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Short Communication

3D Printing

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Introduction

A 3 Dimensional printing, also referred to as additive manufacturing is a process of making 3-D objects with the help of 3-D printers which forms the entire 3-D object by adding multiple layers to create the precise design [1, 2]. In cross section, each layer is represented as thin horizontal section of the object [3]. It is also known as rapid prototyping [4, 5]. Recently, 3-D printing is gaining popularity among various dental fields and is mainly focused in the field of oral surgery, prosthodontics, orthodontics and with less applications in periodontics and endodontics [6]. The first 3-D object was printed using Stereolithography (SLA) by Charles Hull in 1983 [7].

There are three basic steps in 3-D printing technology:

1. Designing of 3-D object using 3-D scanner.
2. Actual printing process using certain materials based on the requirement. For example. Ceramics, metals, resins etc. which enables to achieve the precise design of the object.
3. Finishing process which requires specific skills [8, 9].

3-D printer's works in conjugation with 3-D scanners which can be direct or indirect. The direct scanner scans the information when in contact with the object while the indirect ones gather information with the scanner away from the object. Most of the dental field scanners use indirect technique. CAD software is used along with 3-D scanners for accurate detailing prior to starting of the printing process [10].

What is 3-D Printing?

The 3-D printing is the process in which 3-D printers are used to print 3-D models which are more accurate and the models are built by adding multiple layers [3, 11]. 3-D printing is also known as additive manufacturing. The term itself indicates adding multiple layers at a time to create a desired object. The use of 3-D printing is rapidly increasing in both medical as well as dental fields in order to create more accurate models for educational, study and treatment planning purposes [12].

History of 3-D Printing

Charles Hull in 1983 for the first time invented 3-D printing known as "Stereolithography" and printed the first 3-D object with it. Hull discovered that the acrylic based photopolymers harden once exposed to UV light. With the help of this he built SLA machine which uses UV laser to build multiple layers to form an object [12]. In dental field, 3-D printing was used for the very first time in 1990s to form dental implants. As the technology developed, 3-D printing was used to form organs as well. In 2012, 3-D printed jaw was made in Holland [12, 13].

In Orthodontics, metal rings were used to treat malocclusion in early 1900s. Metal rings were cemented to teeth to support wires for correction of malocclusion but it leads to dental caries as it was difficult to maintain oral hygiene. In 1960s, first brackets were introduced which were made from stainless steel with high strength, less friction, improved salivary flow. To minimize creep deformation, ceramic reinforced, fiberglass reinforced and polycarbonate reinforced brackets were developed [14, 15]. Ceramic brackets were used later on.

Types of Printers [13]

1. Stereolithography (SLA)
2. Selective Laser Sintering (SLS)
3. Polyjet Printing
4. Fused Deposition Modeling (FDM)
5. Bioprinter

Stereolithography

SLA uses a UV laser which scans the resin surface and subsequent layers are being laid and laser hardens the material. Thus forming a complete 3-D object.

Materials Used [16]

1. Poly 1500
   - ✓ Properties similar to polypropylene
   - ✓ Lead time – 3 working days
   - ✓ Impact resistance
2. Protogen white
   - ✓ Resilient
   - ✓ Good surface quality
   - ✓ Good thermal properties
3. Tusk XC2700T
   - ✓ Transparent
   - ✓ Suitable for water- resistant prototypes
4. Tusk XC2700W
   - ✓ White
   - ✓ Suitable for water- resistant prototypes
5. Taurus
   - ✓ Charcoal black
   - ✓ Very high elongation at break
6. Xtreme
   - ✓ High impact strength
   - ✓ Excellent surface quality
7. Tusk somos solid grey 3000
   - ✓ High impact resistance
8. PerFORM
   - ✓ Strong stiff resin
   - ✓ High thermal resistance

Selective Laser Sintering (SLS)

Selective Laser Sintering sinter powdered material by using laser, binds the material to form a solid object.
Developed by Dr. Carl Deckard and Dr. Joe Beaman at university of Texas at Austin under the sponsorship of DARPA.
Use a high power laser to fuse metal, ceramic or glass powders into a mass to obtain 3-D shape.
Typically uses a pulsed laser [17].
Materials Used: Polyamides (PA), Polystyrenes (PS), thermoplastic elastomers (TPE) and Polyaryletherketones (PAEK).
Polycarbonate is of high interest due to its high toughness and thermal stability [6].

Polyjet Printing

Polyjet (Photopolymer jetting) jets a liquid from print head and hardens by UV light. A single layer of photopolymer is being deposited on X-axis and immediately cured by UV light. The depth of each layer is managed by software. After completion of curing the first layer, second layer is being deposited along Z-axis and is cured. The entire process is repeated until 3-D object is formed.

Advantages

- Production of object with different levels of flexibility.
- Easy to build multi-colored objects.
- Excellent detailing [18].

