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Current Trends In 3D - Printing Technology And It's Applications In Orthodontics – A Review

Research Article

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Abstract

Recent advances in3D- Printing technologies haspermitted a widespread distribution in the usage in different fieldof dentistry. 3D printing technology is fetchingcollectiveplace in biomedical applications which requires the custom made fabrication of prostheses and appliances related to patient-specific anatomy. Conventionally, the work comprehensivelyrelieson less accurate alginate impressions, which were turned into stone models of and surrounding structures of oral cavity. These models are used forfabrication of orthodontic appliances. Orthodontic appliance manufacturing is an exceptionallydifficult process that requires a high level of skill to accurately complete and provide the patient with optimal results. Digital technology reduces price, heavy workloads and human errors by automation of dental model fabricating process with 3D printing. This new technology also increases accuracy and efficiency. 3D printing also helps eliminate potential deficiencies and increased appointment alternatives through digital dentistry. This allows for more patient appointments, time management and a prospective increase of revenue in treatment outcome.This article provides recent trends and updates of application of 3-D printing in orthodontics.

Keywords: 3D Printing; Digital Technology; Orthodonticappliances.

Introduction

A 3Dimensional object was printed for the first time by Charles Hull in the year 1983.Hull invented 3D printing which he named "stereolithography". 3D printing was founded in 1990 by WilfriedVancraen, CEO and Director of Materialise NV, the first Rapid Prototyping sector company in the Benelux region[1]. 3D printing technology allows the user to create or print the 3Dimensional physical objects, prototypes, and production parts of any shape or form a virtual digital model in a developingvariety of materials including plastic material, cobalt, nickel, steel,aluminum, titanium, etc. Those materials are joined in successive layers one on top of the other through additive processes under automated computer control. The 3D printing process usually initiates with a 3D model, virtually obtained through scanning of a physical object. The Slicing software automatically transforms the point cloud into a stereolithographic file which is transferred to the additive manufacturing machine for building the object.Today, 3D printing has grown to be competitive with the traditional model of manufacturing terms of reliability, speed, price, and cost of use. In comparison with other technologies, additive manufacturing is more effective due its ability to use readily available supplies, recycle waste material, and has no requirements for costly tools, molds, punches, scrap, milling, or sanding.Three-dimensional printing is becoming commonplace in medicine for custom fabrication of prostheses to replacement of the missing tissues[2]and to provide scaffolding for tissue engineering.Even though subtractive manufacturing has long been the technology of choice in dentistry. Orthodontists are already familiar with several products that use 3D printers, including Invisalign and Clear Correct strau-

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mann group manufacturing company.Computer-aided design and manufacturing (CAD/CAM) software is used to process the file and prepare it for printing. The software then breaks down the objectinto small layers of 17-300 microns each, known as build layers. The time required to produce 3D models depends on the number of layers being printed the vertical height of the model, than the number of models being printed. Every 3D printer requires a computer workstation set up for the print job to build a custom tray for fabrication of the modeland print medium, which is either relaxed from a spool, distributed from a sealed container. The print medium may be any of a number of materials, including plastic, metal, clay, sand, and even human cells, each of which is best suited to a specific types of printers.

Materials And Methods

The electronic databases Scopus, PubMed, Google Scholar, Science Direct, Cochrane Library along with a complimentary manual search of all journals. No limits and language restriction were applied during the electronic search in order to include all the relevant articles pertaining to the topic of interest. Only one relevant article could be extracted through hand search and no articles were retrieved from other databases.

