IJCSE International Journal of Computer Sciences and Engineering Open Access
Research Paper Vol.-7, Issue-1, Jan 2019 E-ISSN: 2347-2693

Design of Process Flow for Dental Prosthesis Using The Concept of Additive Manufacturing

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Available online at: www.ijcseonline.org

Accepted: 24/Jan/2019, Published: 31/Jan/2019

***Abstract*—** Additive manufacturing or 3D printing technology has been developing rapidly since the last 30 years, and it indicates excellent potential for future development. The promising future of this technology causes its significant impact on medical science. Currently, this technology is expensive; however, it is slowly becoming more affordable. 3-D printing has a huge potential to change the future of medical model production and prototyping, due to the beneficial products it can produce. 3-D printing is a revolutionary technology that can positively impact the work of medical professionals while enhancing the lives of others. The findings from the research reveal that digital and rapid prototyping are viable in reducing development time and improving prototype accuracy. Current research work describes about constructing dental implants, bridge, and crowns for damaged tooth using Additive manufacturing. Researchers have obtained a 50% reduction in the manufacturing time of the tooth implants as compared to the conventional manufacturing method. The selected material is biocompatible, and it can perform the desired operation without being affected by the chemical reaction. In addition to the reactiveness, authors have also taken into consideration the patient-specific design and pattern manufacturing. With the help of the digital X-ray one can obtain the precise dimensions of the tooth and the CAD software enables the transformation, further castable resin pattern developed through additive manufacturing aids in the final stage of casting.

***Keywords*—** Biocompatible materials, Digital Dentistry, Castable resin.

I. INTRODUCTION

Additive Manufacturing or Rapid Manufacturing is one of many names used for a group of processes that are based on the layer dominated manufacturing process to produce physical products directly from 3D computer data. The process starts by designing a 3D model of a product the 3D model is exported to the pre-processing software of the rapid manufacturing machine. The original technology is based on ink-jet principles and can print with a variety of materials. When using this technology, a Computer-Aided-Design (CAD) file is processed through specialized software and spliced into a series of two-dimensional layers. The printer produces the object layer-by-layer.

The research in this area has recently received more attention due to the popularity of user-friendly 3D printers. The most common classes of materials used as biomedical materials are polymers, metals, composites, and ceramics. These classes are used singly and in combination to form most of the implantation devices available today. However, the materials that are used to manufacture several body parts are expensive, because of which the medical surgery is also very costly. 3DP is emerging as a powerful tool for tissue engineering. In this field, for the fabrication of tissues, blood vessels, heart valves, bones, synthetic skin and organs. Organ models and tumour models are also being designed using 3DP [1].

A dental application includes dental implants, crowns, and bridge between two teeth. A dental implant is an artificial root made of titanium metal. It is inserted into the jawbone to replace the root of the natural tooth. An artificial replacement tooth is attached to the implant.

The implant acts as an anchor to hold the replacement tooth in place. As shown in the figure 1 a crown is also known as a cap; it is a hollow, artificial cover placed upon a damaged tooth. It restores the tooth and protects the tooth. It also improves the aesthetics of the mouth. A tooth that has been implanted with a crown works like a natural tooth. A dental bridge is a common, affordable, time-tested, and low-risk treatment for missing teeth. The dental bridge is so called because it bridges the gap created when teeth are lost [10].

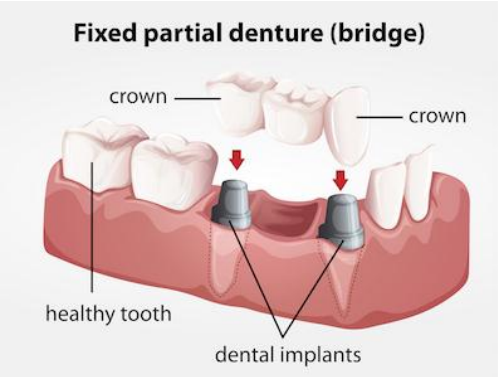

Figure 1. Dental Implants, Crown and Bridge [10]

The current work is concentrated on the innovative way of manufacturing of Dental Crowns. The need for a dental crown is to strengthen the damaged tooth, To restore or to make changes with a tooth's shape and improve the appearance of the teeth. These crowns are constructed using Ceramics, Metal Alloys and combination of Ceramic and metals. Majorly the metallic crowns are made with the fabrication, and the base metals are Gold alloy, Silver-Palladium alloy, Titanium, Nickel Chromium alloy, Stainless steel and many more.

