Republic of Iraq
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College of Dentistry

3D PRINTING IN ORALL AND MAXILLOFACIAL SURGERY

A Project Submitted to

The College of Dentistry, University of Baghdad, Department of MaxilloFacial surgery in Partial Fulfillment for the Bachelor of Dental Surgery

By

Mustafa Mohammed Hussein
Mustafa Montasir Ali

Supervised by:

Ali Mohammed Hassan
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Certification of the Supervisor

I certify that this project entitled **3D printing in oral and maxillofacial surgery** was prepared by the fifth-year students **Mustafa Mohammed and Mustafa Montasier** under my supervision at the **College of Dentistry/University of Baghdad** in partial fulfilment of the graduation requirements for the Bachelor Degree in Dentistry.

Ali Mohammed Hassan

B.D.S., M.Sc., O.M.F.S

Dedication

we would like to dedicate our humble effort to our supportive parents. Their affection, love, encouragement and prays at day and night made us able to succeed with honor.

Mustafa Mohammed

Mustafa Montasir

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First and foremost, praises and thanks to **Allah Almighty** for helping us fulfill my dream, for his blessings throughout my work to complete it successfully.

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Abbreviation	Meaning
3D	Three dimensional
SLA	Stereolithography
FDM	Fused deposition modeling
CAD	Computer-aided design
DLP	Direct light processor
LCD	Liquid crystal display
PPJ	Photopolymer Jetting
SLS	Selective Laser Sintering
UV	Ultraviolet
DMD	Digital micromirror device
PLA	Polylactic acid
ABS	Acrylonitrile butadiene styrene
ASA	Acrylonitrile styrene acrylate
TPU	Thermoplastic polyurethane
μm	Micrometer
ECM	Extracellular matrix
PLGA	Poly (D,L-lactic-co-glycolic acid)
PGS	Poly(glycolides)
PCL	Poly(caprolactone)
PEEK	Polyether Ether Ketone
PMMA	Poly(methyl methacrylate
DMM	Digital master model
OMFS	Oral and maxillofacial surgery
AM	Additive manufacture
GRF	Guided reduction and fixation
CT	Computed tomographic
DICOM	Digital Imaging and Communications in Medicine
VSP	Virtual surgical planning
TMJ	Temporomandibular joint
APE	Altered passive eruption
ASTM	American Society for Testing and Materials

1.Introduction

In 1986, Charles Hull introduced the first three-dimensional (3D) printing technology, and the industry developed many different manufacturing technologies, which have been applied to numerous fields [1–4]. In 1986, Hull patented stereolithography (SLA) and built and developed a 3D printing system. In 1990, Scott Crump received a patent for fused deposition modeling (FDM) [5]. Since then, 3D printing has been increasingly progressing. Three-dimensional printing, the alias of additive manufacturing [6], is an advanced manufacturing technology. It is based on computer-aided design (CAD) digital models, using standardized materials to create personalized 3D objects through specific automatic processes [2, 7, 8]. It is used for rapid prototyping, which has been widely used in industry, design, engineering, and manufacturing fields for nearly 30 years.

In the field of medicine, such as traumatology, cardiology, neurosurgery, plastic surgery, and craniomaxillofacial surgery, 3D printing is often used for digital imaging in surgical planning, custom surgical devices, and patient-physician communication [9]. In the field of dentistry, its applications range from prosthodontics, oral and maxillofacial surgery, and oral implantology to orthodontics, endodontics, and periodontology [10, 11].

Compared with traditional wax loss technology and subtraction computer numerical control methods, 3D printing has advantages in process engineering [12]. Owing to its rapid production, high precision, and personal customization, complete dentures, and implant teeth are easier to obtain [13]. Additionally, the applications of 3D printing in dentistry can assist in providing patients with lower cost and more personalized services and simplify the complex workflow related to the production of dental appliances [7].

Some studies have shown that the edge and internal gap values of 3D printing restorations are significantly lower than those of milling restorations [8]. For example, dental crowns are generally fabricated from traditional plaster models, and currently, dental crowns fabricated from 3D printing models are also popular. The 3D printing technologies can quickly accept CAD data. Moreover, it can rapidly manufacture single and small-batch parts, new samples, complex shape products, molds, and models [14]. It has many advantages, such as high material utilization, high economic benefits, and the production of certain scale products on demand. However, it still has several disadvantages, such as high cost of processing and material and time-consuming postprocessing. Still, in general, 3D printing has been successfully applied in the medical field [16, 15]. This review discusses the 6 main 3D printing technologies, including Stereolithography (SLA) , Direct light processor (DLP) , Liquid crystal display LCD, Selective Laser Sintering (SLS), Photopolymer Jetting (PPJ) and fused deposition modeling (FDM). Finally, this research describes the applications in dentistry of 3D printing in detail, including manufacturing working models and primary applications in the fields of oral and maxillofacial surgery.[18]

Aims of the study

This review aims to show the different 3D printing technology and there applications in an effort to provide a useful guide for the reader when choosing a 3D printer as a part of digital workflow.

Chapter one

Review of literature

1.1 Types of 3D printers according to technology

1.1.1 Stereolithography (SLA) [20]

Stereolithography (SLA, SL) A stereolithography apparatus (Fig. 1055) uses a scanning laser to build parts one layer at a time, in a tank of light-cured photopolymer resin. Each layer is traced-out by the laser on the surface of the liquid resin, at which point a ‘build platform’ descends, and another layer of resin is wiped over the surface, and the process repeated.

Supports must be generated in the CAD software, and printed to resist the wiping action and to resist gravity, and must later be removed from the finished product. Postprocessing involves removal of excess resin and a hardening process in a UV oven. this technology is commonly used for the industrial production of 3D printed implant drill guides.[21]

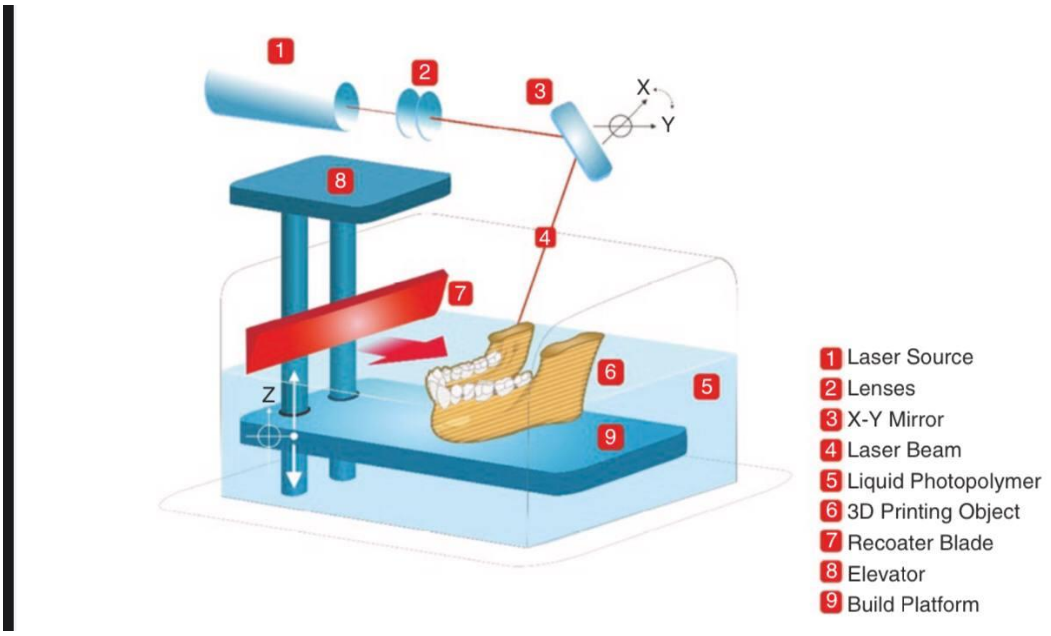


Figure 1: Stereolithography apparatus[19]

1.1.1.1Advantages of SLA [21]

1. high vertical and lateral resolution.

2.relativly high printing speed, This indicates that precision does not slow down the printing speed in SLA .[20]

1.1.1.2 Disadvantages [22]

1.The parts fabricated by SLA are usually made of high-cost low-molecular-weight epoxy or acrylic resins.

2. SLA is limited to photopolymers. It is not also possible to print more than one type of resin during the printing process.

3. the printed parts are brittle and subject to shrinkage after polymerization [15, 18].

Table1: Characteristics of common dental SLA machines (based on information published on manufacturer websites. [19]

Model	Manufacturer	Launched in	Max. build size (xyz)	Min. layer thickness	XY accuracy	Max. printing speed
ProJet 1200	3D systems	2014	43 × 27 × 150 mm	30 µm	60 µm	14 mm/h
Ember	Autodesk	2015	64 × 40 × 134 mm	10 µm	50 µm	18 mm/h
B9CREATOR V1.2HD	B9Creations	2015	104 × 75 × 203 mm	30 µm	30 µm	NR
Form 2	Formlabs	2015	145 × 145 × 175 mm	25 µm	145 µm	10–30 mm/h
Nobel 1.0	XYZprinting	2017	128 × 128 × 200 mm	25 µm	300 µm	5–15 mm/h

1.1.2 Direct light processor (DLP)

A DLP printer is characterized by an LED screen which is composed of a digital micromirror device (DMD). These small micromirrors are able to concentrate the light and form the structure of a layer on the bottom of the resin tank. At the end of the printing process such as SLA, the model needs to be washed and post-cured [23]. DLP technology is based on a digital light projector which is the source of light to photo-polymerize the resin. This projector flashes an image of a layer at once and this makes the procedure much faster because all points of a layer are cured at the same time.

