3D PRINTING - A NEW DIMENSION IN DENTISTRY

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ABSTRACT:

3D printing otherwise known as additive manufacturing, rapid prototyping or layered manufacturing is a relatively new, quickly growing and rapidly expanding method of manufacturing that has got numerous applications in healthcare and also in many other fields. Recently, it has become a subject of great interest in planning surgeries. Additive manufacturing method involves the production of a 3D model by laying down or adding successive layers of material. 3D printers are equipment that produces 3D models using CAD technology or 3D scanners. It has received more importance with the advancement in 3D imaging and modelling technologies such as CBCT, intraoral scanning and CAD/CAM in dentistry. Different techniques are employed in 3D printing namely stereolithography, photopolymer jetting, power binder printers, direct light processing, selective laser sintering, fused deposition modelling, electron beam melting, etc. Dental laboratories are able to produce 3D printed restorations, crowns, bridges, orthodontic appliances, surgical guides and implants quickly with higher precision and accuracy. This is done by methods that combine oral scanning, CAD/CAM designing and 3D printing. The rate of success of 3D printing has improved the quality and accuracy of dental treatment. With the application of 3D printing, it has become possible to replicate the desired complex geometry which was not feasible with conventional techniques. Thus 3D printing has led to a transformation in digital dentistry with its extensive learning and penetrating opportunities and a wide range of applications. The aim of this article was to review the techniques and current applications of 3D printing in dentistry.

Keywords: 3D printing; additive manufacturing; CAD/CAM technology; implants; restorations

INTRODUCTION

Three-dimensional (3D) printing is a rapidly developing technology that has gained extensive acceptance and application in dentistry (Kessler, Hickel and Reymus, 2020). It is also known as additive manufacturing (AM), rapid prototyping or layered manufacturing (Jain, Supriya and Gupta, 2016). The term 3D printing is generally used to describe a manufacturing approach that builds an object by laying down one layer at a time, adding multiple layers (Dawood *et al.*, 2015). The main idea behind this innovation is that the 3D model is sliced into many thin layers and the manufacturing or assembling equipment uses geometric data to build each layer sequentially until the final desired product is completed. All of this begins with making a virtual model that is near enough to the desired item (Cummins, 2010). Scanners might be used to examine and record the anatomy that has to be delivered to the 3D model. The 3D model is cut after which, it is prepared to be taken into the 3D printer of the appropriate type. This is done possibly by the means of USB, Wi-Fi or SD. The record is transferred to a 3D printer and then the model or item is prepared to be 3D printed in layers. The 3D printer uses each 2D picture to make a three-dimensional object. Objects with geometry ranging from simple to complex can be made. This procedure is known as a slicing (Liu, Leu and Schmitt, 2006). It is more often and correctly described as additive manufacturing, and also as rapid prototyping (Andonović and Vrtanoski, 2010).

3D printing has been used since the 1980s. In 1983 Charles printed the first 3D object using the technique of stereolithography (Strub, Rekow and Witkowski, 2006). However, modern additive manufacturing technology was introduced approximately three decades ago (Stansbury and Idacavage, 2016) and its application in dentistry is recent. Additive manufacturing (AM) which involves the deposition of material in increments, is an innovation over subtractive manufacturing (SM) where an object was cut off from a block of material (Azari and Nikzad, 2009; Abduo, Lyons and Bennamoun, 2014)

The term Additive Manufacturing (AM) is used by the ISO and the American Society for Testing and Material. However, in medical and dental applications and general practice in other fields, the term 3D printing is more preferred (Anderson, Wealleans and Ray, 2018). With the rising development of 3D printing, it has become possible to produce the desired complex and precise geometry 3D replicas which were very difficult to furnish with conventional techniques (Vasamsetty *et al.*, 2020). 3D models are produced with the help of CAD/CAM or 3D scanners.

3D imaging plays an important role in the diagnosis and treatment planning of dental diseases. To transform digital images into a real object that can be felt and touched will provide new opportunities to practitioners regarding operative skills, patient communication, treatment planning and could also serve as teaching models in providing skill training for dental students (Moser, Santander and Quast, 2018). 3D modelling and printing technologies are developing due to the increased popularity of 3D printers (Huang and Lin, 2017). With the advancement of 3D imaging and modelling technologies such as intraoral scanning, CBCT and CAD/CAM, 3D printing has acquired great interest and has become a subject of more importance in dentistry (Gabor *et al.*, 2017; Sawhney and Jose, 2018).

