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3D Printing and Orthodontics- A review

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Abstract
With the rapid advancement of new materials, printing technologies, and machines, 3D printing is most likely to completely transform the traditional teaching and experimental modes. It has a wide range of applications in the field of dentistry, from prosthodontics, endodontics, oral and maxillofacial surgery, and oral implantology to orthodontics, and periodontology. High precision, and personal customization, complete dentures, and implant teeth are easier to attain as they are rapidly produced. Additionally, they can assist in providing patients with cost-effective and more personalized services and simplify the complex workflow related to the manufacturing of dental appliances. It has various advantages, such as high material consumption, high economic benefits, and the manufacturing of certain scale products on demand. However, it has several disadvantages as well, such as high processing cost and time-consuming post-processing. The article aims to give insight into the rapidly developing 3D printing technologies, and also to review the literature regarding the application of 3D printing in clinical orthodontics.
Keywords: *3D Printing, CAD-CAM, Stereolithography, Digital Models, Rapid Prototyping, Additive Manufacturing*

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I. Introduction:

The first three-dimensional (3D) printing technology was introduced by Charles Hull in 1986. This field has invented many manufacturing technologies that have been applied to numerous clinical applications. Hull patented Stereolithography (SLA) and developed a 3D printing system in 1986.[1] In 1990, Scott Crump established a patent for fused deposition modelling (FDM). Since then, 3D printing has been growing and evolving. This system is based on computer-aided design (CAD) digital models, using standardized materials to produce personalized 3D objects through specific automatic processes. For nearly 30 years, it is used for rapid prototyping in industry, design, engineering and manufacturing fields. [1]

With the rapid advancement of new materials, printing technologies, and machines, 3D printing is most likely to completely transform the traditional teaching and experimental modes. It has a wide range of applications in the field of dentistry, from prosthodontics, endodontics, oral and maxillofacial surgery, and oral implantology to orthodontics, and periodontology .[2] High precision, and personal customization, complete dentures, and implant teeth are easier to attain as they are rapidly produced. Additionally, they can assist in providing patients with cost-effective and more personalized services and simplify the complex workflow related to the manufacturing of dental appliances. It has various advantages, such as high material consumption, high economic benefits, and the manufacturing of certain scale products on demand. However, it has several disadvantages as well, such as high processing cost and time-consuming post-processing. [3]

3D printing is a manufacturing approach that builds objects one layer at a time, with the addition of multiple layers to form an object. This process is described as additive manufacturing and is also known as rapid prototyping.[1] In 1990, Wilfried Vancraen, CEO and Director of materializing NV, founded additive manufacturing or 3D printing, the first Rapid Prototyping sector company in the Benelux region. Additive manufacturing has shown to be increasing progressively in conjunction with intraoral scanning technology serving as an effective system for orthodontic practices and laboratories for automatic fabrication of high-resolution study models, metal appliances, aligners, retainers and indirect bonding, with an increase in the production time and capability. This article explains the importance of 3D printing in dentistry, and why dentistry induces the development of 3D printing applications. There is more precise control over the tooth movement with the help of an intraoral scanner, software and also quicker appliance production that spared both money and time. In the Mid-1980s, Computer-aided design and computer-aided manufacturing (CAD/CAM) systems were used in the dental field. CAD/CAM system is composed of three key components i.e., 1) data acquisition and digitizing; 2) data processing and design, and 3) manufacturing. In-office chairside or lab, the digital models give a wide range of options for the design and manufacture of various orthodontic appliances such as customized indirect brackets, aligners, archwires, expanders, retainers, etc.[7]. The dental model is 3D printed from an STL generated file. With the recent progress in three-dimensional (3D) imaging, computer-assisted surgical planning and simulation are now frequently used for the analysis of craniofacial structures and also has improved the prediction of surgical outcomes in orthognathic surgery.[4] With the help of computer software and a 3D printer system, orthodontic appliances are easier to fabricate in-office.[5] But, many challenges have to be faced during production and manufacturing such as the availability of the material, biocompatibility, ageing, mechanical properties, transparency, tolerance, resolution and surface roughness. Intraoral scanning, Cone Beam Computed Tomography (CBCT), Computer-Aided Design and Computer-Aided Manufacturing (CAD-CAM) and 3D printed appliances have been at the forefront of this workflow revolution in the digital market. In addition to the customization of orthodontic appliances, the 3D technology allows the practitioner and patient to employ virtual treatment planning software for better identification of the case objectives and visualization of treatment outcomes.[6] It aids in the comparison of different treatment plans, including extraction versus non-extraction as well as various treatment options or substitution versus prosthetic replacement in cases of missing teeth. Communication is the key between the practitioner and patient for more realistic expectations of treatment outcome and an added degree of informed consent.[6] The highly-accurate open file formats are integrated with the patient electronic health record which is stored, retrieved, and managed through a secure, cloud- © 2015 which permits unlimited use, distribution, and eproduction in any kind of medium, provided that the citation of the original work is mentioned. Most of the digital intraoral scanners work in aggregation with cloud-based technology where the raw images are scanned and securely transferred to the cloud storage facility which is further processed/refined for diagnostic purposes. The article aims to give insight into the rapidly developing 3D printing technologies, and also to review the literature regarding the application of 3D printing in clinical orthodontics.

Application of 3D printer material in dentistry:

Materials that are used for 3-D printing are ABS plastic, stereo lithography materials (epoxy resins), PLA, polyamide (nylon), glass filled polyamide, polycarbonate, silver, steel, titanium, photopolymers, wax, Polyether ether ketone (PEEK), Selective Laser Sintering (SLS) Powder such as alumite, polyamide, glass-particle filled polyamide, rubber-like polyurethane, etc. 3D printing helps in production of dental models, surgical guides and splints, orthodontic devices (aligners and retainers), castable crowns, metal crowns, copings and bridges, metal or resin partial denture frameworks. A variety of photopolymers Hospital set-up manufacturing of craniomaxillofacial implants, sophisticated anatomical models, drilling and cutting guides, a facial prosthesis (ear, nose, eye) Bioprinter Cell-loaded gels and inks based on collagen, photopolymer resins, agarose, alginate, hyaluronan, chitosan, etc. [8]

3D printing technology:

1)STEREOLITHOGRAPHY(Fig.1):