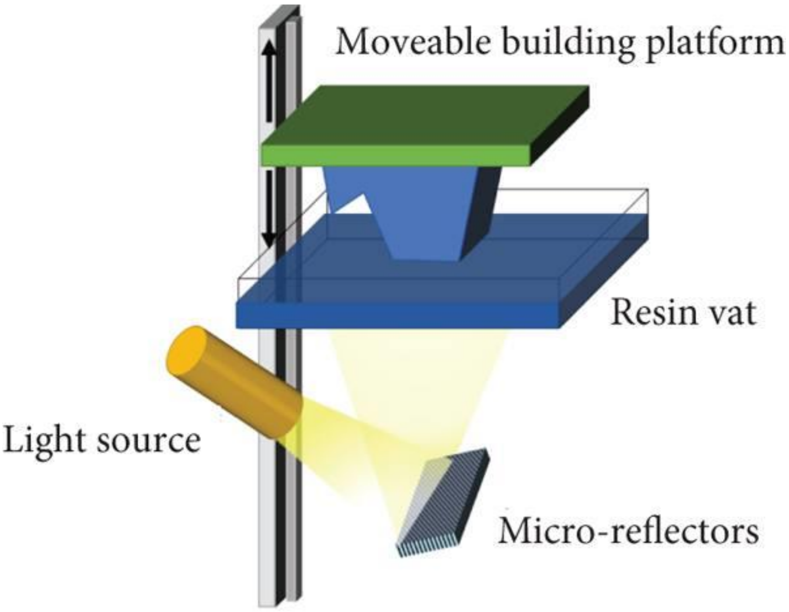


Figure 2: DLP printer[19]

1.1.2.1 Advantages

1. high precision.

2. it can provide 3D printed models in a much shorter time than SLA 3D printers [25].

1.1.2.2 Disadvantages

1.limited build.

2.the DLP 3D printer is very expensive .

[26]

1.1.3 Liquid crystal display LCD

LCD printing technology is becoming very popular because it is more affordable than the other vat polymerization 3D printers. They are more affordable because the parts of an LCD 3D printer and more specifically the light source have a lower cost than other 3D printers [23]. A Liquid Crystal Display is used as a light source for these printers. This Liquid Crystal Display is composed of LCD panels that allow the light to shine in parallel and come through onto the build area. In this 3D printing technology, there is no need to expand the light through lenses or other devices. This process eliminates pixel distortion. The equipment parts are shown schematically in

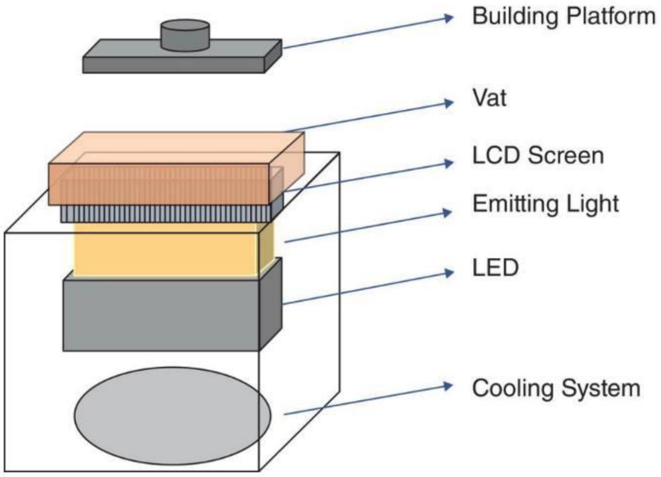


Figure3: LCD apparatus[19]

1.1.3.1 Advantages

1. very cheap

2.has good resolution.

[25,26]

1.1.3.2 Disadvantages

1. the LCD has a short service life

2.needs to be replaced regularly.

3.the light intensity of LCD 3D printing is very weak, because only 10% of the light could penetrate from the LCD screen and 90% of light is absorbed by the LCD screen.

4. mentioned above, the partial light leakage could result in the transition exposure of photosensitive resin at the bottom.

5. the liquid tank needs to be cleaned regularly. Now the LCD 3D photocuring machine is applied in the fields of dentistry, jewelry, toys and so on.

[25,26]

1.1.4 Selective Laser Sintering (SLS)

In 1986, Carl Deckard and Joe Beaman invented a powder-based additive manufacturing method called selective laser sintering (SLS). SLS is performed in two ways—direct and indirect. In the direct SLS high-power laser beam is irradiated to sinter the powder particles at the points of interest . If the powder particles do not fuse under the laser radiation, indirect SLS would be the solution. In indirect SLS, a sacrifcial polymeric binder is added to the formulation. After printing, the as-fabricated part is heated in the furnace to remove the binder from the body of the built part. The term selective laser sintering is mostly used for ceramic and polymer powders. In the case of metals, some authors prefer to instead use the term selective laser melting (SLM). Theoretically, SLS has no limitations on the type of materials, and a wide range of metallic, ceramic, and polymeric parts can be fabricated by this method. SLS resolution varies depending on the size of the particles and the power of the laser beam.[27,28,30]

1.1.4.1 Advantages

1. Any material in its powder form can be printed by this method if the material withstands laser heat and shrinkage.

2. In most polymers, ceramics, metals, and alloys, SLS is performed without the need for binding materials.

3. Low-melting point binders make it possible to print these materials, as well.

4.Therefore, virtually any material that can survive both laser heat and shrinkage could be printed via SLS.

[31, 32].

1.1.4.2 Disadvantages

1.During the SLS, particles undergo heating and subsequent cooling processes that lead to the deformation or shrinkage of the built part

2.Some molecules cannot tolerate high temperatures caused by laser radiation.

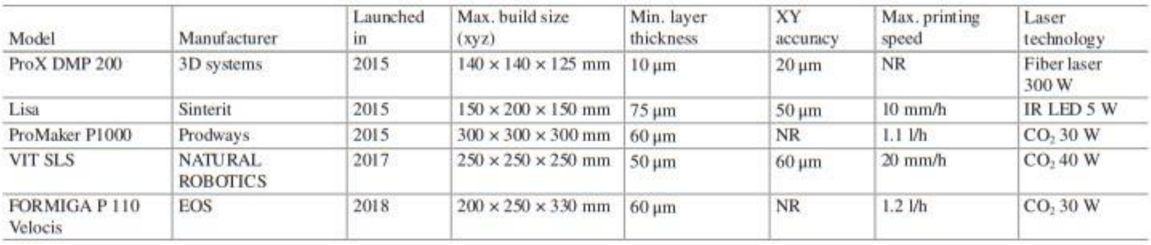
3.For instance, biomolecules degrade at high temperatures and lose their function and, therefore, cannot be printed using SLS

4.The need for polymeric in non-sinterable powders

5. Need for pre- and post-heating treatments of the powdered materials.

[33, 34].

Table2: Characteristics of common dental SLS machines (based on information published on the manufacturer's website). [19]



Model	Manufacturer	Launched in	Max. build size (xyz)	Min. layer thickness	XY accuracy	Max. printing speed	Laser technology
ProX DMP 200	3D systems	2015	140 × 140 × 125 mm	10 µm	20 µm	NR	Fiber laser 300 W
Lisa	Sinterit	2015	150 × 200 × 150 mm	75 µm	50 µm	10 mm/h	IR LED 5 W
ProMaker P1000	Prodways	2015	300 × 300 × 300 mm	60 µm	NR	1.1 l/h	CO_2 30 W
VIT SLS	NATURAL ROBOTICS	2017	250 × 250 × 250 mm	50 µm	60 µm	20 mm/h	CO_2 40 W
FORMIGA P 110 Velocis	EOS	2018	200 × 250 × 330 mm	60 µm	NR	1.2 l/h	CO_2 30 W

1.1.5 Fused Deposition Modeling (FDM)

In 1989, Steven Scott Crump and Lisa Crump invented fused deposition modeling (FDM). FDM is an extrusion-based method in which the materials are melted and deposited in a layered order, according to the CAD model. The FDM device has liquefer elements that melt both the support material and the build material. The molten materials are deposited on the base surface by the movement of the extrusion nozzle in the XY plane. Layers are arranged on top of each other by the vertical movement of the build platform.

FDM was initially designed to build parts from materials that can be melted to form flaments. The most commonly used materials in this method are thermoplastic polymers—including nylon, polylactic acid (PLA), acrylonitrile butadiene styrene (ABS), acrylonitrile styrene acrylate (ASA), thermoplastic polyurethane (TPU), polycarbonates, and polyetherimides. It is also possible to print metals and ceramics via FDM if they are mixed with thermoplastic binders [36,37]

1.1.5.1 Advantages of FDM

1.Low cost and ability to print multiple material types in one printing process.

2.Objects printed with FDM do not require any postprocessing treatments or modifications.

[38]

1.1.5.2 Disadvantages

1.the rough surface finish of the printed parts, which affects the mechanical properties and the performance of the built objects.

2. cooling of the hot melt-extruded filaments usually leads to the wrapping and deviation of the finished parts from the CAD model.

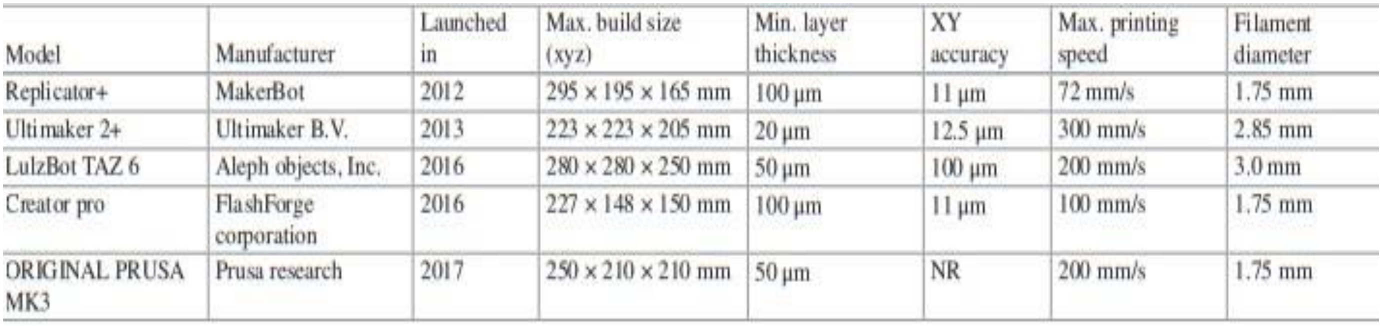
Several studies have been conducted to overcome these drawbacks by optimizing the printing process parameters.