Different Types Of 3-D Printing Technologies

Fused Deposition Modelling (FDM)

Fused Deposition Modeling (FDM) is a 3D printing technique pioneered in the 1990s by Stratasys. The company continues to be a leader in manufacturing 3Dprinters all over the world including India. Alternatively, the 3D printers that are based on this technology are also called as Fused Filament Fabrication (FFF), Plastic Jet Printing (PJP) or material extruding printers, which is the generic name for these 3D printers. The 3D printers that work on FDM technology consist of the printer platform, a nozzle also called as printer head and the raw material in the form of a filament. The printer platform bed is typically made of some metal, ceramic and each successive layer is deposited on this platform. All the movements of the head and the raw material are controlled by a computer set up. The thermoplastic material is capable of being constantly melted when exposed to heat and re-solidified when the heat is inhibited. The thermoplastic filament or metal wire is coiled on a mounted spool. It is then provide through the printer nozzle. The better class of 3D FDM printers allows the temperature of the nozzle to be maintained just close to the glass transition temperature of the material being extruded. This allows the material to form in a semi-liquid state, but return to solid state immediately. This results in a better dimensional accuracy.Commercially, a few of the popular choices of raw material include nylon, Acrylonitrile Butadiene Styrene (ABS) and its variations, polycarbonates, ply-lactic acid, polystyrene and thermoplastic urethane. When the FDM printer begins printing, the raw material is extruded as a thin filament through the heated nozzle. It is deposited at the bottom of the printer platform, where it solidifies. The next layer that is extruded fuses with the layer below, building the object from the bottom up layer by layer. Most FDM printers first print the outer edges, the interior edges next and lastly the interior of the layer as either a solid layer or as a fill in matrix. FDM printers incorporate a mechanism whereby these support structures (called struts) are printed along with the object. They are later removed once the build is complete. They are later dissolved by an

3D Printing and its Application in Dentistry

1	Replica of Anatomical items	• Dental 3D printing allows dentists to create high quality replications of anatomical items, such as a three-dimensional dental model of the patient's jaws[4]. • This permits dentists to obtain a better understanding of a patient's anatomy before emerging a surgical approach, minimalizing the risks that might occur during surgery. Dentists can create new methods and procedures for surgery viewing the mandibles and jaws created by 3D printers. • The application of 3D printing has become conventional, as the high quality image data provided by CBCT can be imported to the 3D printer to create a perfect replica of the patient's jaws
2	Surgical guides	• 3D printers can create drilling and cutting surgical guides to make the surgery process easier for dentists. Surgical guides allow dentists to create a digital 3D surgery plan that guides them through the whole implant procedure
3	Dental Implants	• Dentists have been using 3D printers to create dental implants. 3D printers have the ability to print complex geometries, such as bone-like morphology, with the bone tissue tailor-made to the requirement of each patient and it can act as biomimetic scaffolds for bone cell enhancement. In addition, dentists use 3D printing to create maxillofacial dental implants.
4	Crowns and bridges	• For fixed crowns and bridges, dentists could use 3D printers to indirectly print in burn-out resins or waxes for a lost-wax process, directly in metal alloys. Verifying the fit on, before cementing them to a patient's teeth is often analytically important. With the help of intraoral optical scanners, dentists could develop a precise virtual model of the patient's teeth to test the fit of prosthodontics treatment. This scan data is then used with CAD design to mill or print crowns and bridges
5	Equipment manufacture	• 3D printing has accelerated the development of new and innovative dental equipment. Dentists could use 3D printers to create prototypes of their product ideas quickly, test them, and make adjustments.

solvent. Finally the materials are able to produce build body parts.

Selective Laser Melting (SLM) and Selective Laser Sintering (SLS)

The direct metal laser sintering process (DMLS) is controlled by a computer which initiates the laser to to print theshape, stirring across the powder to trace a cross-section of the product. The Laser pulsates to heat up the metal powder, to just below melting point and this is known as metal Laser sintering, or just above melting point which is known as selective Laser melting.This metal sintering or melting process fuses the powder together and creates a solid form. Once this first layer has been established, the printer platform drops, typically by no more than 0.1mm to expose a new layer of powder and the whole process of first tracing, then heating begins again. The 3D printing process works very well, and the results are of a very high quality material. There may be some small differences in the metal powder used. 3D printing Laser sintering never actually consolidates the material; instead, the Laser simply allows the particles to merge. Unlike the direct metal Laser sintering process, melting actually creates a pool where the materials can consolidate before reforming and hardening to create a new solid structure. One of the reasons melting may be chosen over 3D printing sintering is that the final substance won't be porous, thereby making it more suitable for a greater range of applications(Fig 2). If having a porous material, direct Laser sintering will give you the results you want too.