3D PRINTING PROCESS:

From a mechanical perspective, 3D printers are simple robotic equipment. The apparatus would be nothing without the computer-aided design (CAD) software that allows us to create objects from scratch; since CAD software helps in designing the object that has to be printed (van Noort, 2012). The use of CAD software is wide in industrial designing, engineering and is also becoming a feature of dental surgeries. But in surgery and dentistry, there is ready access to volumetric data in the form of CT data, CBCT data and intraoral scan data (Dawood *et al.*, 2015). The steps involved in 3D printing include acquisition of a 3D patient model which could be physical/digital and creating design using CAD software and preparing a model for 3D printing followed by 3D printing of the model using the method of additive manufacturing, followed by post-processing (Prasad *et al.*, 2018).

TECHNIQUES OF 3D PRINTING:

The following techniques are employed for Additive manufacturing or 3D printing of various applications in dentistry

1. Stereolithography (SLA).
2. Fused Deposition Modeling (FDM).
3. Selective Laser Sintering
4. Photopolymer Jetting
5. Electron Beam Melting (EBM)
6. Power binder printers
7. Direct light processing

Stereolithography:

Stereolithography is the earliest and most commonly employed technique (Kim *et al.*, 2016). History of stereolithography apparatus (fig. 1 and 2) dates back to the 1980s and it was the first commercially available printer for additive manufacturing. First 3D model was created using this apparatus by Charles Hull (Zaharia *et al.*, 2017). The principle of additive manufacturing with stereolithography apparatus is, a photosensitive monomer resin when exposed to UV light gets converted into a polymer and solidifies (Gabor *et al.*, 2017). The apparatus uses a scanning laser and the exposure path of the UV laser is directed onto the surface of the photosensitive resin (Anderson, Wealleans and Ray, 2018). The layers bind to each other upon sequential curing and form a solid mass, the formation of which begins from the bottom and keeps building upwards (van Noort, 2012) and there is subsequent 3D printing of each layer. SLA could be used to produce implant surgical guides, surgical and burn stents, obturators, etc (Jain, Supriya and Gupta, 2016). The main disadvantage of SLA is the unavailability of biocompatible resin with properties suitable for SLA (Chia and Wu, 2015). Another disadvantage is that the process of SLA is costly when it is employed for large objects (Dawood *et al.*, 2015). The inventor also developed the STL or stereolithography CAD/CAM file format along with SLA (Torabi, Farjood and Hamedani, 2015). Further challenges in SLA are the use of photoinitiators and radicals which may delay the post-processing time, become cytotoxic and may also cause the entrapment of unreacted monomers within itself (Melchels, Feijen and Grijpma, 2010).

Fused deposition modelling:

FDM was developed by Schott Crump (Jain, Supriya and Gupta, 2016). In this technique, layers of molten material are deposited from a nozzle and then solidification takes place within 0.1 seconds (van Noort, 2012). It resembles a robotic glue gun. FDM allows printing of crude anatomical models with simple geometry like an edentulous mandible. The advantage with FDM is that it is less expensive than other 3D methods and is used by most of the low-cost 'home' 3D printers. In addition to this, it is easy to be installed and easily available (Huang and Lin, 2017). But the disadvantage of FDM is that it is less accurate (Kim *et al.*, 2016). FDM printers with higher cost and accuracy are available and are used in the production of anatomical study models, but have lesser application in dentistry and surgery (Darwood *et al.*, 2015; Torabi, Farjood and Hamedani, 2015)

Photopolymer jetting:

This technique uses photopolymer material or light cure resin material and multiple print heads. The use of print heads is to lay down the layers of the material wherein each layer is cured after deposition or laying down (van Noort, 2012). This technology may either use a stationary platform and a dynamic print head or a dynamic platform and stationary print head (Dawood *et al.*, 2015)**.** A variety of materials can be printed using this technique namely resins, waxes for casting, silicone rubber, materials with complex geometry and fine details (Ibrahim *et al.*, 2009). It gives a resolution of approximately 16 microns. Implant drill guides with lesser bulk can be quickly and cheaply produced (Jain, Supriya and Gupta, 2016). Advantages with this technique are it is quick, cost-effective, produces materials with high resolution and high-quality finish (21). Disadvantages include difficulty incomplete removal of the material, high cost of material, skin irritation and inability to sterilize the material by heat (Jacquet *et al.*, 2018).