Stereolithography (SLA) was the first 3D printing technology that was invented and patented by the founder of 3D printing, Charles Hull. Stereolithography makes the use of photocurable liquid resin as a photopolymer printing material. A single layer of a printed object is hardened by a spot of an ultraviolet laser beam, which initiates the cross-linking of the polymer which solidifies the material. Following curing, on top of the previous layer, the resin is applied, and the cycle is repeated continuously until the object is fabricated. Stereolithography involves certain procedures of post-processing after printing the object. The un-polymerized resin has to be removed carefully following that the object needs to undergo a post-curing process in a UV oven to accentuate the conversion degree of the polymer. Advantages of stereolithography include high quality as well as high resolution of printed objects, with a layer thickness of 25 µm. To ensure the smooth surface of a printed object, Low thickness has to be maintained without stair-stepping which is a crucial factor that can result from inaccuracies in the binding process. Stereolithography is used for the manufacturing of surgical guides in dental implantology. In orthodontics, this technology has been applied to fabricate orthodontics dental models.[9]

Figure 1: SLA 3D PRINTER

2)FUSED DEPOSITION MODELLING/FUSED FILAMENT FABRICATION:

Fused deposition modelling/fused filament fabrication (FDM/FFF) technology is the most extensively and commonly used 3D printing method worldwide (Fig.2). The technology utilizes thermoplastic materials to build an object. The procedure involves the melting of thermoplastic material until melting temperature is reached, which is then followed by deposition of the melted material through extrusion heads by the printer in a definite pattern thereby creating a single layer of a solid object. There is an application of the material layer by layer and later fused as the solidification of the material occurs. The important advantage of fused deposition modelling is that the technology requires no post-processing of the object following printing which enables it to print with a minimal layer thickness of 127 µm. Material shrinkage is the most common disadvantage and limitation of this technology during the hardening procedure. It results from the usage of materials with sufficient thermal and viscoelastic properties. Available materials for FDM include polycarbonates (PCA), acrylonitrile butadiene styrene polymer (ABS), polylactic acid (PLA), waxes, and polyphenyl sulfones. MakerBot Replicator2 (Stratasys Ltd., Eden Prairie, MI) is an example of an FDM 3D printer. According to the manufacturer's data, the printer is utilized to fabricate retainers and aligners. But, due to stair-stepping effect, it possesses inferior aesthetic quality.[9]

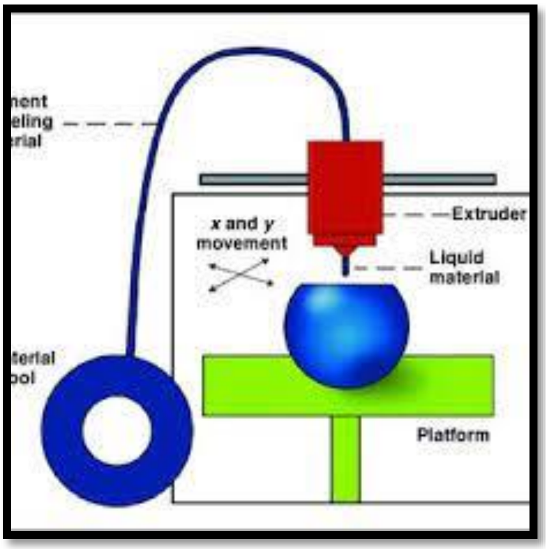


Figure 2: FUSED DEPOSITION MODELLING

3)SELECTIVE LASER SINTERING/MELTING AND ELECTRON BEAM MELTING (Fig. 3):

Selective laser sintering (SLS) makes the use of powder materials to print 3D solid objects. A high energy CO2 laser beam is applied to heat the powder above the glass transition temperature in a definite pattern following which the particles are sintered together. The printer building platform lowers after the completion of a single layer which is followed by another layer of powder is added on the preceding layer and sintering continues until the printing of the object is completed. This technology does not require any support structures to be included in the design because the partially sintered unbound powder particles provide sufficient support for complex geometries of a printed object. Following 3D printing, excess powder particles are removed. Powder materials, which may be applied for SLS technology printing include polymers like polycaprolactone, polyamides, hydroxyapatite, glass, ceramics, and powdered metallic alloys such as stainless steel, titanium, and Co/Cr. Electron beam melting (EBM) technology employs metal powder as a printing material. Metal alloys utilized in EBM are stainless steel, titanium, and copper. Structures printed using EBM are highly porous and mechanically strong, therefore EBM technology is used in orthopaedics and oral surgery to fabricate customized Osseointegrated implants. [9]

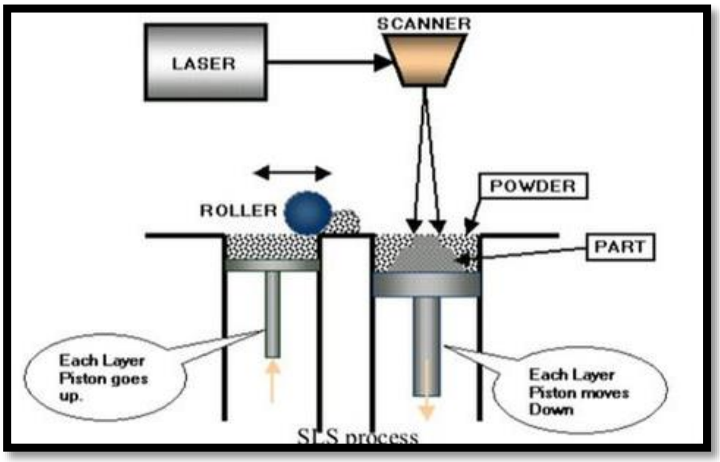


Figure 3: SELECTIVE LASER SINTERING/MELTING

4)DIGITAL LIGHT PROCESSING: Digital light processing (DLP) is analogous to stereolithography. It also uses photopolymer as a printing material. Photopolymer is light-cured with the use of a digital micromirror device (DMD)(Fig.4). The main difference to stereolithography is that the light is projected on the whole layer, while in stereolithography spot laser beam is applied. DLP has an advantage over stereolithography i.e., fabrication of faster printing of models with a layer thickness of less than 30 µm. Envision TEC (Gladbeck, Germany) launched 3D printers applying this technology to the market i.e., Ultra 3SP Ortho and Perfactory Micro Ortho. Ultra 3SP printer is made to manufacture accurate dental working models for fabrication of orthodontic appliance.[9]