Fused Deposition Modelling (FDM)

Developed by Schott Crump.
In this process, thermoplastic material is melted, extruded and hardens immediately due to the cold temperature of air.
Materials: Polycarbonate, Acrylonitrile, Butadiene styrene, Polyphenylsulfone, Nylon, Calcium Phosphate based ceramic [19].

Bioprinter

Combination of engineering and cell biology.

Used for artificial construction of living tissues by adding multiple layers.

Types:

- Inkjet Bioprinting
- Laser assisted Bioprinting (LAB)
- Microentrusion Bioprinting (MEB) [20].

Comparison [21]

Stereolithography	*Selective Laser Sintering*	*Fused Deposition Modelling*
• Laser cures photopolymer resin. • Highly versatile material selection. • Highest resolution. • High accuracy and fine details. • FUNCTION: Function prototyping patterns, molds and tooling dental applications	• Laser fuses polymer powder • Low cost, high productivity • Excellent mechanical properties • FUNCTION: Function prototyping short run, bridge or custom manufacturing	• Melts and extrudes thermoplastic filament. • Lowest price of material. • Lowest resolution and accuracy. • FUNCTION: Low cost rapid prototyping, basic proof of concept models.

3D Models VS Gypsum Models

Advantages of Digital Models

- Instant Accessibility
- Positive Patient Perceptivity
- No risk of breakage, wear
- Virtual images can be transferred anywhere for quick consultation [22]
- High accuracy [23]
- Allows correlation of Occlusal conditions with patients own photographs [24, 25]
- The printed models can be used in case if the patient loses the retainers. Thus reducing the chair time and lesser number of appointments [26].
- CAD CAM Softwares like OrthoAnalyzer, Orchestrate or Suresmile elemetrix can be used for the correction of malaligned teeth on the digital models [26].

Dental Stone – 3rd class plaster

- Easy manufacturing and availability
- Reduced production cost
- Accurate small anatomic details of Occlusal surfaces, interdental spaces, gingiva
- DISADVANTAGES:
- Crack/ scratch easily
- If damaged, impossible to replicate it [27]

Making Indirect Bonding Trays

Scan

In order to make indirect bonding tray, digital impression is required. In order to achieve this, 3D intraoral scanner is used to scan the patient.

Design the Indirect Bonding Tray

- Correct insertion direction being ensured which will impact physical insertion of the final appliance.
- There are two ways to create indirect bonding trays:
    - Bar

- Offset

Bar design is recommended because of its flexibility around the brackets, provides rigidity to the appliance, ability to print directly on build surface

Print

- Import the designed file by dragging them into PreForm
- Material selection (Locate IBT in material drop down)
- Orientation:
  - Positioning Bar type appliances: Open Orientation tool and click select base and next click bottom surface of the part to attach it to the build surface
- Angulation: ensures accuracy and fit. Always Position the appliance with intaglio surface facing away from build platform. The part should be parallel to build platform or at most 45 degree angle.
- Generate support structures
- Printing layout (no overlapping of the parts)
- Transfer to the printer
- Set up the printer: Insert the cartridge after shaking, a build platform and a resin tank into formlabs 3D printer. The printer will complete the print.

Post Processing

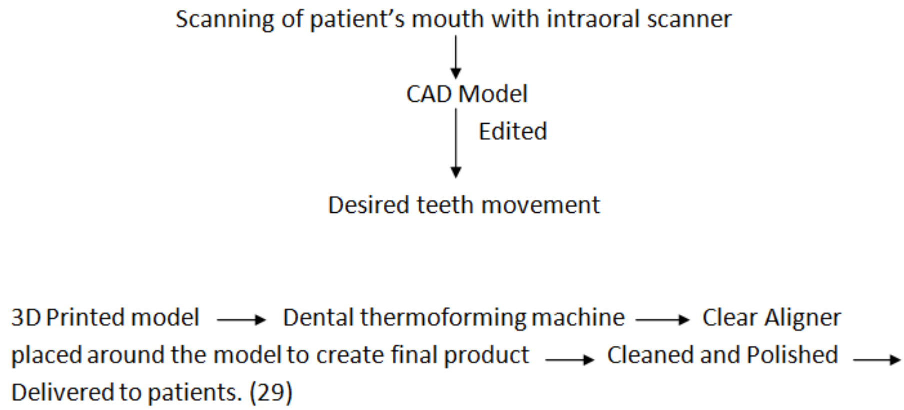
- Remove the printed parts from the build platform
- Printed part is being washed with the solvent. Place the trays in form wash filled with Isopropyl Alcohol and wash it for 20 minutes.
- Avoid excess washing as it will result in dimensional inaccuracy
- Drying at room temperature for atleast 30 minutes. Inspect the parts to ensure they are clean and dry.
- Post curing in formcure at 60°C (140°F) for 60 minutes must be done to maintain dimensional accuracy
- Support removed with the help of clippers provided in the finishing kit.
- Finishing: any support structure in 3D printed indirect bonding tray which are left, are removed with iris scissors.