Electron beam melting:

This technique makes use of an electron beam as the power source instead of a laser (Sawhney and Jose, 2018). This electron beam liquefies the metal powder in successive layers inside a high vacuum chamber and complete liquefying of the material is achieved (Gali and Sirsi, 2015). This technology has found its application in orthopaedics and oral and maxillofacial surgery wherein it is employed for the production of customized implants in the form of porous scaffolds (Hung *et al.*, 2016; Osman *et al.*, 2017).

Power binder printers:

This apparatus uses a modified inkjet head, a pigmented liquid (usually water) and a powder (mostly plaster of Paris). A single layer of the powder is deposited and liquid droplets are made to infiltrate into the powder. This is done layer by layer, in increments. Thus the final model is built of many layers with a new fine layer of un-infiltrated powder on the surface. This un-infiltrated powder layer serves the purpose of support material (Liu, Leu and Schmitt, 2006; Dawood *et al.*, 2015). The advantages of this technique are that the cost of materials and machines is low, the printed models are fully coloured, the processing is faster and it is safe to use (Ciuffolo *et al.*, 2006). Disadvantages include the production of models with limited accuracy, low resolution, low strength and fragility which cannot be sterilized (Chia and Wu, 2015).

Direct light processing:

A projector is used as a light source. The photosensitive resin is deposited and cured layer by layer through the projector (Zaharia *et al.*, 2017). The object is constructed on an elevating platform and the layers are created upside down. Printing occurs sequentially in layers as and when the resin is cured (Masri and Driscoll, 2015; Nayar, Bhuminathan and Bhat, 2015).

Selective laser sintering (SLS):

Selective laser sintering, also known as selective laser melting (SLM) (Torabi, Farjood and Hamedani, 2015; Anderson, Wealleans and Ray, 2018) has been used since the 1980s and was developed by the University of Texas. A fine material powder is fused by a scanning laser for the incremental building of structures. As the powder drops down, the material is uniformly spread as a layer using a computer-directed roller. The difference between SLS and SLM is that SLS has powder-based material (Kalsoom, Nesterenko and Paull, 2018) and SLM has liquid-based material; also each new layer is sintered in SLS whereas, it is melted in SLM (Buican, Oancea and Martins, 2017; Montoya Ashton, 2018). These computer-directed lasers and rollers are used to distribute layers of powdered material on top of a preceding layer due to which a solid object is formed as and when each new layer is sintered or melted (Buican, Oancea and Martins, 2017). SLS is used to fabricate metal objects (fig.3) through direct metal laser sintering (Kim *et al.*, 2016). It is employed in the production of anatomical study models, cutting and drilling guides, dental models, etc. Advantages include ease of autoclaving the materials, full mechanical and functional efficacy of the printed objects, no support material is required as the surrounding powder itself serves the purpose and low cost of materials if used in large volumes (Pattanayak *et al.*, 2011). Disadvantages are that the powders are messy with having an increased risk of inhalation, the cost of purchase and running is high and the technology requires specifications of climatic conditions for its working (Chen *et al.*, 2014)(Xiong, Qian and Jian, 2012).

APPLICATIONS OF 3D PRINTING IN DENTISTRY:

Regaining the comfort, function, speech and esthetics is the ultimate goal of providing dental treatment to the patient (Ariga *et al.*, 2018) (Ashok *et al.*, 2014). These problems result in affecting the psychology of the patients (Venugopalan *et al.*, 2014). 3D printing technology has gained acceptance and is employed for a wide range of applications in almost every field of dentistry.