SLM/SLS have found an acceptance for production of orthopedic and dental implants, dental crowns and bridges, partial denture frameworks, and bone analogs[6] .

Electron Beam Melting (EBM)

Electron beam melting (EBM) is a 3D printing technology that, at first glance, appears very similar to SLS 3D printing. However, closer inspection reveals that EBM differs in several ways. The most significant differences are that the energy source comes from an electron beam instead of a CO2 laser and that the material used is conductive metal instead of thermoplastic polymer. In particular, EBM often uses titanium alloys and its not capable of printing plastic or ceramic parts. That's due to the fact that the technology is based on electrical charges. They are what produce the reaction between powder and electron beam, causing the former to solidify

Before the printing process can begin, the powder bin is filled with themetal powder. The powder bin is placed into the 3D printer, and the internal pressure is set to around 0.0001 mBar- that's around 10 million times less than atmospheric pressure. When the desired pressure is achieved in the build chamber, the electron beam is fired up, heating the build platform to high temperatures. Interestingly, while high part temperatures are undesirable, high surrounding temperatures have a "stress relief" effect on the parts, helping to reduce the amount of distortion. This is a unique benefit only present with electron powder bed fusion systems.When parts are finally finished, the powder bin is taken out of the 3D printer. Afterward, EBM parts can be polished, coated, or machined using traditional techniques. EBM is able to form extremely porous mesh or foam structures in a wide range of alloys including stainless steel, titanium, and copper. The technology is commonly used in orthopedic and oral and maxillofacial surgery for manufacturing customized implants (Fig 3). Their structure permits the ingrowth of bone, provides better fixation, and helps to prevent stress shielding[7].

Stereolithography (SLA)

Figure.1: Fused Deposition Modelling

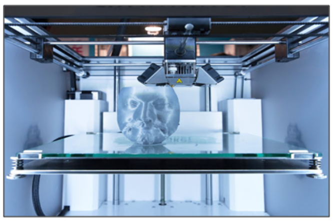
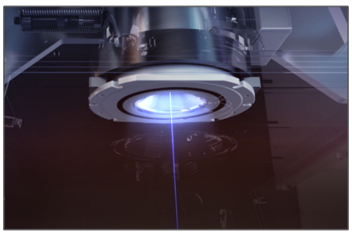


Figure. 2 :(a) Selective laser sintering in progress. (b) Printed metal crown copings

Figure 3: Electron beam melting Process



Stereolithography (SLA) is an additive manufacturing process that belongs to the Vat Photopolymerization family. In SLA, an object is created by selectively curing a polymer resin layer-by-layer using an ultraviolet (UV) laser beam. The materials used in SLA are photosensitive thermoset polymers that come in a liquid form. SLA is famous for being the first 3D Printing technology: its inventor patented the technology back in 1986[8]. If parts of very high accuracy or smooth surface finish are needed, SLA is the most cost-effective 3D printing technology available. Best results are achieved when the designer takes advantage of thebenefits and limitations of the manufacturing process. SLA has many common characteristics with Direct Light Processing (DLP), another Vat Photopolymerization 3D printing technology. For simplicity, the two technologies can be treated as equals.SLA models are currently used for planning cranial, maxillofacial, and neurosurgical procedures and constructing highly accurate replicas of human anatomy, customized implants, cranioplasties, orbital floors, and onlays.

3D Polyjet

Polyjet (short for 'photopolymer jetting') 3D printers are a subclass of the Material Extruding / Jetting 3D Printers category. Material jetting is the name for any 3D printing technology that jets a liquid (the build material) from a print head, which is then solidified by UV light. In most material jetting processes, the build material is a photopolymer. Stratasys, which is the leader in FDM 3D printing technology the world over, has acquired Objet to offer PolyJet (or PolyJet Matrix) printers[10].