Appliance Care and Use

- Cleaning using neutral soap and water at room temperature, inspection of any cracks
- Disinfection: soaking the finished indirect bonding tray in fresh 70% IPA for 5 minutes
- Store in closed, opaque containers
- Disposal: any cured resin is disposed as regular waste while the liquid resin in accordance with government regulation [28].

3-D Printed Dental Aligners

Invisalign use 3-D printer to fabricate accurate model in order to make clear aligners.



Applications

1) 3D Printing aids in the treatment planning for orthognathic surgical cases, anchorage device placements [30].
2) Virtual changes can be made in digital models for analyzing arch form, crowding, spacing, teeth size, or type of malocclusion [30].
3) Simulation of treatment planning, indirect bonding in orthodontic cases [30].
4) Tooth size discrepancies, overjet, overbite are achievable [30].
5) Congenital maxillofacial defects can be corrected using 3D printing and patients are able to see the final result of the treatment [7].
6) 3D printed models helps in implant placement by fabricating surgical guides [31].
7) 3D printer helps in recording accurate impressions of the teeth, oral mucosa and other structures in patients with gag reflex, temporomandibular joint problems/disorders, reduced mouth opening [13].
8) Rapid prototyping helps in the fabrication of chrome-cobalt dentures [32].
9) Normando et.al. in 2014 invented 3D face scans/printer in order to achieve accurate model of dental arches and orthodontic brackets [33].

Discussion

In Orthodontics, 3 D printing is gaining popularity and is widely used for the correction of malocclusion. The 3 D software enables the orthodontist to show the post treatment results to the patient prior to the treatment. The main advancement of 3 D printing involves the fabrication of the orthodontic aligners which are removable unlike fixed orthodontic procedure. Thus reducing the number of chairside appointments [9]. Treatment efficiency can be improved using digital models and with the help of CAD CAM software, brackets can be removed digitally and 3 D models are printed for the fabrication of the retainers [34].

Types of printers used in 3D printing includes Stereolithography, Selective Laser Sintering, Polyjet Printing, Fused Deposition Modeling and Bioprinter [13]. SLA use highest resolution and offers high accuracy with fine details and great efficiency. FDM uses various materials like polyphenylsulfone, calcium phosphate based ceramic and can be used for the production of complex objects with high accuracy. SLS use materials like polyamides, polycarbonate, polystyrenes and offers high productivity and have excellent mechanical properties. Polyjet printing offers excellent detailing and flexibility. Digital models offers various advantages including correction of malalignment, positive patient perceptivity, reduce chair time, high accuracy [23, 26].

The use of 3D printing is increasing in the fields of prosthodontics, orthodontics, implantology and oral and maxillofacial surgery. The main use of 3D printing is to create an accurate replica of the teeth and surrounding tissues for diagnosis, treatment and educational purposes. A study was conducted in which 2209 articles were taken. Out of which 28 studies were analyzed based on different criterias including sample size, 3D printing technology used, material type, layer thickness, accuracy of scanner, limitations etc. were being used. It was conducted that errors were low for certain printers. Therefore they can be recommended for use in dental fields especially for orthodontic study models. The accuracy of the final 3D printed model depends on data acquirement, layer thickness, base design and processed images of the oral tissues. There is no review of data depicting the accuracy of 3d printers. Hence the existing data on 3d printing was evaluated to depict accuracy of 3D printing [38].

3D printers can replicate models in less time period but the high cost of 3D printers is still a challenge. The usages of 3D printers require high skilled operators. The 3D printing should aim to decrease the cost, enhance the surface quality, improved process solidity. In the future, new materials and technologies should be developed further ensuring high accuracy and low cost [39]. With advancements, new biocompatible materials and transparent flexible resins will be introduced giving excellent aesthetic results. 3D printing will significantly improve the workflow in dental field [40]. With growing capabilities and gaining experience of 3D printers, the use of these technologies is going to expand in future [41].

Current State and Future Possibilities of Clear Aligners

Patients seek orthodontic treatment for various reasons including aesthetics and to improve facial appearance which helps in building confidence [35]. The conventional orthodontic treatment with brackets and archwires is somehow not comfortable for many patients as they experience lip discomfort and problems while eating [36]. With recent advancements, patients are opting treatment with clear aligners which offers simplicity of use and higher comfort levels. Patients can take out the aligners when eating while maintaining the oral hygiene. The chair side appointment time of clear aligners is less as compared to the conventional orthodontic treatment [35].

For the first time, clear aligners were developed for retention purpose after completion of orthodontic treatment or for treating minor tooth malpositioning [37]. With the advancements, clear aligners are now used to treat moderate to severe malocclusions. 3D printed aligners offers several advantages like digitally designed borders with smooth edges, no undercuts, higher precision, better fitting [35].

Three-dimensional printing is revolutionizing dentistry. Clear aligners are fabricated using 3D technology which offers great advantages over conventional orthodontic treatment. Various fields of dentistry are now using 3D printing technology. Thus 3D printing has established a new era among various dental fields.

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Volume 1 Issue 3 April 2022