3D printing in prosthodontics:
Custom trays can be manufactured or 3D printed from computerised scans of impressions or models (Gabor *et al.*, 2017; Zaharia *et al.*, 2017). Model printing directly from intraoral scan helps quick fabrication of prosthesis (fig. 4). In RPD, resin framework can be tried in a patient's mouth before casting. In fixed and removable prosthodontics, restorations could be designed using CAD software and crowns, bridges, copings, abutments, etc can be printed using 3D printers (Dawood *et al.*, 2015; Dodziuk, 2016). Printing of coping or full contour resin patterns (fig.5) can avoid the process of making manual wax patterns, followed by which, the consequences of wax distortion can also be minimized. The marginal fit is of paramount importance for long term success of restorations (Ganapathy *et al.*, 2016) (Ranganathan, Ganapathy and Jain, 2017). Provisional crown and bridge resins were 3D printed (fig.5) and showed higher accuracy and good mechanical properties and marginal fit when compared to conventional ones (Ishida and Miyasaka, 2016; Tahayeri *et al.*, 2018).

3D printing in implant dentistry:

The use of tooth implants has rapidly evolved and widely accepted for replacing single or multiple missing teeth (Ganapathy, Kannan and Venugopalan, 2017) in the last two decades (Ajay *et al.*, 2017). The use of 3D printing technology has gained popularity and acceptance in dental implantology due to the introduction of guidelines for a surgical procedure which implies the usage of surgical guides (fig.6) for insertion of dental implants (Papaspyridakos and Lal, 2008). Jugaad technique involves the use of available dental materials such as PMMA, impression compounds, etc as index material in the fabrication of surgical guides. Costs of this planning are minimal; it produces the desired functional outcome as well. 3D printing helps in the easy production of complex geometry dental implants and surgery guides or drill guides (Dawood *et al.*, 2015). 3D printers also print bone tissue favouring the requirements of the patient that can act as a biomimetic scaffold in the mouth for bone cell enhancement, tissue growth and differentiation (Heo *et al.*, 2017). 3D printed bone implants can replace the deficient part using biocompatible materials like PEEK (polyetheretherketone). The integrity of the implant is important in minimising the stress transfer to the bone (Duraisamy *et al.*, 2019). 3D printing is capable of producing implants with bone-like morphology, in order to reduce the stress-induced on the bone (Chen *et al.*, 2014). Prefabricated dental implant surgical guides can be used for verifying or guiding the proper location, angulation and rotational positioning of the implant prior to the placement in order to provide better aesthetics and functionally stable prosthesis (Gittelson, 2008).

3D printing in surgery:

The development of 3D imaging has enabled us to attain a more precise diagnosis and improved treatment planning (Dawood, Tanner and Hutchison, 2013). 3D models of detailed replicas of the skull (fig.7) and jaws of patients serve as anatomical models which have been beneficial in pre-surgical planning and also serve as a reference during surgery (Chan, Misch and Wang, 2010). Surgical guides (Louvrier *et al.*, 2017), augmentation of bone defects and creating replicas of jaws that could serve as study models for students, fixation plates etc can be 3D printed and used for Oral and Maxillofacial and Orthognathic surgeries (Lonic *et al.*, 2017; Lin, Lonic and Lo, 2018). The absent parts of the external ear caused due to birth defects or disorders when tried to restore, demands for a very clear understanding of the complex anatomy. 3D printing could serve the purpose (Zaharia *et al.*, 2017).

3D printing in endodontics:

3D printing serves as a solution for endodontic challenges; some of which include guided access with pulp canal (Connert *et al.*, 2018) application in autotransplantation (Kim *et al.*, 2016), accurately locating the osteotomy perforation sites, pre-surgical planning (Anderson, Wealleans and Ray, 2018), educational models (Robberecht *et al.*, 2017) and stent guides (Patel, Aldowaisan and Dawood, 2017).

3D printing in orthodontics:

Indirect bracket-bonding splints, occlusal splints, aligners, etc can be 3D printed (Normando, 2014). Adjustment or customization in terms of angulation, bending, etc is possible during the manufacture of brackets (Metelmann *et al.*, 2016). In addition to this, it is now virtually possible to present the changes that will be caused by the braces in advance (Jheon *et al.*, 2017)

3D printing in periodontics:

Another area of expertise in dentistry where 3D printing is employed is periodontics, where the prime focus is regenerative periodontal research. Few of the major periodontal post-operative complications include mobility, loss of attachment, furcation, painful and bleeding gums (Subasree, Murthykumar and Dhanraj, 2016), gingivitis (Basha, Ganapathy and Venugopalan, 2018) cellulitis (Vijayalakshmi and Ganapathy, 2016) and MRSA mediated skin and soft tissue infections (Selvan and Ganapathy, 2016). It is recommended to keep the gingival margins relieved and retracted (Kannan and Venugopalan, 2018) to avoid such complications (Jyothi *et al.*, 2017). 3D printed guides are used for aesthetic gingival correction (Oberoi *et al.*, 2018).