The objectives of the proposed work are:
- To analyze potential changes in the manufacturing process of crowns. In current days the manufacturing process of dental prosthesis takes longer time.
- To evaluate the current state of play and future developments, in the era of the dental implants manufacturing process by Additive manufacturing.
- To identify opportunities to fabricate dental prosthesis using 3D Printing technology.

Section I defines and introduces basics of dental prosthesis and Additive manufacturing process, Section II briefs about related works done to develop dental prosthesis using Additive manufacturing process, Section III about the entire manufacturing process flow. This section is categorised into two parts 1) Traditional process flow to develop dental crown and 2) Applying Additive manufacturing process, Section IV explains the advantages of the innovative process, Section V is of result and discussion, Section VI of acknowledgement and Section VII of References.

II. RELATED WORK

The research problem is come up from the extensive literature review; it consists of major areas such as Manufacturing of prosthesis using 3D printer and Manufacturing methods of Dental Crowns. The related works in these areas are given below:

Li Yanga, Shanshan Zhanga, Gustavo Oliveirab, Brent Stuckera, Development of a 3D Printing Method for Production of Dental Application [2], The primary material used for this study is VITA VM13 Base (Vita Zahnfabrik, Germany), which is a leucite-reinforced glass ceramic widely used for dental practice. The original powders exhibit significant aggregation which made it unsuitable for the process. The basic procedures of this process involve the presenting of ceramic blocks followed by a CNC machining process that produces accurate shapes, then the green machined parts are subject to a densification sintering process to generate the final densities as well as mechanical performance.

Jian Sun and Fu-Qiang Zhang, The Application of Rapid Prototyping in Prosthodontics [3], RP technique research progressed rapidly in the molding material and the forming process. This technology is no longer used exclusively for prototyping but it can be used to manufacture real functional parts. Therefore, RP is becoming more attractive in dental applications. RP techniques can also be used to design, develop, and manufacture dental prostheses such as copings, crowns, and fixed partial dentures.

Dr. M. Taruna, Dr. Ch. Vyshnavi, Dr. G. Kalpana and Dr. Aditya Sai Jagini - Concept of rapid prototyping and its uses in dentistry [4]. This rapid prototyping technology develops 3D physical models using additive or subtractive process. There are many techniques in rapid prototyping. In prosthodontics, it has several applications. The introduction of CAD/CAM milling systems in the dental field enabled zirconia ceramics to be used as a standard material for dental prosthetic restorations. Application of this technology reduced the time and had a better outcome. But it also has some limitations such as its expensive and there is wastage of material in few techniques.

James Klim & Edward- Innovation in Dentistry: CAD/CAM Restorative Procedures [5]. Alternative soft tissue management techniques include electrosurgery and one of the standard manual retraction techniques. In addition, a modified preparation design may be necessary. The latest type of resin cement is self-adhesive and are dual-cured. They require only one step and do not require separate application of etchant, or etchant and bonding agents, prior to application of the cement. These cements are effective for CAD/ CAM zirconia restorations CAD/CAM now offers automated production, accuracy, aesthetically pleasing and strong restorations, and flexibility to both the dentist and the laboratory technician. Figure 2 indicates virtual design of crown.

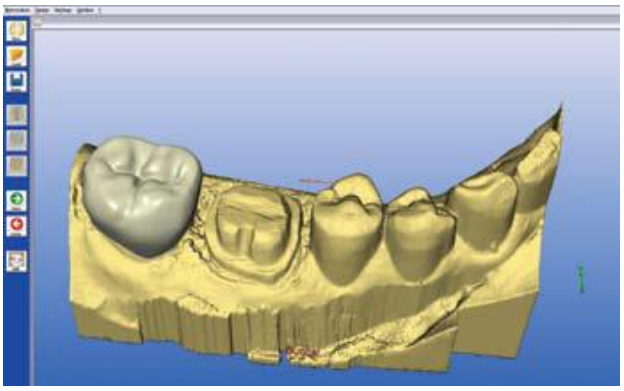

Figure: 2 Virtual design of posterior crown [5]

After reviewed related works of the research problem, identified the innovative process flow to develop dental crown.