3.FDM is relatively slow.

4.the dimensions of the printable objects are limited in this method.

[39,40]

Table3: Characteristics of common dental FDM machines (based on information published on the manufacturer's website)[19]



Model	Manufacturer	Launched in	Max. build size (xyz)	Min. layer thickness	XY accuracy	Max. printing speed	Filament diameter
Replicator+	MakerBot	2012	295 × 195 × 165 mm	100 µm	11 µm	72 mm/s	1.75 mm
Ultimaker 2+	Ultimaker B.V.	2013	223 × 223 × 205 mm	20 µm	12.5 µm	300 mm/s	2.85 mm
LulzBot TAZ 6	Aleph objects, Inc.	2016	280 × 280 × 250 mm	50 µm	100 µm	200 mm/s	3.0 mm
Creator pro	FlashForge corporation	2016	227 × 148 × 150 mm	100 µm	11 µm	100 mm/s	1.75 mm
ORIGINAL PRUSA MK3	Prusa research	2017	250 × 210 × 210 mm	50 µm	NR	200 mm/s	1.75 mm

1.1.6 Photopolymer Jetting (PPJ)

PPJ is based on material jetting. In this technique, the photopolymers and supporting materials are jetted from an inkjet-like printhead on the build platform. Then, the materials are cured and solidified by ultraviolet radiation. The print head moves along the build platform and deposits the layers one by one. After the completion of the printing process, the supporting materials are removed from the built part [40]. A broad range of photopolymers, rubbers, and waxes can be printed by PPJ [41].

1.1.6.1 Advantages

1.PPJ is a relatively fast method that has the ability to print objects with high resolution and quality.

2. The cost of PPJ technology is relatively low.[42]

1.1.6.2 Disadvantages

1. the high cost of materials restricts its application.
2. the printed parts are mostly thermally unstable and do not allow heat sterilization.
3. complete removal of the support materials is not always straightforward and may cause structural damage.

[43]

Table4: Characteristics of common dental PPJ machines (based on information published on the manufacturer's website) [19]

Model	Manufacturer	Launched in	Max. build size (xyz)	Min. layer thickness	XY accuracy
3Z Lab	Solidscape	2012	152.4 × 152.4 × 50.8 mm	6 μm	25.4 μm
Objet30 Dental Prime	Stratasys	2015	300 × 200 × 100 mm	16 μm	100 μm
ProJet MJP 3600	3DSystems	2016	298 × 185 × 203 mm	16 μm	25 μm
J700 Dental	Stratasys	2017	490 × 390 × 200 mm	10 μm	100 μm
ProJet MJP 5600	3DSystems	2017	518 × 381 × 300 mm	13 μm	25 μm

1.2 Material used in 3D printing

1.2.1 Metals

Metals have various biomedical applications, but not many of those applications take advantage of the printability of the metals [44]. Printable metals include titanium alloys, cobalt, iron, stainless steel, and chromium [45].

3D printed constructs of metals can be appropriate for use in hard tissue-related applications due to their mechanical strength [46,47]. Among the few uses of 3D printed metal constructs in biomedical applications, one may refer to the use of 3D printed titanium alloys [48, 47], cobalt-chromium alloys [49], nitinol [50], and stainless steel [51] in various implants.

1.2.1.1 Advantages

Fabrication of complex objects without the help of tools, fixtures, lathes or molds, directly to the production of 3D graphics such as stl /step /solid. product into a physical model.

According to the size of the product, it can be formed within a few hours, and complex structures can also be formed at one time without welding, which can save time and be more efficient than traditional manufacturing.

[52]

1.2.1.2 Disadvantage

- Metal powders are much more expensive than "normal" metal materials
- Metal 3D printer equipment is expensive, which indirectly increases the cost.
- the printed product requires surface treatment, and the error and precision are lower than those of traditional CNC machining.
  [52]

1.2.2 Polymers

three common categories of thermoplastics, elastomers, and synthetic fibers are known as synthetic polymers [53]they are used for a wide range of functions in biomedicine, including applications in therapeutics, drug delivery, diagnostics, and tissue engineering and biomedical applications[53]. This is attributed to their excellent mechanical properties, low cost, and possible degradability [54,55]. They can be used in the form of filaments in the FDM method, solutions in SLA technique, and beads or powders in SLS [56]

1.2.2.1 Poly(caprolactone) (PCL)

PCL is a biodegradable, biocompatible, and low-cost polyester and thus FDM technology takes advantage of its use by making abundant PCL filaments for 3D printing [57,58,59]. In fact, tissue engineering and 3D printing have an effective role in making this polymer accessible and popular for biomedical applications [75]

PCL is one of the critical materials in the SLS method and is being employed as 10–100 μm beads [60,61]. This technique can result in a porous scaffold with interconnected pores, good roughness, and a mechanical property comparable to the properties of bone [60].

Synthetic polymers, and specifically PCL, are suitable to be used for 3D printing of complex shapes, such as ears and nose [62,63] or even as a skeleton for complex configurations needed in critical-sized defects in oral and maxillofacial surgeries

PCL works very well in melt-based extrusion printing due to its rheological and viscoelastic characteristics and appropriate melting temperature. However, its slow degradability and stiffness make it mostly applicable for hard tissue regeneration [60]. 3D printed PCL constructs can be utilized as a support material during tissue repair, as it can stay stably and non-toxically for more than 6 months in the body and be fully resorbed in approximately 3 years [60].

The mechanical property of PCL allows its 3D printing in a flexible membrane shape.

PCL have some disadvantages

- PCL is highly hydrophobic and is not suitable for cell adhesion [61]. This is an important problem with most of the synthetic polymers, which results in reduced proliferation and differentiation [62].
- like many other synthetic polymers, it does not have a good biological activity to facilitate tissue regeneration compared to naturally derived extracellular matrix (ECM) polymers.

1.2.2 Poly (D,L-lactic-co-glycolic acid) (PLGA)

PLGA is a biocompatible copolymer of PLA and poly(glycolides) (PGA) [63]. The primary use of PLGA in biomedical applications is its suitable function as a carrier for controlled drug delivery [63].

The degradation of PLGA can be varied from 24 hours to several years, depending on the molecular mass distribution and crystallinity of these elements, along with the molecular weight ratio of lactic acid and glycolic acid (LA:GA) [64].

The major disadvantage of PLGA, which is highly unfavorable for its possible use in delicate biomedical applications, is having the potential trigger for the buildup of acidic oligomers, leading to inflammatory responses in the tissues [65]. Although inflammation is important in the regeneration of tissues, it is vital to control the inflammatory responses [66].

1.2.3 Polyether Ether Ketone (PEEK)

PEEK is known as a semicrystalline polymer [73], that can be utilized to 3D print customized craniofacial implants [74]. PEEK is usually used for bone replacement, as it is bioinert, radiolucent, biocompatible, and robust with a mechanical property similar to cortical bone [75]. It has a very high melting point

(~350 °C) [76] and thus cannot be printed with usual extrusion-based printing. Only the SLS method is popular for 3D printing this material [76,77];

Due to the lack of ability to integrate with body tissues, the risk of triggering foreign body reaction—such as dislodging, encapsulation, and extrusion—is very high for PEEK [77]. 3D printed PEEK implants are also more expensive than other polymer constructs [77].

1.2.4 Acrylonitrile butadiene styrene (ABS)

ABS is a triblock and petrochemical based copolymer with a melting point of 105 °C. As it is composed of acrylonitrile and butadiene elements, its mechanical strength is outstanding [78]. While polyester synthetic polymers suffer from brittleness, ABS possesses good toughness due to its styrene units [79]. It has been shown that blending poly (l-lactide) (PLLA) with ABS can increase the toughness of PLLA [80]

1.2.4.1 Disadvantages

- ABS is nondegradable and very poor in cell integration
- it is not often being used as scaffold or membrane materials for biomedical applications such as for oral and maxillofacial surgery.
- There are limited reports of using this material in tissue engineering of bone, cartilage, and other tissues [81,82]

1.2.5 Poly(methyl methacrylate) (PMMA)

It is the most commonly used vinyl polymer in dental 3D printing. It is polymerized from methyl methacrylate monomer via fiber reinforced polymer or anionic polymerization.

PMMA is the most favorable material for printing denture base materials owing to the ease of its processing, low cost, lightweight, stability in the oral environment, and esthetic properties.

However, PMMA has poor surface properties and weak me- chanical properties.[83,84]

1.3 Accuracy and precision of 3Dprinter.

1.3.1 Precision and Trueness

The trueness of a 3D printer is described as the deviation of the printed object from its actual dimensions, and the precision of a 3D printer is the deviation between repeated prints [85.86].

High trueness describes the proximity to the original dimensions of the measured object.

High precision defines a 3D printer’s ability to manufacture the same product with the same dimensions in repetitive prints [87].

in 2021 the department of prosthodontics : **gulhance** faculty of dentistry health science made an study to evaluate the trueness and precision of complete arch models printed with three dimensional printers via three different printing technologies (SLA , DLP & Polyjet technology)

An arch-shaped master model to simulate the mandibular arch (14 mm in height and 16 mm in width) was designed with CAD software. Six abutments with a 6o total angle of convergence and 1 mm at the circumferential shoulder finish lines were produced to resemble prepared teeth . Cross marks were added at the middle of each abutment's occlusal surface and were used as reference points to allow measurements of the X, Y, and Z coordinates.