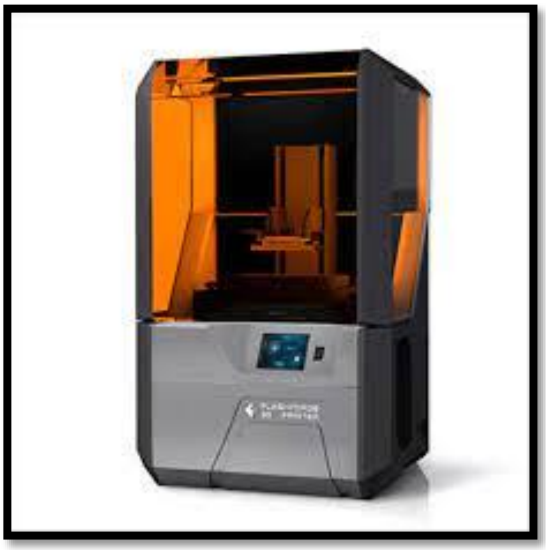


Figure 4: DIGITAL LIGHT PROCESSING 3D PRINTER

5)Inkjet 3D PRINTING AND POLYJET(Fig.5): Inkjet 3D printing (3DP/IJP) manufactures the structures by incorporating a pattern of binder liquid on a powder substrate. The object is formed as a result of a reaction between liquid and powder, while the phase transformation is caused by ultraviolet curing, chemical or thermal reaction, or by dehydration. In the following technology, a varied variety of materials may be utilized during one printing cycle allowing to manufacture objects with different materials, thus exhibiting diverse properties. The thickness of a layer has been reported to be up to 12 µm. 3DP has the advantage of being faster than FDM, but accuracy and surface finish may be inferior to those models which were attained with Stereolithography. Further innovations in the technology have led to the creation PolyJet (polymer jetting) by Stratasys Ltd. (Eden Praire, USA). Polyjet uses liquid photopolymer as a 3D printing material. A nozzle is used to spread the material on a building platform, which is subsequently UV light-cured. Supportive structures are formed with layers of photo polymeric material. Supporting material is removed easily after completion of the process. On the contrary to stereolithography, an object printed with Polyjet is cured maximally and also no additional post-curing is required. The layer thickness attained by Polyjet printers ranges from 16 µm to 32 µm, which makes this technology more accurate. Polyjet printers that are commercially available include Objet30 Orthodesk, Objet30 Dental Prime, and Objet500 Dental Selection (Stratasys Ltd., Eden Praire, USA). Objet30 Orthodesk printer is used to manufacture orthodontic study and working models, surgical stents and dental mock-ups, depending upon the printing material.[9]

Figure 5: INKJET 3D PRINTER

Commonly used 3D printers:
The global additive manufacturing industry has been led by three large companies: Stratasys, Ltd. (Eden Prairie, MN), 3D Systems (Rock Hill, SC), and Envision TEC (Gladbeck, Germany)
1)Objet30Orthodesk (Stratasys, Ltd., Eden Prairie, MN) utilizes the Polyjet printing technology which is suitable for orthodontic offices and small- to medium-sized labs (Fig.6). The 3D printer fabricates an orthodontic model which is durable with high feature detail and ultrafine layers of surface quality. Twenty models can be printed with every print run. Three dental materials come in the sealed cartridges with the printer: VeroDentPlus (MED690), a dark beige, acrylic-based material prints layers as fine as 16 microns with accuracy as thin as 0.1 mm which is used for most appliances; Clear biocompatible, Medical proven and approved for temporary intraoral applications and guides for a surgical procedure; and VeroGlaze (MED620), an acrylic-based durable material is used to fabricate veneer models or diagnostic wax-ups in A2-shade colour match.[10]

Figure 6 : OBJET30 ORTHODESK

Features: 1. Company: Stratasys, Ltd., Eden Prairie, MI
2. Technology: Polyjet Printing technology
3. Build Volume 300 x 200 x 100 mm
4. Applications: High-quality orthodontic models, temporary intraoral appliances, surgical guides and restorations
5. Weight: 93 kg

2)ProJet® 3510 MP (3D Systems, Rock Hill, SC) is one of the numerous healthcare printing solutions, used for uniformly precise thin wax-ups of the crown, bridges, and partial dentures. (Fig.7) The system can also fabricate any size dental model with a selection of two materials in smooth or matte printing mode. At one time, up to 24 quad cases can be manufactured. These professional printers utilize the VisiJet® line of materials, specially engineered to meet a varied range of applications. ProJet ® 3510 series utilizes three UV curable acrylic materials: Dentcast, a dark-green, wax-up material that burns out cleanly for ash-free castings. PearlStone is a white material with a solid stone appearance; and Stoneplast is used for transparent, clear or stone finish models. VisiJet® S300 is the fourth material which is a white in colour, non-toxic wax material for hands-free melt-away supports.[10]

Figure 7: ProJet ® 3510 MP

Features: 1. Company:3D Systems, Rock Hill, SC
2. Technology: PolyJet Printing technology
3. Build volume:298 x 185 x 203 mm
4. Applications: Drill guides, jaw models, orthodontic thermoforming model
5. Weight: 323 kg

3)ULTRA® 3SP™ Ortho (Envision TEC, Gladbeck, Germany) utilizes a DLP variant, the Scan, Spin, and Selectively Photocure (3SP™) technology, which makes the use of a laser diode with an orthogonal mirror spinning at 20,000 rpm (Fig.8). The printer can produce relatively accurate and stable dental models that could be used for the fabrication of orthodontic appliances. It has high-temperature resistance and negligible water absorption. ULTRA® 3SP™ Ortho utilizes specially engineered photosensitive resins for dental and orthodontic applications: Press-E-Cast (WIC300), a wax-filled photopolymer for fabrication of copings with extremely thin margins as well as up to 16 multiple unit bridges; EDenstone (HTM140 Peach), a peach colour material is used to achieve the aesthetic of traditional gypsum models with a high-accuracy detail; and D3 White, a tough fast-growing, material shares the similar characteristics to ABS plastic. It is the most frequent medium for dental model manufacturing for the fabrication of orthodontic appliances. [10]