III. PROCESS FLOW

The development of dental prosthesis like dental crown categories into two process flow: 1) Traditional way of manufacturing and 2) Applying Additive manufacturing to develop Crown.

1) Traditional process flow

Traditionally, the fabrication of metallic crowns having the following stages:

1. Creation of Patient-Specific impression (of the missing tooth),
2. Prepare pattern of the tooth in porcelain / Plaster,
3. Wax pattern fabrication,
4. Investment casting and finishing of the Crowns.

The dental impression techniques depend on different factors: 1) The type of restoration that will be manufactured. 2) The clinical expertise of each practitioner. Generally, there are conventional methods in use for the dental impression which include: 1) Full or complete dental impression. As shown in figure 3. 2) Partial or Segmental Dental Impression.

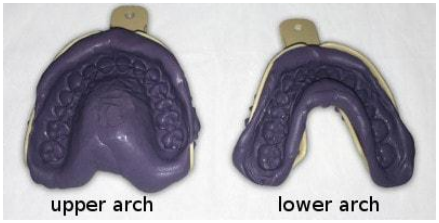

Figure 3. Full or complete impression [16]

The very next stage is to prepare the pattern (Rigid Impression). The main component of impression plaster is calcium sulphate hemihydrate, which reacts with water to form calcium sulphate dihydrate, and forms a rigid impression. That desired substantial part is trimmed for creating a wax pattern as showed in figure 4.

Figure 4. Impression of Dental Plaster [11]

After trimming, marking the finish line, applying to die spacer, and performing the wax fabrication, it is later divided into methods, 1) Add-on technique and 2) Dip-in Technique. It consists of wax coping, Proximal contact area, Axial surfaces, Occlusal Surfaces and Margin finishing. This is a complex and time-consuming process as drafted in below images.

Figure 5. Finish line & applying die spacer [12]

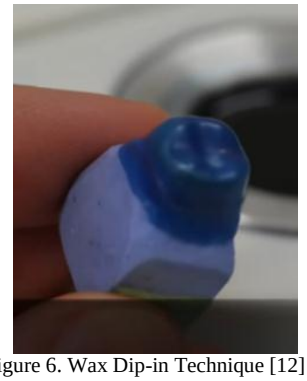

Figure 6. Wax Dip-in Technique [12]

Once the wax pattern is ready, it is shifted to the Investment casting arrangement. In this process, the first stage is to create a pattern by mixing the investment liquid, water, and Dental Plaster. After mixing it well, it is poured into the arrangement. In the burning stage the wax is going to come out and the further the metal is poured in liquid form. Crown from the plaster is removed and at last Trimming and surface grinding of the metals takes place as shown in the figure.

Figure 7. Set-up of Investment Casting [13]

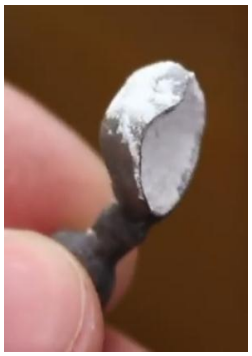

Figure 8. Crown after Casting Process [13]

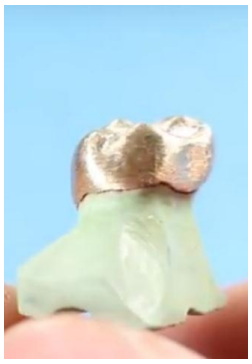

Figure 9. Finished Metallic Crown [13]

The Conventional process is time-consuming, imprecise, and requires materials that might not provide the best durability or aesthetic appearance. Frequent calibration and constant adjustment must be done which takes time and decreases daily production [7].

B) Application of Additive manufacturing.

The primary and first step is Digital Scanning. The digital scanning replaces the traditional concept of taking the impression. Currently, image processing is among promptly rising technologies. It customs primary research area within engineering and computer science disciplines too [9].

The benefits of digital scanning are [17]:

1) Eliminate the uncomfortable experience received by the patient during traditional impressions,
2) Utilize advanced digital technology to maximize the fit of restorations.
3) Achieve superior fitting prosthetics with little or no adjustments.
4) Enjoy increased patient satisfaction.
5) Realize improved clinical results.