Then, the digital master model (DMM) was saved in Standard Tessellation Language (.stl) format and transferred to each of the 3D printers. digital master model was printed 10 times with three-dimensional printers using stereolithography (SLA), direct light processing (DLP), and Polyjet technology (n = 30).

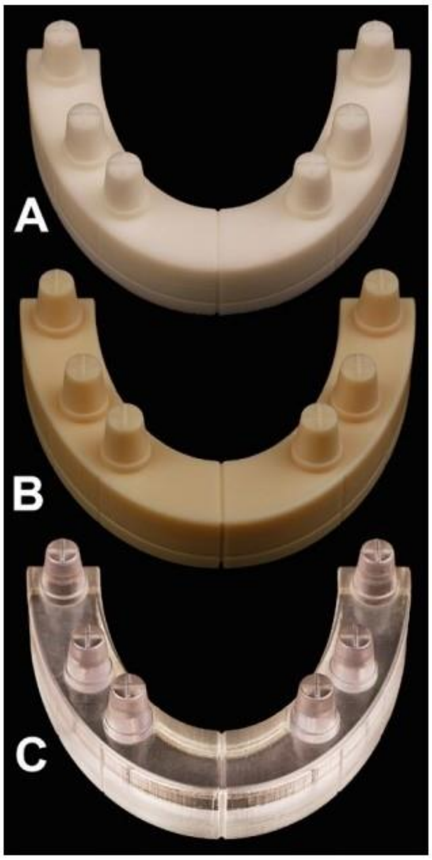


Figure4: models printed by three printers (a) SLS (b) DLP (c) polyjet[88]

1.3.2 Results

The comparison of trueness measurements for the three technologies presented significant differences. The mean trueness was 51.6 µm for the SLA models, 46.2 for the DLP models, and 58.6 µm for the Polyjet models

While the mean precision was 59.6 µm for the SLA models, 43 µm for the DLP models, and 41 µm for the Polyjet models. The Polyjet models were more precise than the SLA and DLP models.

So dentists or dental technicians should choose a suitable printer according to cost-effectiveness or the most important value that is needed for the clinic, study, or laboratory.

[88]

1.4 Application of 3D printer in dentistry

1.4.1 Maxillofacial surgery

1.4.1.1 surgical guide

Surgical guides can significantly improve the accuracy and time efficiency in clinical treatment, reduce operation errors, make the treatment result more predictable for dentists, and allow patients to better understand the implant prosthodontic treatment [89].

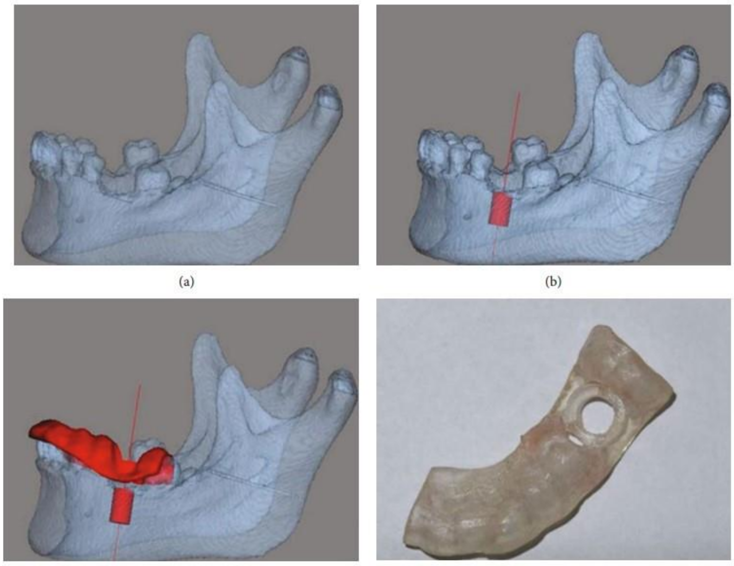


Figure 5: The design and production process of the surgical guide. (a) Digital model of the mandible obtained by scanning. (b) Specify the implant position in the design software. (c) Design surgical guide. (d) Print surgical guide using stereolithography[91]

Once the treatment planning is completed by using the application preoperative planning software, the surgical guides can be produced by SLA. The drill guides indicate the insertion position, angles, and depth of the implant, which accurately transfers it to the patient through the simulated plan, establishing a link between the planned and the actual operation while in use (Figure 10) [90].

1.4.1.2 Mandible reconstruction

Mandibular reconstruction after ablative tumour removal is still a challenging task to head and neck surgeons, which aims to achieve the best possible functional and esthetic outcomes. **Hidalgo** reported the utility of vascularized fibula flaps for mandibular reconstruction in 1989 (92), Since then, the fibular free flap has become the first option for mandible reconstruction (93,94). This flap has many advantages, including high quality of long bicortical bone grafts, long pedicle, wide vessel, and the ability to incorporate skin and muscle which are required for mandibular reconstruction (95,96,97). However, the mobility of the mandible increases the difficulty in the appropriate position of fibula flap to achieve the ideal functional and esthetic outcomes.

The sharping and position of fibula free flap in mandibular reconstruction was based on the surgeon's experience in the past. This operation is difficult to control during conventional surgery and occasionally result in dissatisfying occlusion and appearance. Now, the virtual planning and three-dimensional (3D) printing modeling using preoperative computed tomographic (CT) data has been introduced to permit more accurate reconstruction (95.96.97). Base on the data, we can simulate the resection of mandibular bone, segment and shaping of fibular flap and transfer the virtual plan to intraoperative templates. The true-to-size models and templates is easy to obtain by the 3D printing technology. Pre-bending of titanium plate was allowed on the model. These techniques help the surgeons to achieve near perfect position of the pieces of fibular flap.

The process of virtual planning began with high-resolution axial computed tomography (CT) scans using fine-cut (0.45 mm) of maxillofacial skeleton and lower extremities. Images were saved in DICOM (Digital Imaging and Communications in Medicine) format. 3D virtual models of the maxillofacial skeleton and fibula, as well as the simulation of mandibular osteotomies was performed using this software (Fig.6). In the process of virtual mandibular resection and fibular osteotomies, the designer work with the surgeon and confirm the osteotomies line together. The shaping and placement of fibular bone were planned by visualizing the reconstruction superimposed on the preoperative image of the mandible such that the outer (inferior-lateral mandibular border) contour of the mandible was restored. If the contour of the mandible was destroyed by the tumor, mirroring tools were used.

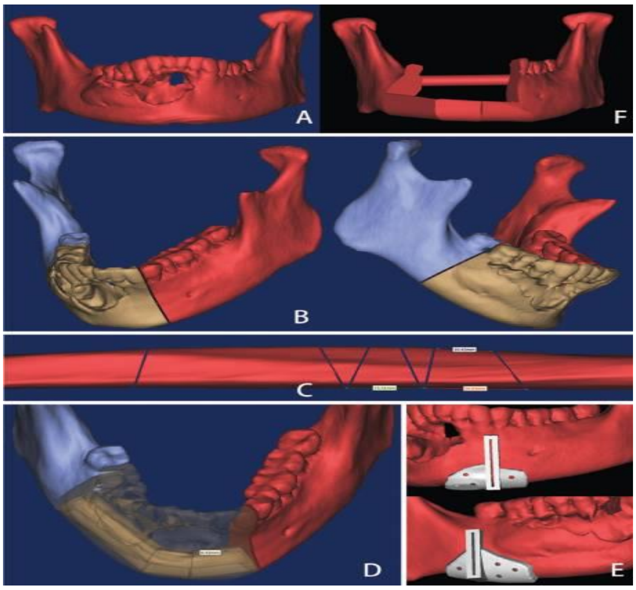


Figure6 : Computer assisted design and virtual planning (A. 3D virtual models of the maxillofacial skeleton; B. Simulation of mandibular osteotomies; C. Simulation of fibular osteotomies; D. Shaping and placement of fibular bone; E. Cutting guide design; F. Virtual mandible reconstruction using fibular bone).[98]

When the virtual surgery was finished, design of the cutting guide was beginning which allow the surgeon to precisely resect the lesion of mandible and segment the free fibular flap. The cutting guide should be fit the patient's anatomy, easy to fix to the mandible and fibula bone and not affected the operation. Cutting guides and 3D model were manufactured in polyamide using SLA three-dimensional (3D) printer FIG 7. The model and guides were then sterilized for intraoperative use.