PolyJet 3D printers deliver high quality, multi-material printing and that too in multi-colour form.At the core of PolyJet printers are the jetting heads. The jetting heads deposit a single layer of the build material (typically photopolymers) by sliding to and fro along the X axis. The depth of each layer of photopolymer deposited by each jetting head is selectively controlled by software. Raster scanning the head across the build platform delivers the capability to produce precise models .

There are four important advantages of PolyJet 3D printers

- There can be a number of jetting heads that allow different build materials to be ejected at the same time. This makes it possible for 3D PolyJet printers to produce an object with different levels of flexibility in a single build. PolyJet 3D printers hence are useful to build complex objects with a smooth finish.
- As 3D PolyJet printers have multiple jetting heads, they allow for using photopolymers with different colours in a single build. You can therefore build multi-coloured objects easily.
- Since the build platform is typically lowered after an iteration of layer, there is more control over accuracy. High quality 3D PolyJet printers have an accuracy of 16 microns (0.016 mm). This allows for excellent detailing. Once a model is complete, it is perfectly structured and does not require additional curing or processing. If a support material is used, it is easily removable. In most cases, it can be simply washed off with water.
- There is a wide choice of raw material that is available for printing. At present, there are more than 100+ types of build material available for 3D PolyJet printers, and their number is increasing.

Digital Light Processing (DLP)

Digital Light Processing (DLP) is a type of nanotechnology that uses a digital micromirror device as a power source projector to cure liquid resin into solid 3D objects. DLP is similar to stereolithography as the method also employs light polymerization. One difference is that DLP creates a single layer as one digital image in tiny volumetric pixels as opposed to SLA's laser process which must scan the vat with a single point. DLP printing is faster and can build objects with a higher resolution,(Fig 6) typically able to reach a layer thickness of fewer than 30 microns. Furthermore, DLP can produce objects with a wide variety of properties such as high clarity, spngness, flexibility, water resistance, thermal resistance, and durability. The photopolymers have been designed to mimic ABS, polypropylene, and wax, blending layers together much more smoothly than plastic filament is able to.

However, photopolymer prints can becomebrittle with increased light exposure over time. Objects may begin to show cracks and

Figure 4 :Stereolithographic 3D printing Digital machineSurgical guides for dental implant placement are routinely produced bystereolithography[9].

Figure 5 :PolyJet printers a) Stratasys J700 Dental 3D Printer

become more susceptible to breaking. The DLP process can only use one material at a time since the object is built out of a vat containing a singular photopolymer solution. Post-print processing involves washing away the remaining resin and removal of the supports by snapping or cutting. DLP-based technologies are found in such diverse applications as movie projectors, cell phones, video wall, digital cinema, medical, security, and industrial uses[11] .

Laminated Object Manufacturing (LOM)

Laminated object manufacturing (LOM) is a process that combines additive and subtractive techniques to build an object. It works by successively layering sheets of material one on top of another and binding them together using adhesive, pressure, and heat application. Once the process is complete, objects are cut to desired dimensions with a knife, a laser, or additionally modified by machine drilling. The technology is able to produce relatively large parts since no chemical reaction is necessary. The most common materials used in LOM are plastics, paper, ceramics, composites, and metals which are widely available and yield comparatively inexpensive 3D printing method (Fig 7). Materials can be mixed in various layers throughout the printing process giving more flexibility in the final outcome of the objects. Paper models have a wood-like texture and characteristics and can be finished accordingly. Surface accuracy is slightly inferior to stereolithography and selective laser sintering. LOM systems are used in sand casting, investment casting, ceramics processing, for concept modelling, and architectural applications[12] .

