce arbitrary and complex shapes with cavities using the "layered manufacturing" or "solid free form fabrication" method. A 3D computer aided design model of an object is decomposed into cross sectional layers and virtual trajectories are used for physically rapid building up of these layers in an automated fabrication machine to form the object called the prototype [12]. The main advantage of this type of mechanism is its ability to create minor details such as undercuts, voids and complex internal geometries.

Basic Operation [13]

- ✓ CAD model - entire rapid prototyping process begins with a CAD model.
- ✓ Translator - CAD file goes from CAD to rapid prototyping translator, so that CAD data is input in the 'tessellated' stereo lithography format, which has become standard of rapid prototyping field. In this, boundary surfaces of object are represented as numerous triangles just like 'facets of a cut jewel.'
- ✓ Supports - To ensure that the recoater blade will not strike the platform upon which the part is being built and to provide a simple means of removing the part from the platform upon completion supports are provided.
- ✓ Slice - Part to be built and supported must be sliced, i.e., the part is mathematically sectioned by the computer into a series of parallel horizontal planes like floors of a tall building.
- ✓ Merge - Supports and parts have their computer representations merged.
- ✓ Prepare - In this step certain operational parameters are selected such as number of recoater blade sweeps per layer, the sweep period, and the desired Z- wait. Z-wait is the amount in seconds that the system is instructed to pause after recoating.

2. Advantages of Rapid Prototyping:

- ✓ The obvious benefit is the speed of the entire fabrication process.
- ✓ It quickly delivers a better design communication tool.
- ✓ It also facilitates the early detection and correction of flaws.

3. Types of Rapid Prototyping Technologies:

Stereo Lithography (sla): The first process of this type of RP was patented by Hull in 1984 [14].A photosensitive liquid resin bath, a model forming platform and an ultraviolet (UV) laser for curing the resin are the components of a stereo lithography device. The layers are cured and bond sequentially to form a solid object for impressions used in reconstructive surgeries and subperiosteal surgery in dental implant therapies. The self adhesive property of the material causes the layers to bond o each other and eventually form a complete 3D object. SLA made surgical drill guides have been proven to provide maximum accuracy [11].The manufacturing process has fairly good speed. Such prototypes can be used as master patterns for injection moulding, thermoforming, blow molding and metal casting procedures [7].

Inkjet Based System or 3dp: The working of this system is similar to a 2D printer. In this technique a measured amount of raw powder-form material is initially dispensed from a container by moving a piston. A roller then distributes and compresses the powder at the top of the fabrication chamber. A liquid adhesive is then deposited from a multi-channel jetting head in a 2D pattern onto the powder, make it bond and form a layer of the object. When a layer is completed, the piston helps spread and join the next powder layer. This incremental (layer-by-layer) method is gradually continued to achieve a complete prototype. Unbound powder is wept up subsequent to a heating process, leaving the fabricated part sound and intact [11]. Cost effective all-ceramic restorations can be best fabricated using this method.

Selective Laser Sintering (SLS): In SLS method, layers of particular powder material are fused into a 3D model by adopting a computer-directed laser. A roller distributes the powdered material over the surface of a build cylinder. Powder is spread layer by layer on top of the preceding hardened layer and sintered repeatedly. To hold the new fresh layer of powder, the supporting platform relegates one object layer thickness. The surface of this firmly compressed powder is then exposed to a beam of laser [15]. SLS technique is of great benefit to prosthodontics as thermoplastic materials such as nylon composite, investment casting wax, metallic materials, ceramics and thermoplastic composites can be used in this method [16].

Fused Deposition Modeling (FDM): The FDM is a rapid prototyping technique in which a thermoplastic material is extruded layer by layer from a nozzle, controlled by temperature. In this technique, a filament of a thermoplastic polymer suckles into the temperature controlled FDM extrusion nozzle dome. It is then heated to a free-flowing semi liquid form. The motion of the nozzle head is controlled by a processor and traces and deposits the material in extremely thin layers onto a platform. The head leads the material into place with an ample precision. A portion of the subject is built up layer by layer and the material solidifies within 0.1s after being ejected from the nozzle and bonds to the layer below. The supporting structures are contrived for overhanging geometries and later removed by cutting them out from the object [11].