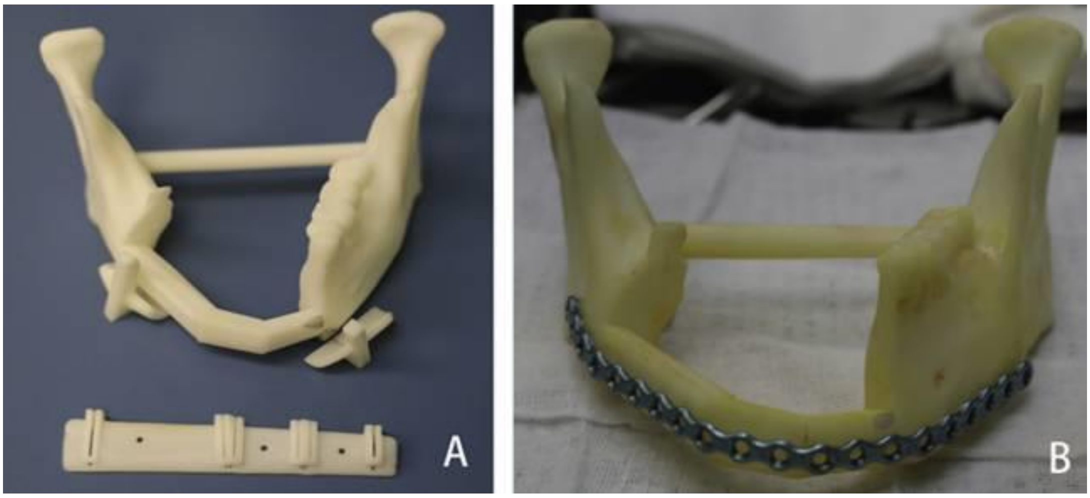


Figure 7: 3D printing modeling (A. The mandibular model and cutting guide was manufactured by the 3D printer; B. The titanium reconstruction plate was pre-bent along the contours of the model).[98]

The titanium reconstruction plate was pre-bent along the contours of the model to save operative time . In the surgical phase, the sterilized cutting guide was temporarily fixed to the mandible using monocortical screws, and a reciprocating saw blade was inserted into slots of the cutting guide to make osteotomies. After resection of the mandible, the reconstruction plate was placed as the plan dictated, spanning the defect, and temporarily fixed with at least 2 screws on each side. The osteotomies of harvested fibula bone using the same protocol at the lengths and angles required to replicate the virtual plan (Fig8) The proper fibular segments were transferred to reconstruct the defect. Remaining holes were of plate drilled and screws were placed as planning.

Vascular anastomosis and wound closure were performed using the standard method.

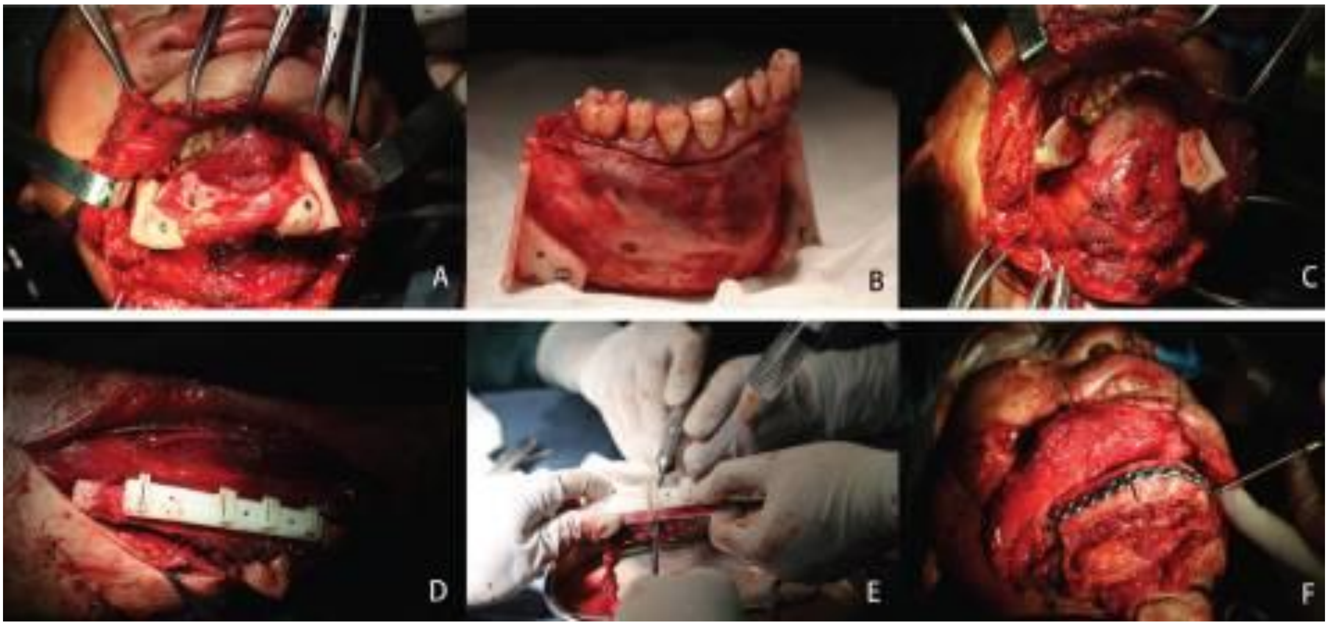


Figure8: The surgical phases (A. Cutting guide was fixed on the mandible; B. Making osteotomies of mandible according to the guide; C. After resection of the mandible; D. Cutting guide was fixed on the fibula; E. Making osteotomies of fibula according to the guide; F. The proper fibular segments were transferred to reconstruct the defect).[98]

Figure9: Preoperative and postoperative appearance of the patient (A. Preoperative appearance; B. Postoperative appearance).[99]

1.4.1.3 Planning and Manufacturing for Management of Facial Trauma

The variety of trauma injuries that the Oral and maxillofacial surgery OMFS team encounters, as well as the need to reduce the time between pre-operative assessment and treatment, necessitate flexibility and adaptation of both design and additive manufacture (AM) technologies. The establishment of 3DP facilities within the healthcare campus can reduce the duration of the primary guided reduction and fixation (GRF) process, from hospitalization and up to 3D-based instrument fabrication, down to approximately one week, a reasonable timeframe for the treatment of most oral and maxillofacial injuries.

A. Midface fracture

3DP-based treatment of trauma to the midface and zygomatic complex follows a similar workflow, using anatomical models prepared via FDM, SLA for the pre-bending of fixation plates [100,101,102] (Figure10) While pan-facial fractures can be managed by utilizing inter-occlusal relations and fragment repositioning, the occlusion is sometimes insufficient or irrelevant for the reduction of fractures. In these cases, virtual surgical planning (VSP)-based design of patient specific implants (PSIs) for fragment reduction can be extremely beneficial [103,104]. Reconstruction of the orbit follows similar treatment protocols, with preoperative 3D evaluation of the anatomy serving as the new standard of care. Numerous reports on 3D-based treatment approaches describe evolving treatment regimes. Pre-bending of titanium meshes [100,105], bioabsorbable implants [101] and even autologous bone [102] have been reported, using SLA or FDM models of the fractured orbit. Another methodology utilizes mirroring of the intact contralateral anatomy instead of the fractured orbit, which is subsequently 3D printed and used for pre-bending [100,103]. In parallel, the mirrored anatomy can serve as the basis for VSP and subsequent PSI design, usually achieved by utilizing software such as Mimics 3D (Materialise NV Inc., Leuven, Belgium) or FreeForm plus (3DSYSTEMS) and SLS or milling techniques for implant fabrication [106] (Figure 11).

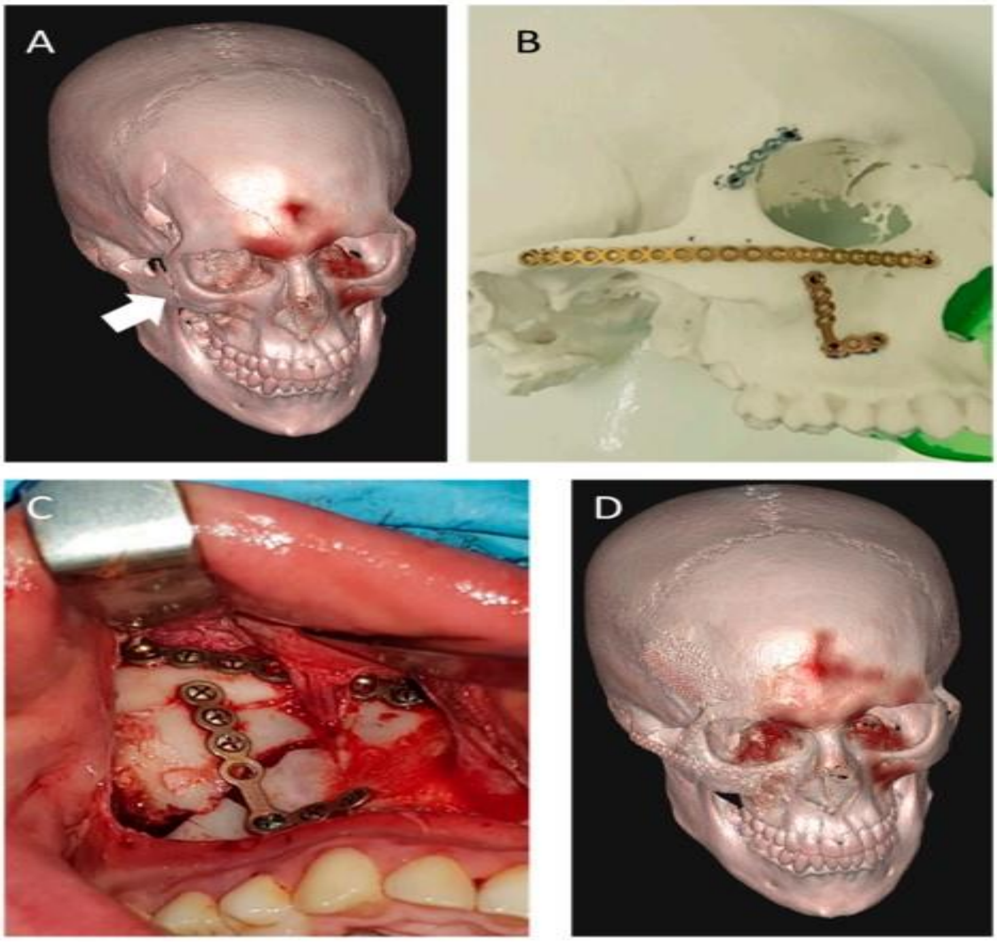


figure 10: 3D design and printing for midface reconstruction. Volumetric representation of a zygomatic complex fracture (white arrow) is obtained, followed by mirroring and pre-bending reconstruction plates based on a 3D printed model (A,B). Intra-operative installation of pre-bent implants (C) and 3D visualization of the postoperative result (D).[107]