ADVANTAGES OF 3D PRINTING:

When 3D printed restorations are compared with conventionally made ones, their high-quality precision, accuracy, detail recording capacity and finely finished restorations make 3D printing technology the winner among all other available processing methods in dentistry (Prasad *et al.*, 2018). Its higher efficiency, resolution, flexibility, ease and quick fabrication, lesser material wastage due to additive procedures, superior diagnostic and learning abilities stand for the importance of 3D printing in dentistry.

DISADVANTAGES OF 3D PRINTING:

3D printing is a costly technology. The techniques involved in 3D printing have disadvantages of skin irritation, mess, inflammation due to contact and inhalation of powders, the requirement of support materials, etc. Ceramics, one of the widely used materials in dentistry (Ashok and Suvitha, 2016), lack the ability to be 3D printed due to high porosity caused during fabrication (Prasad *et al.*, 2018). With furthermore research and employment of improved techniques in the upcoming years, the disadvantages of 3D printing could be corrected.

CONCLUSION:

3D printing technology has the ability to evolutionize dentistry. It has a high potential of serving as an educational tool. The ultimate goal in dental practice is to provide the most technologically advanced dental treatment to the patients with high accuracy and least discomfort. Innovations like 3D printing help in creating the most accurate models and provide extended learning opportunities for providing better treatment care to the patients. The advantages of 3D printing technology outweigh the disadvantages. Overall, 3D printing technology has a tremendous potential to transform education, research and treatment care in dentistry.

Conflict of interest: Nil.

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Figure 1: SLA 3D PRINTER (FORM2 FORMLAB)

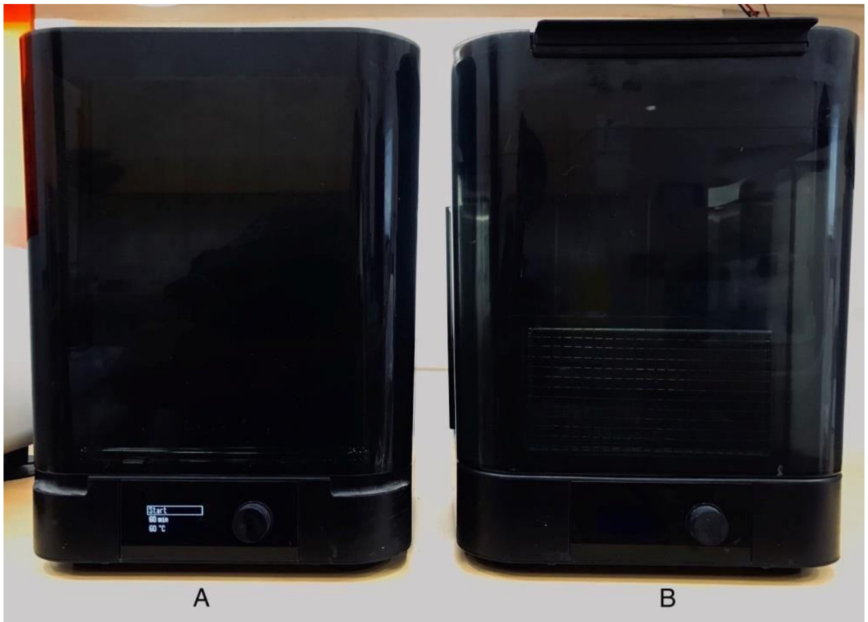

Figure 2 A: UV curing unit B: Isopropyl alcohol washing unit

Figure 3 and B: 3D design and metal printing (implant restoration framework)