4. Application in Maxillofacial Prosthesis:

Rapid prototyping has been applied in the following aspects of maxillofacial prosthodontics [4]:

- ✓ Production of auricular and nasal prosthesis
- ✓ Obturators
- ✓ Duplication of existing maxillary and mandibular prosthesis
- ✓ Manufacturing of surgical stents for patients with large tumors which require excision.
- ✓ Manufacturing of lead shields to protect healthy tissue during radiotherapy treatment.
- ✓ Fabrication of burn stents.

5. Application in Dentistry:

With the wide scope available, it was inevitable for rapid prototyping to be applied in the field pf dentistry.

Dental Prosthesis Wax Pattern Fabrication: It can be used for mass production of wax patterns for casting purposes. The process is more affordable than other technologies like laser melting or sintering direct manufacture processes, but still remains financially unaffordable for most dental laboratories [17].

Mold for Facial Prosthesis: The generated resin mold fabricated using RP technologies is long lasting and allows pouring in multiple times thus eliminating the need for conventional flasking and investment procedures [18].

Direct Dental Metal Prosthesis Fabrication: Selective laser melting and selective laser sintering technology has been used for fabrication of high precision metal parts without extensive manual pre- and post- processing steps [19].

All Ceramic Restoration Fabrication: A direct inkjet fabrication process has been indicated for the fabrication of zirconia all ceramic dental restoration using a slurry micro extrusion process which has high precision, cost competence and minimum material intake [20].

Application of Rapid Prototyping in Fabrication of Complete Dentures: Very few publications on 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.

Mold for Complete Dentures: 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 [21]:

- ✓ 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.

Summary of Clinical Studies Evaluating Application of Rapid Prototyping in Complete Denture Prosthodontics:

Studies conducted earlier by Kanazawa et al[22] used the patient's pre-existing denture to record the data on a computer and fabricate a new denture using CAD/CAM. Data for the denture space was recorded using 3D CAD software and denture shapes were designed. The mucosal surface and jaw relationship records were obtained from the pre-existing dentures using cone-beam computed tomography (CBCT). Artificial teeth arrangement and polishing surface was designed and complete denture bodies were produced using computerized numerical control (CNC) processor. However, it was extremely difficult to perform a trial insertion when this method was applied. To overcome this hurdle of denture trial Inokoshi et al [3] conducted a study titled "Evaluation of a complete denture trial method applying rapid prototyping" in the year 2011. 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. The methodology of the study was as follows. Ten edentulous patients were enrolled in the study conducted by Inokoshi et al [3] at the University Hospital of Dentistry at Tokyo Medical and Dental University. For each patient, maxillary and mandibular duplicate dentures were made using an auto-polymerizing resin. Duplicate dentures were used to take impressions and jaw relation records with a silicone impression material and a vinyl polysiloxane impression material. The final impressions were taken without border molding. The final casts were made and articulated and wax dentures were made according to the conventional method. For fabricating the trial dentures using RP technology, a CBCT scanned the wax dentures. CT images were reconstructed and transferred into 3D images which were sent to the work station as standard triangulated language (STL) files. Using 3D software, artificial teeth arrangement was done. Trial dentures were then fabricated using stereolithography. Prosthodontists evaluated the accuracy of both the types of trial dentures: conventional and RP fabricated, on each patient in terms of esthetics, stability, comfort of dentures, fit and overall satisfaction [3]. The statistical analysis revealed that there was no significant difference between the methods in terms of esthetics, predictability of final denture shape, stability, comfort, and overall satisfaction from the patients point of view. 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. The author's reported that though RP systems show high degree of accuracy in the processing step, the dentures fabricated by the conventional method are more stable. This may be due to a difference in the scanning process using CBCT. The authors also believed that 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 [3].

Conclusion:

It is noteworthy that rapid prototyping technology has been successfully employed in the field of medicine and industry. Although, the use of this emerging technology in dentistry is relatively new. Better methods need to be formulated to make data acquisition from the patient much more accurate and to reduce the cost of production. Also, there is a dearth of clinical studies which can substantiate the quality and ability of such technologies to replace the conventional methods of manufacturing. Application of rapid prototyping in fabrication of complete dentures, is therefore a relatively recent advancement which requires great deal of research and clinical trials to prove its advantages over other methods.

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