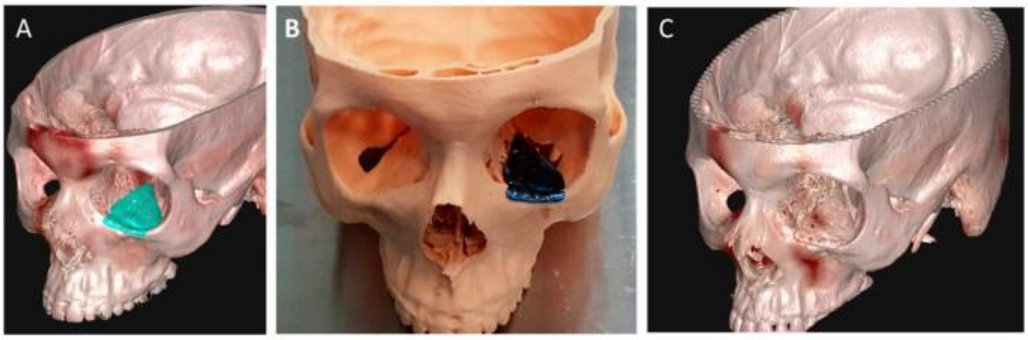


Figure 11: PSI design and 3D printing used for orbital floor reconstruction. VSP-based mirroring is utilized to design PSI for orbital floor reconstruction (A). Designed titanium implant fabricated via SLS 3D printing (B). Post-operative 3D imaging depicts accuracy of implant adaptation to the damaged anatomy (C).[107]

B. Mandible fracture

To assess the extent of his injuries, a standard maxillofacial CT scan , After the consultation was complete, the DICOM files from the CT scanner were transferred to a compact disk and loaded onto our CAD/CAM computer within our 3D printing lab. The patient's occlusion was reestablished virtually to aid in reduction of the fractures, essentially a virtual Maxillomandibular fixation. The mandible was then printed according to the protocol described above[108] . Two locking reconstruction plates were preoperatively adapted to the 3D printed mandible. Once the patient was taken to the OR for definitive reconstruction, the fractures were all exposed in standard fashion. The mandibular bone was reduced, and the pre-bent mandibular reconstruction plates were applied with near perfect adaptation. The incisions were closed in standard fashion and a postoperative CT scan was ordered. The final result obtained was overlaid to our preoperative virtual plan to assess how accurately we executed the surgery using Geomagic Design X (3D Systems, Rock Hill, SC, USA).

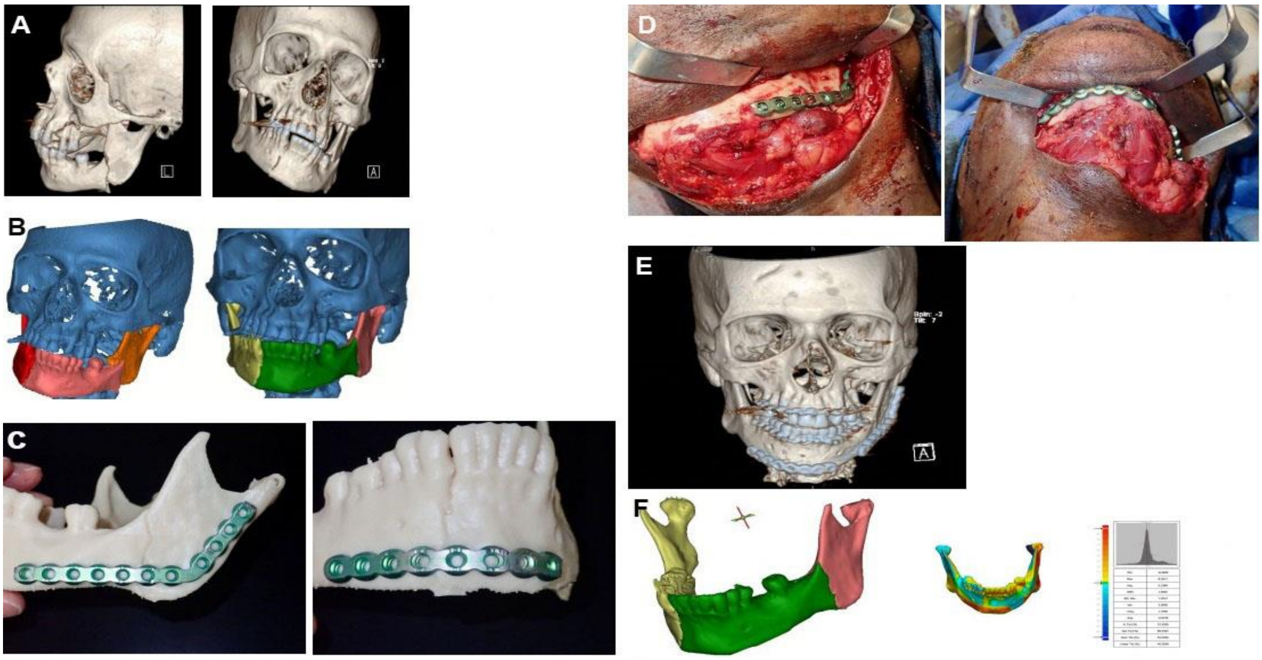


Figure 12: Representative case. A 48-year-old male who suffered mandibular fractures: (A) preoperative CT scan; (B) (Left) segmentation of fractured mandible and (Right) virtual reduction of mandible; (C) 3D-printed reconstructed facial bones with preoperatively bent reconstruction plates; (D) transcervical approach to the mandible to expose both fractures; (E) postoperative CT; and (F) (Left) preoperative plan and (Right) heat map of merged postoperative result and preoperative plan. Areas cold in color (blue and green) represent areas of high accuracy, while areas of hot color (orange and red) represent areas of relative lower accuracy.[108]

1.4.1.4 Orthognathic surgery

Orthognathic surgery is a corrective surgery, aiming to restore the proper anatomic and functional relationship in patients with dentofacial skeletal anomalies. The classic approach involved using an articulator and dental casts to transfer the skeletal relations, mock surgery on the casts based on our measurements, and acrylic wafers as guides in the operation room for repositioning of the jaws. Nowadays, 3D preplanned waferless operations can be used for performing accurate osteotomies and perfect positioning of the unaligned jaw.

Three-dimensional printing of cutting guides for the osteotomies and 3D printed patient-specific fixating plates for accurate final positioning of the jaws, based solely on the 3D preoperative planning, greatly reduce the incorporation of human errors (Figure 13).20 Intraoperative 3D printed dental splints for accurate repositioning of the jaws/midface based on 3D preoperative planning can also be prepared in cases where patient- specific fixating plates are not an option (Figure 14).[109]

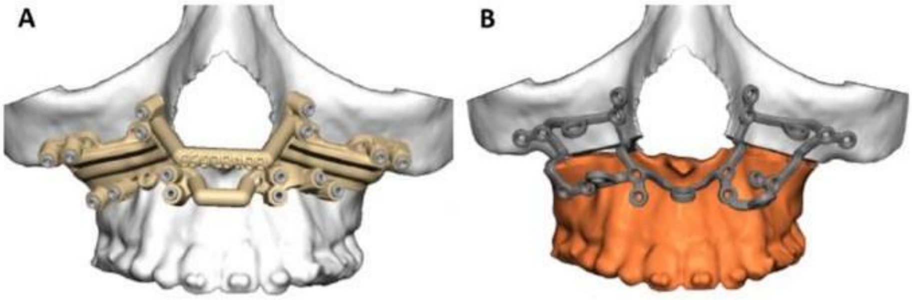


Figure13: cutting guide in orthognathic surgery[109]

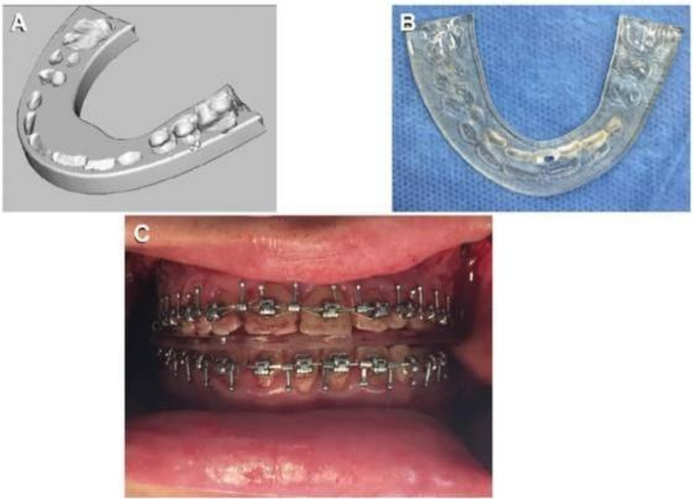


Figure14: (a) 3Dplaninng of the splint, (b)the printed splint, (c) interoperative positioning of the jaw according to the splint.[109]

1.4.1.5 TMJ Models

3D printed TMJ anatomical models provide details of the hard and soft tissues of the TMJ in normal and pathological situations. These models make TMJ surgeries simpler and more convenient for the surgeon and the patient.