3D Printers Used In Orthodontics

The global additive manufacturing industry has been dominated by three large companies: Stratasys, Ltd. (Eden Prairie, MN), 3D Systems (Rock Hill, SC), and EnvisionTEC (Gladbeck, Germany), with market shares of 57%, 18%, and 11%, respectively [13] .As of January 2014, Stratasys sells 3D printing systems that range from $5,000 to $900,000 in price and are employed in several industries: aerospace, automotive, architecture, defense, medical and dental, among many others (Figure 22). MakerBot and Objet are the 3D printers recently acquired by Stratasys and currently used in dentistry and orthodontics. For example, ClearCorrect employs Objet in the aligner manufacture process while Invisalign uses the 3D Systems' SLA technology. Other companies like Concept Laser (Lichtenfels, Germany), Realizer (Borchen, Germany), and SLM Solutions (Lübeck, Germany) are also offering printing technologies and new materials to be used in dental 3D printing. Furthermore, a broad line of innovative professional 3D printers, orthodontic practical solutions, and price points exist for generating full-color parts, wax patterns, and investment castings. (Table.1) summarizes some of the characteristics of several 3D printers used in orthodontics[14].

3D Printing Technology In Orthodontics And Dentofacial Orthopaedics

Diagnostic And Working Model In Orthodontics

Diagnostic and Orthodontic models 3D printing technology may be used in orthodontics to manufacture models of patients' dentition. Increasing popularity and growing application of intra- and extraoral scanners and digital dental models, contributes to a significant decrease in a need to acquire alginate impressions and casting plaster models, thereby allowing avoiding drawbacks of conventional orthodontic models. Digital models may be used for orthodontic diagnostic purposes (Fig 8). Diagnostic measurements performed on digital models represent high validity, reliability, and reproducibility, and thus may be regarded as an equal alternative to conventional plaster models. Although in cases, in which manufacturing of orthodontic appliances is planned, a physical model of patient's dentition is required. 3D printing enables to transform digital, virtual dental model of patient's dentition into a physical model, omitting certain steps, which are conventionally required, including impression taking and model casting. Moreover, rapid prototyping technology allows to manufacture many identicalcopies of a digital model without any risk of distortion or deformation, being available at any time. Kim et al.[15] investigated precision and trueness of selected diagnostic measurements performed on scans of models, which were printed with 4 technologies including SLA, PolyJet, DLP, and FFF. The results of the study revealed statistically significant differences between measurements taken on models printed with all 4 methods. Measurements on PolyJet and DLP models had higher precision than for SLA and FFF models. The differences for tooth widths,

Figure 6 : Digital light processing Unit.

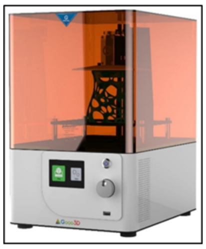
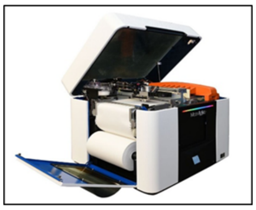


Figure 7 : Laminating processing manufacturing machine



tooth heights, and arch width measurements. acceptablefor orthodontic diagnostics.Camardellaet al.[16] investigated the influence of the design of a model base on the accuracy of models printed with stereolithography and PolyJet technology. The researchers assessed 3 types of model bases: regular ABO (American Board of Orthodontics) base, horseshoe-shaped based, and horseshoe-shaped base with a transverse bar. Horseshoe-shaped bases are frequently designed in models used to manufacture thermoformable orthodontic aligners, thus the assessment of their accuracy is of significant.clinicalimportance.These differences were not observed for PolyJet printed models

Removable Orthodontic Retainers

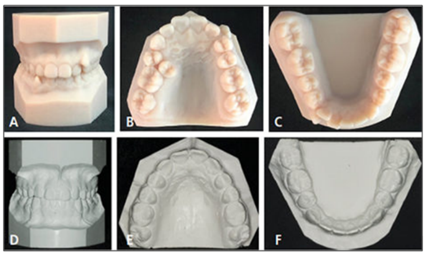
Computer-aided design and 3D printing open new possibilities in orthodontics to manufacture customized removable retainers. The procedure has been presented and described[17]. The pro-cess integrates the application of new technologies, including cone beam computed tomography (CBCT), CAD and 3D printing. The first step in the procedure is scanning patient's dentition using CBCT and image conversion into a STL file to create a 3D model of patient's dentition. Followingimporting the file into dedicated software (Zbrush 4R4, Pixologic, Los Angeles, California), the Essixretainer is designed virtually (Fig 9). The virtual project representing the retainer is (upon acceptance) manufactured by printing and Formiga P100 3D printer (EOS, Munich, Germany). The printer applies SLS technology. The printing material used was a fine polyamide PA 2200 (EOS). A certain disadvantage of the material used may be its white opaque color. The application of stereolithography technique would allow to use another printing material, achieving an ideal transparency. Another disadvantage of SLS, named by authors, are high costs and still low availability. However, according to the authors, the described method may be successfully used with other 3D printing technologies and materials.