Figure 8: ULTRA® 3SP™ Ortho

Features: 1. Company: Envision TEC, Gladbeck, Germany
2. Technology: Digital Light Processing
3. Build Volume:266 x 177.8 x 76 mm
4. Applications: High-quality orthodontic appliances
5. Weight: 90 Kg

4) MakerBot Replicator 2 (Fig.9):
Features: 1. Company: Stratasys, Ltd., Eden Prairie, MI
2. Technology: Fused Depositing Modelling
3. Build Volume:285 X 153 X 155 mm
4. Applications:
Retainers and aligners with less aesthetic appearance due to stair-stepping
5. Weight:11.5 kg

Figure 9: MAKERBOT REPLICATOR 2

5)FORMIGA P 110 (Fig.10):
Features: 1. Company: EOS, Munich, Germany
2. Technology: Selective Laser Sintering
3. Build volume:200 x 250 x 330 mm
4. Applications: High quality retainers and orthodontic appliances
5. Weight:600 kg

Figure 10: FORMIGA P 110

6) Formlabs 3D printer:

The Formlab 3D printer could be a high-performance printer with Scale prototyping and production. It's also affordable with industrial-quality SLA and SLS 3D printers. The Formlabs Dental team has collaborated with Medit, a worldwide provider of dental 3D scanners. The goal with this collaboration is to form chairside 3D printing convenient to all or any dental practices.(https://www.formlabs.com/)

The Medit Link users must download Formlabs' PreForm app which incorporates software integration to fabricate dental CAD designs for faster printing on Formlabs printers.

Formlabs Dental and Medit will enable clinicians to simply 3D prints dental components with greater speed and efficiency through a simplified in-office workflow.
They are available in several generations:
1.Form 3+
2.Form 3L
3.Fuse 1
4.Form 3B+
5.Form 3BL

i. Form 3+:

- Produce functional, high-quality prototypes and end-use parts in record time with the Form 3+, an reasonable, industrial-quality 3D printer that consistently delivers. The Form 3+ offers reliable print quality and accuracy, easy setup and maintenance, and a wide range of high-performance materials. The build volume is 14.5 × 14.5 × 18.5 cm. The technology utilized in this 3D printer is Stereolithography (SLA).
- It is cost effective, faster and provides better experience to the market together with delivering parts for huge range of applications. (Fig.11)

Indications:

a) Rapid prototyping and production
b) Rapid tooling and manufacturing aids
c) Patterns for molds and casting
d) Model making

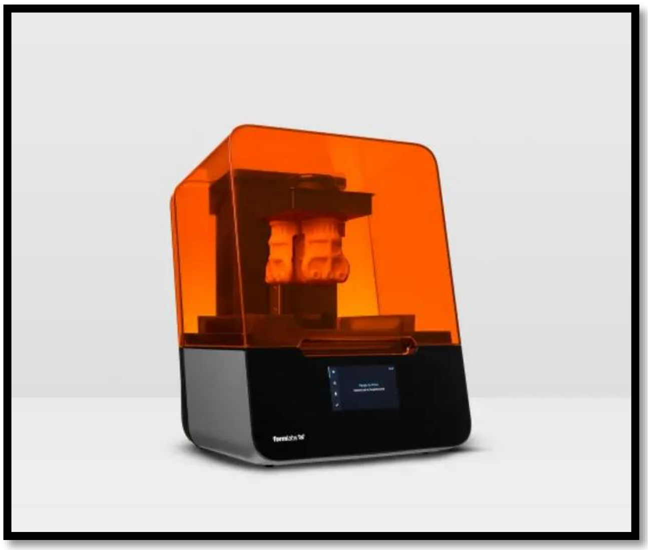


Figure 11: FORM 3+

ii. Form 3L:

- It has a control of large-scale part production, increase the throughput, and bring your biggest ideas to life with the Form 3L. It is a cost-effective large format 3D printer that doesn't compromise on the details. The build volume is 33.5 × 20 × 30 cm. The technology used is Stereolithography (SLA).(Fig.12)

Indications:

a) Full-size rapid prototyping
b) Large-scale models
c) Rapid tooling and manufacturing aids
d) Batch production

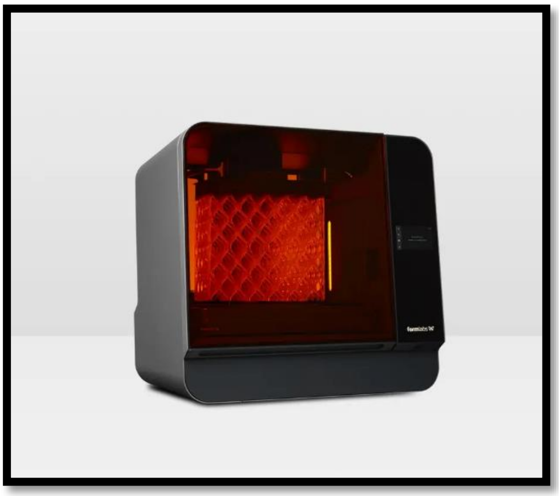


Figure 12: FORM 3L

iii. Fuse I:

- It is affordable, compact selective laser sintering (SLS) platform with easy-to-use hardware and software which maximizes the efficiency of production of several appliances. The build volume is 16.5 x 16.5 x 30 cm. The technology used is Selective Laser Sintering (SLS).(Fig.13)

Indications:

a) Functional prototyping
b) Complex geometries
c) Short-run, bridge, or custom manufacturing
d) Ready-to-use, patient-specific and biocompatible medical devices.

Figure 13: FUSE I

iv. Form 3B+:

The Form 3B+ is compatible with the SLA materials library, including biocompatible, sterilizable materials. It is an advanced 3D printer for health care professionals. The build volume is 14.5 × 14.5 × 18.5 cm. The technology used is Stereolithography (SLA).(Fig.14)

Indications:

a) Small and medium parts requiring biocompatibility and sterilization compatibility
b) Medical device prototypes, jigs, fixtures, molds, and end-use parts
c) Patient-specific anatomical models and surgical instruments
d) Visual aids for diagnosis and education
e) Surgical planning models for diagnostic use in FDA-cleared workflow.