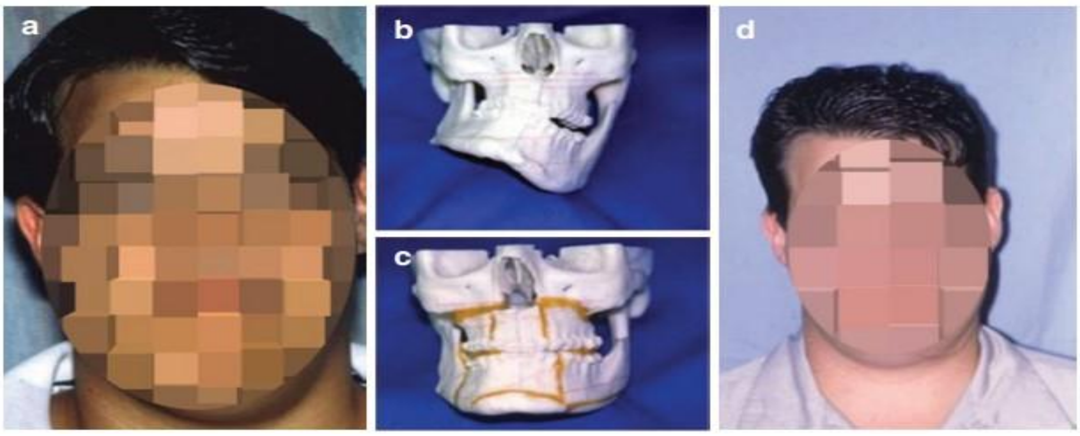


Figure 15 : Patient with facial asymmetry caused by an osteochondroma in his left TMJ. (b) SLA facial model of the patient. (c) Facial model after the simulated surgery. Osteotomy segments are luted with wax in their new positions. (d) The same patient with signifcantly improved facial symmetry and contouring. Reproduced from [110].

In 2011, **Mehra et al**. [110] reported the reconstructive surgery of a 26-year-old male patient with facial asymmetry caused by an osteochondroma in his left TMJ

1.4.2 Endodontic treatment

Guided access opening

novel treatment approach for root canal treatment of teeth with pulp canal calcified and apical pathology using special drills and surgical templates were introduced. In a 15 year old male patient with history of pain in upper right lateral incisor which showed signs of apical pathology and canal calcification it was anticipated that because of pulp canal calcification root canal location would be difficult and there was a high chance of perforation. CBCT and Intra-oral scan was done and combined using virtual implant planning software. A special drill was designed for root canal location. Its position was planned, virtual template was designed, exported as STL file and sent to a 3D Printer. The template was placed on the anterior maxillary region, a special drill was used to penetrate through the obliterated portion of the root canal and obtain minimally invasive access to apical portion. Root canal was accessible at 9mm distance from apex and further root canal preparation was done using endodontic rotary instrumentation system. After 15 months patient was examined and there were no signs of pain on percussion and radiographs showed no signs of apical pathology (fig.16). This study concluded that guided endodontic approach seems to be a secure, clinically possible method to locate root canal and avoid perforation in teeth with pulp canal calcification (112).

In addition, 3D printed resin teeth are useful in educating students and general practitioners in all steps of the root canal therapy. The trainee can observe endodontic working length, root canal morphology and anatomy of the apical delta, using trans- parent resin teeth constructed using CBCT data derived from extracted natural teeth. During canal shaping, errors associated with the use of endodontic instruments, such as gauging of preparation walls and canal transportation may be readily observed.[113,114]

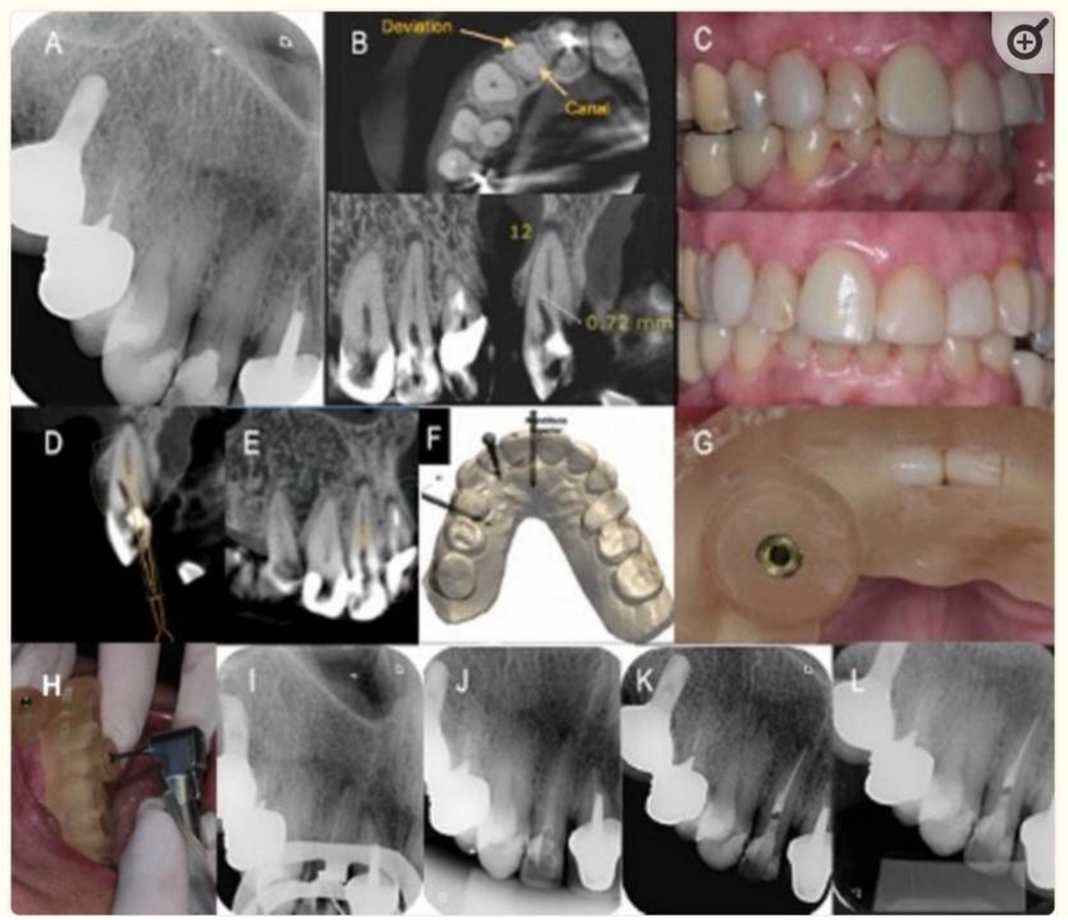


Figure 16 : A) Preoperative radiographic image showing partial obliteration and perapical bone resorption; B) CBCT axial, coronal and sagital images showing periapical bone resorption, partial obliteration of the root canal and buccal deviation; C) Discolored maxillary lateral incisor: frontal and lateral views; D, E, F) 3D root canal planning; G, H) The prototyped surgical guide; 1) #15 K file in the working length; J) Intracanal dressing with calcium hydroxide after instrumentation; K) The final radiograph; L) The radiograph at 12-month follow up[112]

1.4.3 Periodontic Treatment

Excessive gingival display, which can be due to altered passive eruption (APE) or gingival enlargement, results in short clinical crowns; this is a cause of common esthetic concern for many patients. Gingivectomy or esthetic crown lengthening with bone resection is often required to increase the clinical crown length and achieve acceptable esthetic outcomes [115].

The decision whether to perform bone resection is largely dependent on the location of the alveolar bone crest in relation to the cementoenamel junction. If the bone crest is at, or coronal to, the cementoenamel junction, then osseous resective surgery is indicated [116]. In order to locate the bone crest, bone sounding and periapical radiograph assessments are typically performed [117,118] However, these methods may be challenging and could provide inaccurate assessments [119].

Cone beam computed tomography (CBCT) has been suggested as a precise and reliable alternative approach for diagnosing APE [120]. To achieve adequate esthetic results, A recent report described a digital workflow in which digital waxing was used to design the surgical guide for crown lengthening [121].

A 22-year-old female patient Upon initial examination the patient did not show any gingival tissues at rest, however on full smile, 4 mm of gingival band was shown below the lower border of the maxillary lip.

Figure17: preoperative smile view

Furthermore, there were no significant findings on the extra-oral examination and patient was normally asymmetrical. The facial three thirds were analyzed and found to be normal. A lateral cephalometric analysis confirmed absence of vertical maxillary excess and dentoalveolar extrusion. The maxillary lip length was 19 mm, the incisal display at rest was 4 mm, and the lip mobility was also assessed and found to be 6 mm. The clinical crown lengths of central incisors, lateral incisors, and canines teeth were 8 mm, 7 mm, and 8 mm, respectively.

A CBCT scan was acquired to analyze the level of the alveolar bone was acquired to analyze the level of the alveolar in relation to the cementoenamel junction. The radiographic parameter Based on the sagittal cross section of the maxillary anterior teeth show the level between the bone crest and the respective cementoenamel junction was at a maximum of 1.04 mm (Figure 18). the patient was diagnosed with excessive gingival display as a result of altered passive clinical findings, the patient was diagnosed with excessive gingival display as a result of altered eruption APE

Figure18: Distance form bone crest to CEJ[121]

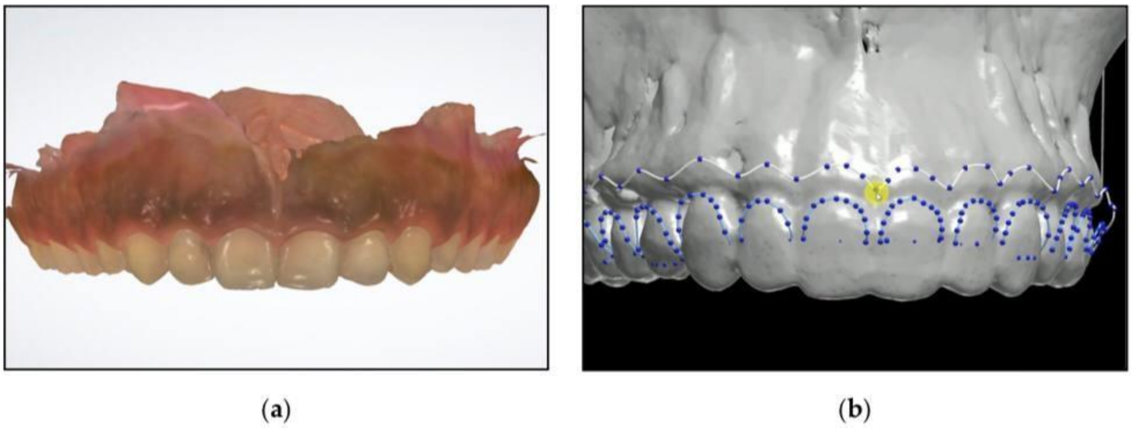

(a) (b)