In digital image processing fundamental steps are image enhancement, image restoration, image acquisition, color image processing, image compression, image segmentation and recognition [8].

Figure 10. Digital Dental Impression Technology [14]

The output obtained from digital dentistry is a Dental impression in the form of a radiologic image. The scanned radiology image can be converted into 3D Models by 1) MIMICS and 2) 3D-Doctor Software. This Software converts the radiologic image to 3D CAD Model. The CAD model received will be in the .prt (Part file format), .stp (Step file format), .or iges (Initial Graphics Exchange Specification) format. The advantage of the CAD file is, one can edit the same as per the need and stored for the further requirement.

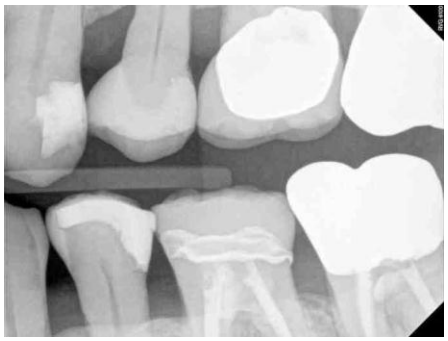

Figure 11. Radiograph of Dental Crowns [15]

The well finished CAD File can be exported to the Meshmixer a software of Autodesk to convert the 3D printing ready file .stl (Stereolithographic) format. Such a format can be directly imported to the 3D Printer.

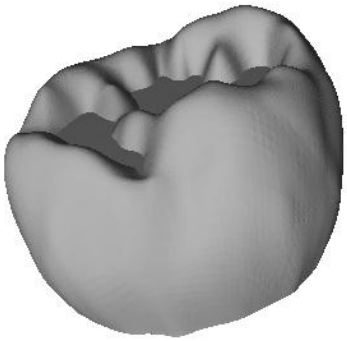

Figure 11. Crown of Upper Molar (.prt file)

The need of such 3D printer which can print the wax material or Castable resin. The properties of Wax and Castable Resin is showing in the below table:

Table: 1. Materials Comparison

Sr. No.	Specification / Property	Wax Material	Castable Resin
1	The technology used for 3D Printing	MultiJet Printing	SLA
2	Density (g/cm3) at 25°C	1.32	1.17
3	Processing Temperature (°C)	70-140	550 to 600
4	Elongation at Break (%)	3.5	5
5	Specific Gravity	0.92	1.1
6	Flexural Modulus (MPa)	8.84	1500

Figure 12. 3D Printed Upper Molar (Castable Resin)

The manufacturing process for both materials is different. The wax printing process is a type of stereolithography that uses a wax-like resin. Support structures are printed along with the model to make sure your model doesn't fall apart. These support structures are automatically generated and manually removed after the printing process. After support structures are removed, and your model is cleaned, the model can be prepared for casting. [18]

The last stage is followed by the Investment casting process. This is the last stage of an innovative way to develop patient-specific Crown.

IV. ADVANTAGES OF INNOVATIVE PROCESS

Advantages of application of Additive manufacturing for the fabrication of Dental Crowns:

1) Application of this technology reduced the time and had better outcome [6].
2) The simple flow of the process.
3) Complex shapes can be cast precisely.
4) Patient-Specific Entity can be created.
5) Easy to modify the 3D Model of the Crown.

V. RESULTS AND DISCUSSION

As per the research findings, application of Additive manufacturing for the dental crowns saves approximately 50% time compared to the traditional process. Also, it has been investigated that the Complex shapes of Dentures can be successfully fabricated with better surface finishing and it ultimately leads to find an innovative way of manufacturing Dental Crowns.

VI. FUTURE SCOPE

An exciting future study might involve the fabrication of the Dental Crown itself using the tough resin materials which are biocompatible.

VII. ACKNOWLEDGEMENT

I would like to express my special thanks of gratitude to my Guide Dr Kartik Kothari and my workplace (RK University) for giving me the golden opportunity to do this wonderful project on the topic: Design of Process flow for dental prosthesis using the concept of Additive manufacturing, which also helped me in doing a lot of Research and I came to know about so many new things. I would also like to thank Dr J B Devmurari (Dentist at Samarpan Dental Clinic) and Dr Bhoraniya (Dentist at Saumya Dental Clinic) who provided the necessary information, support and guidance for the research as and when needed.

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