Figure 14: FORM 3B+

v. Form 3BL: It is a large format medical 3D printer compatible with the majority of SLA materials, including biocompatible, sterilizable resins which has an ISO 13485 certified, FDA-registered facility. The build volume is 33.5 × 20 × 30 cm. The technology used is Stereolithography (SLA).(Fig.15)

Indications:

a) Large parts requiring biocompatibility and sterilization compatibility
b) Full-size, anatomical models at 1:1 scale, including pediatric and adult anatomy
c) Medical device prototypes, jigs, fixtures, assemblies, and end-use parts
d) Surgeon-specific or patient-specific surgical tools
e) Surgical planning models for diagnostic use in FDA-cleared workflows

Figure 15: FORM 3BL

Applications:

1. Model & Draft Resin: It is used to fabricate Crowns and bridges model, Orthodontics study models, Implant Analog models & diagnostic models. (Fig.16)

Figure 16: Model and Draft resin

2. It is used to fabricate surgical guides, drilling templates, device sizing templates and pilot drill guides. (Fig.17)

Figure 17: Surgical guides

3. Dental LT clear resin: It is used to fabricate occlusal guards and splints. (Fig.18)

Figure 18: Dental LT Clear Resin

4. Castable Wax Resins: It is used to fabricate casting coping and substructures and removable partial denture frameworks. (Fig.19)

Figure 19: Castable Wax Resin

5. It is used to fabricate digital dentures and try in dentures. (Fig.20)

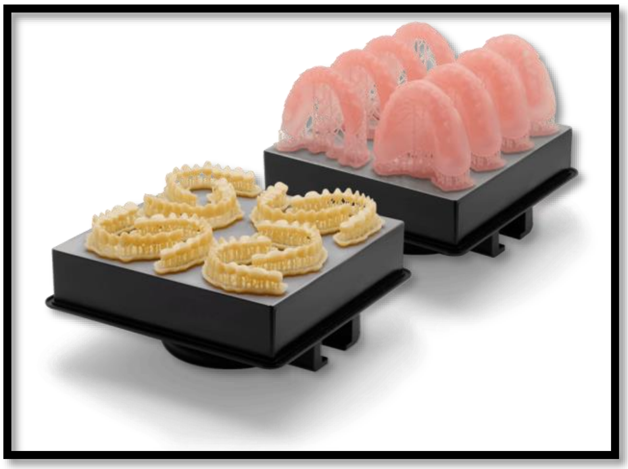


Figure 20: Digital Dentures

6. Custom tray resin: It is used to fabricate custom impression trays. (Fig.21)

Figure 21: Custom Tray Resin

7. Permanent and Temporary Crown resins: It is used to fabricate inlays, onlays, crowns and veneers. (Fig.22)

Figure 22: Permanent and Temporary Crown Resin

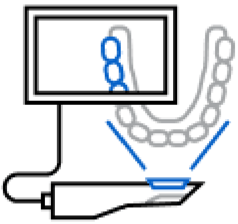
8. IBT Resin: It is used to fabricate indirect bonding trays and is used for orthodontic bracket placement. (Fig.23)

Figure 23: IBT Resin

9. It is used to fabricate Hawley retainers and various other appliances. (Fig.24)

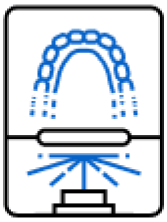
Figure 24: Fabrication Of Hawleys Retainers

WORKFLOW

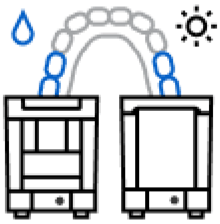


Scan or Receive Digital Impression

Design



Print



Post-Process
(https://www.formlabs.com/)

7)Phrozen 3D printer:
The most commonly used generation in dentistry is Phrozen Sonic Mighty 4K LCD & Sonic 4K 3D printer. It is used to fabricate models 400 times faster than the other traditional printing devices. It is easy to use, highly accurate and super stable. (http://phrozen3d.com)
1)Phrozen Sonic Mighty 4K LCD 3D Printer:
It comes in simple yet well-protected packaging which all the necessary parts that helps to jump-start the printing. With an extended printing area of 9.3" & a 22cm Z-axis, Sonic Mighty 4K allows the clinician to print larger. It also offers high-resolution printing at 51µm. It also has a monochrome LCD screen which printers the model 4 times faster than other traditional printers. (Fig.25)
It is exceptionally productive as it supplies the models at once which minimizes the printing of models in batches. The print volume is 20x 12.5 x 22 cm. The slicer software used is CHITUBOX.
The printing speed is 80mm/hour which takes only 2 secs to print on the layer. It has multi resin compatibility along with ultra-high resolution which makes it a premium choice for printing larger builds.
It has a resin-based LCD printing technology. It is highly versatile and is used for both personal and professional use.
Other available series are Sonic miniseries, Sonic series and sonic mega series.

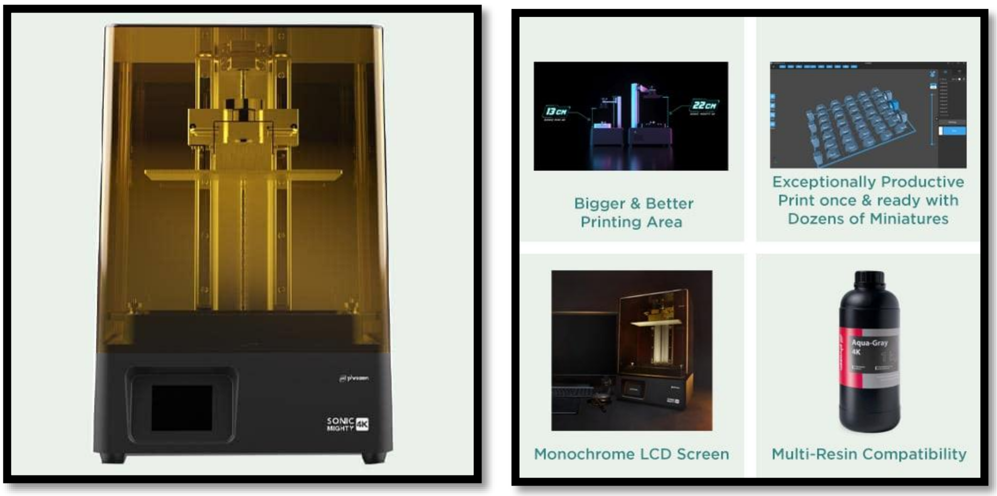


Figure 25: Phrozen Sonic Mighty 4K LCD 3D Printer

2) Sonic 4K:

It has a printing area of 6.1 in which is best for printing precise dental parts in 4K resolution. The dental parts such as bridges, crowns and immediate dentures require precision which can be achieved by this series of printers.(Fig.26)

It prints out only 1 layer in 1 second which is suitable for bulk printing. It is compact in size and is easy to store in dental clinics and labs.