Figure19 : (a) Intraoral scan of the maxillary jaw; (b) After superimposition of the CBCT and the intraoral scan, the cementoenamel junction and future bone level marked. [121]

Figure20: 3D printed surgical guide. [121]

Figure21: surgical incision based on the guide. [121]

Figure22: tooth length after gingival incision. [121]

Figure23: Mucoperiosteal flap elevated. [121]

Figure24: surgical guide placed to determine level of osteoectomy. [121]

Figure25: Smile view after six months. [121]

1.4.4 Orthodontic Treatment

Orthodontic appliances and orthotics 3D printing provides exciting opportunities for fabricating tooth-fitting orthodontic devices such as Invisalign® aligners [122]. Aligners are popular alternatives to braces for treatment of mild malocclusion because they are transparent and can be removed for eating, drinking and tooth brushing. In 3D printing of clear aligners, the orthodontist takes a virtual impression of the patient’s upper or lower arch using an intraoral scanner. Stereolithography or FDM is then used to print the model for thermoforming the aligner. 3D printing reduces production time without altering the quality of the aligners. This acceleration is attributed to the reduction in manufacturing steps (Fig. 26).

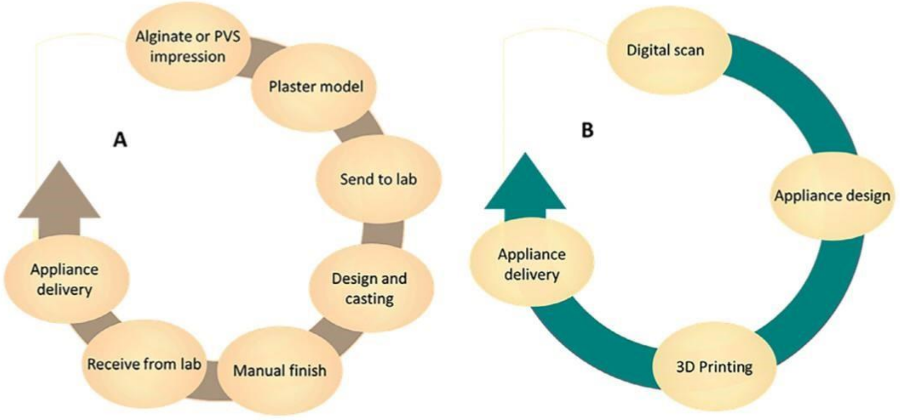


Figure 26: Designing an aligner. (A) Steps involved in conventional processing (B) Workflow in 3D printing.[122]

1.4.5 Prosthodontics Treatment

It is undisputed that 3D printing has a great potential for prosthetics, as doctors can prepare, scan, and print their teeth in a session in clinically relevant situations, saving time and money [123].

1.4.5.1 Crown and Bridge Dentures.

The use of interim crowns is a transitional phase of fixed dentures, which should fulfill mechanical, biological, and esthetic requirements [123]. They have several functions. For example, interim crowns ought to protect periodontal tissues, reduce slight movement of teeth, and maintain occlusal function [123]. The traditional method highly relies on the skills of the operator, and voids created during material mixing can weaken the mechanical strength of manually manufactured temporary crowns, which may eventually lead to fractures [124]. Moreover, there are inherent limitations in machining tools and material properties [127,126]. Crown and bridge dentures can be fabricated using resinbased 3D printing technologies such as SLA or DLP [125,126]. Compared with milling, the amount of materials used in 3D printing technologies is less, with almost no material loss [126].

Furthermore, it can print a variety of materials simultaneously with favorable detail reproducibility [127]. Wang et al. found that the external trueness of 3D printing crowns was not less authentic than the actuality of the corresponding milled crowns (Figure 27) [128]. Temporary crowns fabricated using 3D printing were found to have excellent edges and internal fit, which are more accurate than traditional milling methods [128].

Figure27: temporary crown [124]

1.4.5.2 Removable Partial Denture Frameworks.

Accuracy and mechanical properties are the most important factors to be considered in dentistry. Compared to conventional casting , additive manufacturing of metal parts reduces manufacturing time and cost. More importantly, AM almost eliminates all human errors as well as possible defects in the resulting product. According to the definition of the American Society for Testing and Materials (ASTM), ASTM F2792, AM is “a process of joining materials to make objects from 3D model data, usually layer upon layer, as opposed to subtractive manufacturing methodologies” [129]. Selective laser sintering, selective laser melling (SLM) are the most commonly used techniques for 3D printing of metal parts [130].

The use of 3D printing technologies to manufacture RPD enables the denture base to provide more uniform contact pressure and then reducing the risk of long-term bone resorption. **Tregerman** [131] found that when SLM Co-Cr alloy frames were compare with cast or milled RPD frames, the former is regarded as having improved organization and mechanical properties.fig.28

Scanning

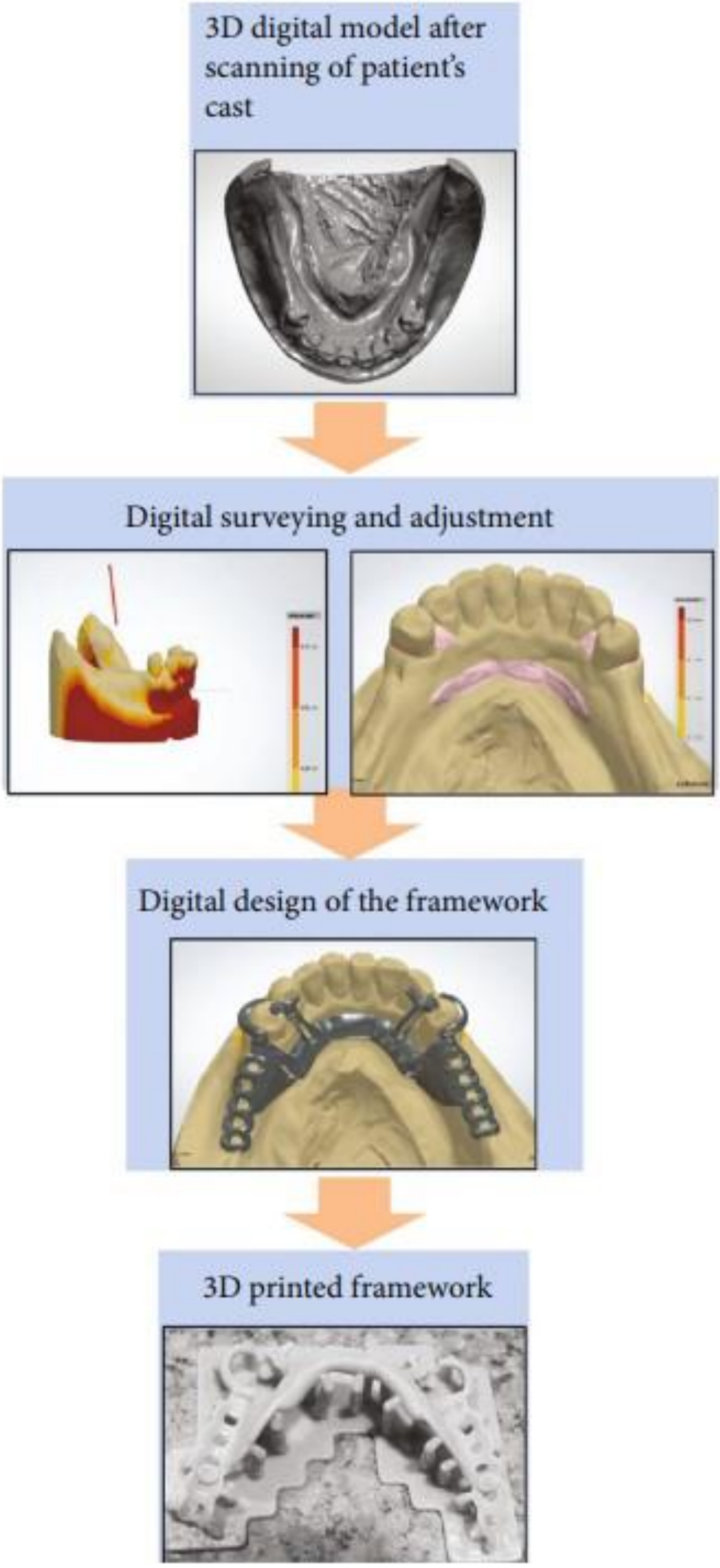


Figure28: The computer-aided design (CAD)/computer-aided manufacturing (CAM) process of constructing a partial prosthesis framework. (Images from the study of Harb et al. [130]

CHAPTER TWO

Conclusion and Suggestions

In order to select best 3D printer the dentist should choose a suitable printer according to cost or most important application that need in clinic. So when we need to print a high accurate object like surgical guide , temporary crown and orthodontics Invisalign you have three choose either SLA which high accurate but time to print is slower than DLP and expensive the second choose are DLP which little less accurate than SLA but the printed speed is very fast and this technology is very expensive the last one is LCD technology which have high accuracy and fast printing speed and low cost .the LCD technology is best for the beginner.

when we need to print object which accuracy is not important like mandible model , skull ,study model for educational purposes to students the best is FDM technology because material is cheap and printer also low price and can print large objects.

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