Figure 4: 3D printed model

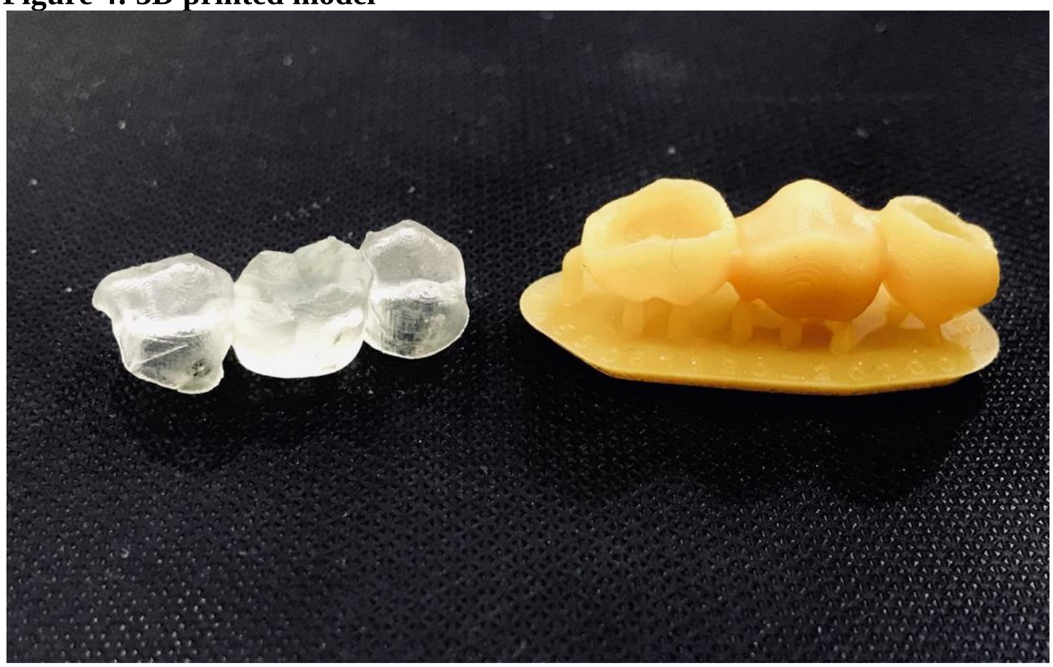

Figure 5: 3D printed temporary crown and resin pattern for casting

Figure 6: 3D printed surgical guide for implant placement

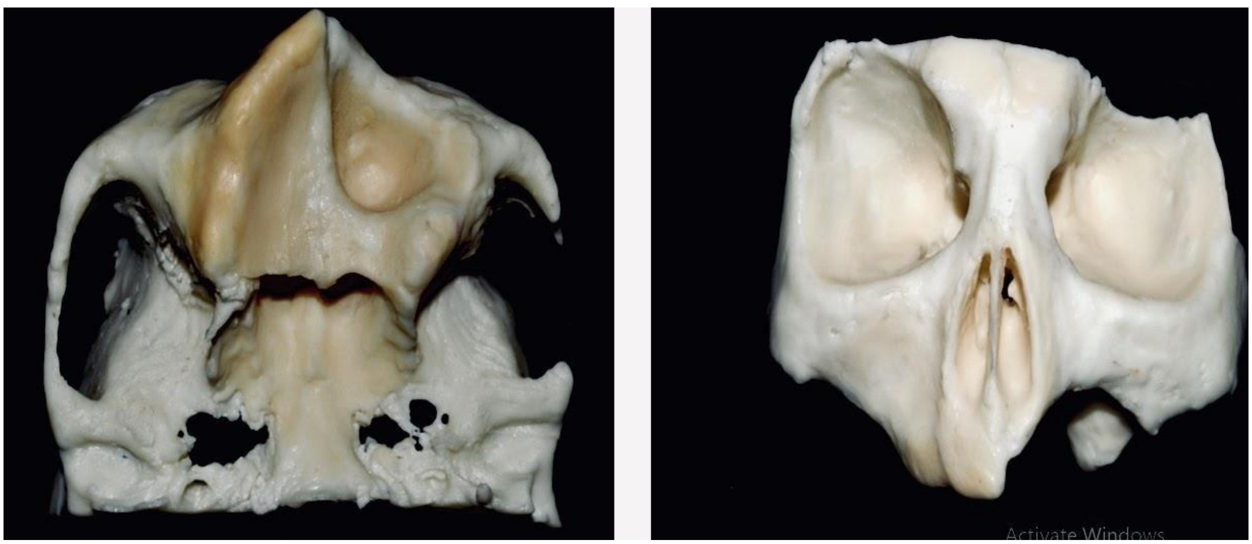

Figure 7: 3D printed skull model