Features:

- 6.1in Printing area
- 5in Touch Panel
- 35 µm XY resolution
- 90mm/hr Print speed

Figure 26: Sonic 4K

3) Sonic XL 4K:

It has 45% bigger printing space than the Sonic 4K 3D printer which allows fabricating dental models faster. It increases the productivity to manufacture the dental models. It allows printing full plate of dental arches within 25 minutes.

It is mainly used to fabricate dental splints and surgical guides for implant placement.(Fig.27)

Features:

- 8.9in Printing area
- 5in Touch Panel
- 50 µm XY resolution
- 90mm/hr Print speed

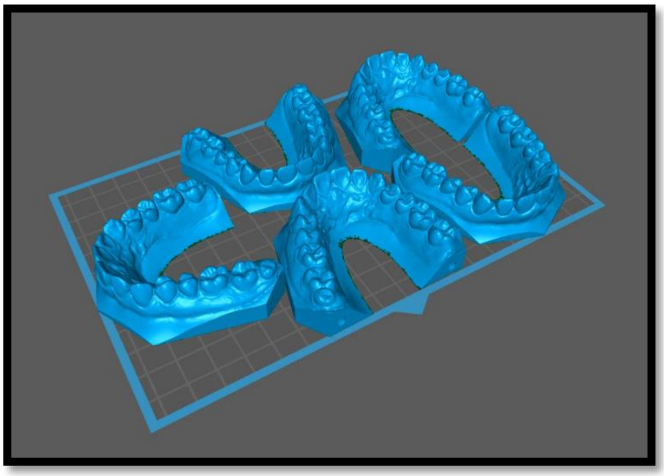


Figure 27: Sonic XL 4K

4) Phrozen Sonic 4K 2022:
It is an upgraded version of Sonic 4k to maximize efficiency. It comes with a Phrozen dental synergy slicer software which allows the fabrication of precise dental models.(Fig.28)
It has an internal heater that keeps the temperature constant throughout the process in order to produce high-quality dental prints. It also has a resin purifier that clears out the resin fumes to enhance the 3D printing experience.
It also allows the clinician to restart the print at any time and continue printing from where they have left out which saves time and reduces print failures.

Features:

- 6.1in Printing area
- 5in Touch Panel
- 35 µm XY resolution
- 90mm/hr Print speed

Figure 28: Phrozen Sonic 4K 2022

These Printers are highly economical as well as compatible with various software, scanners and resins.

Applications :
1) Digital dentures
2) Orthodontic models
3) Indirect bonding trays
4) Surgical guides
5) Bite Splints

Advantages:
The advantages of 3D printers are
1. Full integration with a digital workflow which represents the final stage in the full utilization of intraoral scanning and digital models.[11]

2. Accuracy: SLA/DLP printers provide analogous accuracy to high-quality plaster dental models (Brown et al., 2018; Hazeveld et al., 2014). [11]
However, the conventional models are more prone to clinical technique errors, warp of impressions and shrinkage of model materials. In contrast, a 3D-printed model is a reliable replica of the dentition which allows a plastic model to be used multiple times. It also can identify and repair scan defects before the printing of 3D models. It is cost-effective as compared to conventional model processes and materials. A full intraoral scan takes a similar amount of time to record an alginate impression as well as an occlusal registration. However, dental impressions have to be disinfected, bagged, poured and the models have to be trimmed. This includes direct staff time and indirect time delays while the impressions disinfect and the model material hardens. In contrast, there is an increasing number of digital software and automated physical steps which reduces staff involvement.[11]
The overall time differences between conventional and digital processes will depend on the staff learning curve to become proficient as well as the efficient management of printer capacity.[11]

Disadvantages:
A switch to 3D printing involves a capital investment for the purchase of the 3D printer postprocessing hardware and additional software (or licences) for the fabrication of in-house orthodontic aligners. The Dental staff needs to master new skills and must be efficient to deal with a major initial obstacle since they may be completely unfamiliar with 3D software and hardware. Hence, the invention of a digital workflow necessitates a clinical downtime for staff training This can be achieved by the provision of step-by-step instruction documents for staff on the main key stages (digital model preparation, printing and postprocessing) for the errors to minimize and to maximise efficiency. Any online training facility is suggested by the printer manufacturer to expertise the proper usage of the software. There is a need for post-print washing and curing phases if SLA/DLP printers are utilized. While these steps can be relatively automated, they also increase the time from scan to appliance fabrication. There is a need for awareness about the practice health and safety guidelines on the handling and storage of new materials.[11]

Limitations:
There is a large learning curve that has to be conditioned in the virtual staging and fabrication. There seems to be an error occurring between actual treatment results obtained after usage of a particular stage aligner when compared to the virtual 3D stage model.
Digital Workflow (Fig.29): The process from digital 'impression' to the appliance will be deliberated in chronological order:
1. Intra-oral scanning
2. Digital model manipulation
3. 3D printing
4. Post-print processing
5. Appliance fabrication [11]

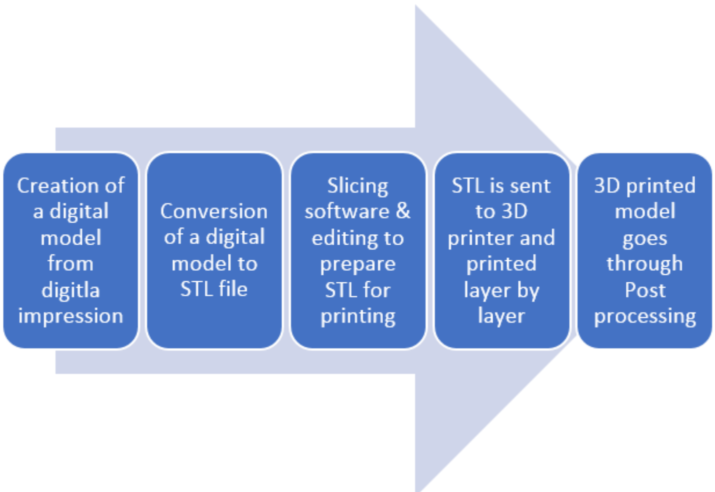


Figure 29: DIGITAL WORKFLOW

3D Printing:

These 3D printers' contrast from one another in terms of

a) The build platform size, especially its surface area, and consequently the maximum number of models feasible per print cycle. Print platforms are listed as small, medium or large. In general, a small platform allows rapid printing of numerous 'horizontal' models, such as retainer models for debonded cases. However, it can neither enable a large number of 'flat' models, even for slow printing, nor several vertically orientated models for a large batch print. Therefore, the smaller the platform size then the greater is the requirement to fabricate 'thin' models. This configuration may be applicable for the construction of retainer/aligner models, but not for appliances that require a 'deep' model that includes the palatal vault, buccal (alveolar) areas or mandibular lingual depth.[11]

b) If an orthodontic practice requires more than four models printed per day, then the medium size print platform will solve the associated problem. In addition, large and more affordable dental-specific printers are made available into the market, e.g., the Photocentric LC Dental (310 × 174 × 200 mm) (https://photocentricgroup.com/lcdental; accessed 20 April 2020) and the Formlabs 3L (335 × 200 × 300 mm) (https://formlabs.com/uk/3d-printers/ form-3l; accessed 20 April 2020). These are certainly suitable for dental laboratories but may also be appropriate for large orthodontic practices with a high volume of retainer and aligner model requirements. [11]

c)Print resolution and speed: The higher the resolution setting then the greater the level of detailing and the smoother will be the surface finish. Resolution and speed are co-dependent: the lower the resolution then the faster is the print. Overall, the 100-μm layer thickness is considered to be adequate for orthodontic purposes. Print speed is also influenced by the orientation of the models on the build platform such that models must be orientated parallel to the platform print relatively quickly because the z-axis (total height) is reasonably low. In contrast, vertically oriented models will comparatively have a slower print time because of the distance from the platform to the furthest model surface (typically an incisor labial surface). Print times for dental models are frequently in the range of 1–10 hours, depending on horizontal and vertical model set-ups, respectively. A short print time is beneficial for same-day appliances such as retainers. Conversely, a 10-hour print is appropriate for non-urgent printing of numerous models in a single cycle. [11]

d) Supports: These are vertical struts and inter-connecting scaffolding bars that provide structural integrity to the model. They are mainly important when the model base is irregular and requires support. Supports can vary in terms of their shape, length, diameter and density so that it is much easier and more convenient for the clinicians to automatically make addition in the software. Individual supports can be edited, especially if their touchpoint is on a key tooth surface. Interestingly, the position of supports changes with the vertical orientation of the model. In contrast, supports connects to tooth surfaces, especially incisors, when the model is orientated vertically. Consequently, tilting of models by 20°–70° to the platform is required if the supports are incorporated.[11]

e) Ease of use: The software should be user friendly as well as convenient in terms of the physical aspects of using the printer such as resin filling and cleaning requirements. In particular, software manipulation of the models should be as automated as possible in terms of their orientation (on the build platform) and support additions. It should enable us to use the software remotely to prepare and fabricate models for printing and start the print job offsite. As outlined already, the orientation of models on the build platform is important and it affects the numbers of models that can be fabricated in one print run and the print speed. Horizontal models are usually not recommended. Instead, most manufacturers suggest at least 20° of model tilt (to orientate the incisal edges furthest away from the build platform) with help of the supports.[11]

The overall time differences between conventional and digital processes will depend on the staff learning curve to become proficient as well as the efficient management of printer capacity.

Post-print processing:

These may vary according to the particular resin used, so the printer manufacturer's recommendations should be followed carefully. The two finishing stages included are:

a) Model washing. After printing, isopropyl alcohol (IPA) with at least 95% concentration is used to wash the models for minimum 10mintues to remove any uncured residual surface resin. This is best accomplished with the assistance of mechanical agitation, i.e. with the use of either an ultrasonic bath or a printer-specific washer, to continuously stir the IPA solution. Particularly, IPA is a volatile and flammable chemical compound, so washing in a closed chamber and good room ventilation is usually recommended. The models are then air- or blow-dried to remove any residual IPA. [11]

b) Model curing. The model surface will harden during daylight. However, both for workflow efficiency as well as to ensure full curing of the model, it is best to expose the models to a combination of ultraviolet light and heat up to 60 °C for 30 minutes. The models can be handled without gloves at this stage. [11]

Appliance fabrication:

This stage duplicates conventional techniques for the fabrication of both orthodontic retainers and aligners, where a vacuum or pressure forming machine has certainly used the form to the thermoplastic material around the model. Fortunately, 3D-printed models can be easily stored and re-used if necessary. This is particularly helpful if a patient fractures or loses a retainer or aligner and also patient appointment and potential delay can be avoided. Patient attendance is not required if further working models need to be prepared.[11]

New Era in 3D printer:

Graphy Inc.:

History: Graphy Inc. has led to the innovation of new materials (photo-curable resin) for 3D printers, which is a main key element of the 4th industry.

In particular, it has received worldwide recognition for its capability by successfully commercializing the direct 3D printing clear aligner material. Sim un seob is the CEO of Graphy, Inc which was founded on January 2, 2017. It is the world's first direct printing aligner material in which no working model is required. It is CE Class IIa and KFDA Class II certified.[12]

It has made the dental industry digitalized all over the world. There were various shortcomings of current 3d printable materials that limited the use of 3d printing technology. To overcome the limitation of 3d printing material, Graphy introduced this photopolymer material. The materials used are biocompatible, hypoallergenic, high-heat resistance and highly accurate.TC-85DAC/DAW is the first world's direct aligner printing material. Other uses are the fabrication of Dental Prosthesis, Denture Bases, Dental Model, Surgical Guide.[12]

Application:

1. Fabrication of Clear Aligners (Fig.30):

Tera Harz TC-85 is a photopolymer material that is developed to overcome the drawbacks of the previous thermoforming sheet type aligner. It can be 3D printed directly with a 3D printer which provides efficient orthodontic treatment and is also less painful for a patient.

A direct aligner is the orthodontic dental device with a new technology introduced for the benefit of the patient as well as the orthodontic expert.[12]

Property and Advantage:

Dental professional expert requires only one-day orthodontic treatment with Tera Harz TC-85DAC. It requires very less expenditure to set up a manufacturing facility. It can fabricate products in bulk with minimized facility investment. It is not time-consuming and has increased the productivity rate.[12]

3D software is used to fabricate the direct aligners which can also manage its material strength and elasticity. Therefore, this helps the dental experts to fabricate direct aligners for various orthodontic treatments which can yield a better treatment result.

It can be customized depending upon the patient's requirements.[12]

Tera Harz TC-85 is bio-compatible photopolymer material and it is already acquired CE, FDA, and KFDA medical device certification.

TC-85DAC (clear) is fully transparent and durable as an orthodontic treatment device. TC-85DAW (white) is a choice of selection if aesthetics is a concern. In addition, Graphy Inc has the technology of supplying customized colours that meet the needs of business partners.[12]

Colour

Clear, White

Figure 30: Clear Aligner Fabrication

2. Fabrication of crown, Models, Surgical Guides, Flexible dentures, Casting resin.

Different Types of 3D printers:
1.SprintRay Pro 3D Printer:
It is the most accurate 3D printer for the dental office. It has two versions: SprintRay Pro 95 & SprintRay Pro 55. It is highly precise as well as highly flexible. It is user friendly and can deliver an outstanding patient experience. It can be used to fabricate surgical guides, Study and wax-Up models, models for aligner production, indirect bonding, digital dentures& occlusal guards.
SprintRay Pro 55 (Fig.31) is an ideal printer for clinics or labs that mainly specialize in restorative applications. The Treatment cost, as well as the delivery time, is reduced thereby improving the workflow.
It is made up of Aluminium chassis, Super strong PMMA polymer, tempered glass and magnetic locks. It is a highly aesthetic, advanced, durable 3D printer backed by Smart software. The latest version of the software is PrintOS 6.32.5 which enables all the new features available on SprintRay Pro. It has a key innovation with the proprietary STEM Tank technology which helps in the improvement of speed and reduces the mechanical complexity.

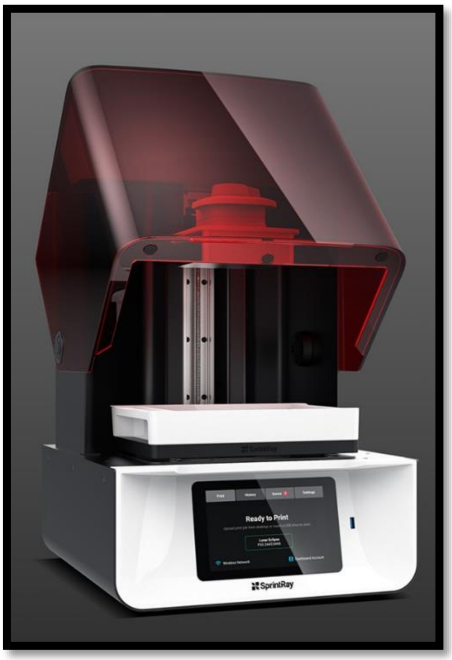


Figure 31: SprintRay PRO 55 3D printer

2. Asiga 3D Printer:
The Asiga MAX™ (Fig.32) is the world's most advanced lab 3D printer. With 62µm HD print precision, the Asiga MAX™ is used for dental and audiology lab production.
It has a Lifetime technical support guarantee with WIFI connectivity, Automated support generation, Touchscreen interface, Proven manufacturing reliability.[13]

Applications:
1.Dental:
• orthodontics
• crown & bridge
• surgical guides
• dental models
• custom trays
• partial dentures
2. Audiology:
• ear-shells
• ear moulds
• silicone ear moulds

Figure 32: ASIGA 3D Printer

3. Slash 2 3D Printer :
It is a new generation of professional Desktop 3D printers with an 8.9" 4K ULTRA HD LCD Light engine. It is the New Era of industrial 3D printing which is more reliable, fastest and more precise than any other device. Stereolithography is the printing technology used.[12]
It is consumer-friendly, with a durable and replaceable screen. It also has a greater processing power with 6 –Core CPU and 4 GB RAM with a dedicated light array for better uniformity.
It has an intelligent heat management system with new dual layers and an ultra-durable resin tank.[12]
It is available in two versions (Fig. 33): 1. Slash 2
2. Slash Plus

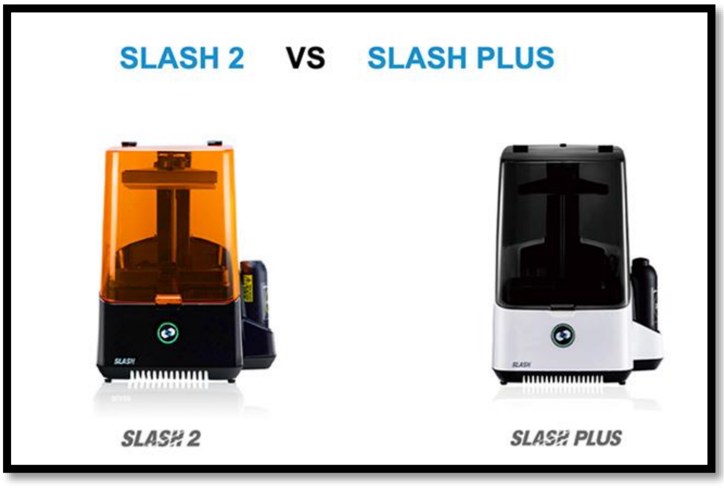


Figure 33: Slash 2 & Slash Plus 3D Printer

Discussion:
3D printing has transformed the era of fabrication of various appliances by providing customized, efficient, highly accurate, and reproducible facilities in orthodontics. With the invention of the computer-aided technique, it is now possible to virtually achieve the changes caused by the braces in advance.

Conclusion

3DP is revolutionising digital dentistry which has provided certain opportunities in diagnosis, treatment planning and education aid. The enhanced research in this industry and optimism would provide more opportunities to help in transforming digital dentistry.

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