Removable Orthodontic Appliances

Table 1 : Different manufacturer 3D printers currently used in orthodontics

Features	Objet30 OrthoDesk	ProJet® 3510 MP	ULTRA® 3SP™ Ortho	Perfactory® Micro Ortho	MakerBot Replicator 2	FORMIGA P 110
Company	Stratasys Ltd., Eden Prairie, MI	3D Systems, Rock Hill, SC	EnvisionTEC, Gladbeck, Germany	Envision-TEC, Gladbeck, Germany	Stratasys, Ltd., Eden Prairie, MI	EOS, Munich, Germany
Technology	PolyJet Printing technology	PolyJet Printing technology	Digital Light Processing	Digital Light Processing	Fused Depositing Modelling	Selective Laser Sintering
Build Volume	300 x 200 x 100 mm	298 x 185 x 203 mm	266 x 177.8 x 76 mm	100 x 75 x 100 mm	285 X 153 X 155 mm	200 x 250 x 330 mm
Layer Thickness	0.0011 in	0.001-0.002 in	0.00098 in	0.0039 in, 0.002 in, 0.004 in	0.0039 - 0.0133 in	0.0024 in, 0.0039 in, 0.0047 in
Applications	High quality orthodontic models, surgical guides, temporary intraoral appliances and restorations	Drill guides, jaw models, orthodontic thermoforming model	High quality orthodontic appliances	High quality models for the fabrication of orthodontic appliances	Retainers and aligners with less aesthetic appearance due to stair-stepping	High quality retainers and orthodontic appliances
Weight	93 kg	323 kg	90 Kg	13 kg	11.5 kg	600 kg

Figure8 : Compare of 3D Printed orthodontic study models fabricated with a three dimensional printer (A, B, C) with traditional plaster study models (D, E, F).



First trials to manufacture removable acrylic orthodontic appliances using computer-aided design and 3D printing have been made and presented. A machine dedicated for this particular purpose has been used to add and polymerize layers of acrylic, which were added according to the computer design of the appliance. The screws and wires however needed to be placed manually onto the working model, their incorporation in the virtual design and manufacturing process has been reported not to be possible at that time. A procedure was described aboutAdresen activator and sleep apnea appliance fabrication using computer-aided design and additive manufacturing technology[18](Fig10). The first step in the procedure was digitalization of plaster models of patient's dentition using a laser scanner. Construction bite and virtual appliance design was made using CAD software (FreeFormModeling Plus, version[11].

The acrylic baseplate of the appliance has been designed. The design involved modlling of a palatal plate, bite blocks covering occlusal surfaces of mandibular, and maxillary teeth to form a monoblock and anterior capping covering lower incisors. The labial bow was bent manually in a conventional way, with 0.9 mm stainless steel wire. To incorporate the labial bow into the acrylic, the authors designed special guiding jigs, which enabled precise positioning of the wire in the acrylic plate. Manufacturing process of the virtually designed activator was held using stereolithography machine (SLA 250-50; 3D Systems). Following printing, the appliance was cleaned in isopropanol solvent (99%) and support structures were removed. Post-curing was achieved by ultraviolet light polymerization to increase the degree of polymer conversion. The next development in the field was fabrication of Hawley retainer with CAD and 3D printing. Al Mortadiet al.[19] presented Hawley retainer manufacturing using intraoral scans obtained with TRIOS (3Shape, Copenhagen, Denmark), eliminating the need of conventional impression taking and pouring plaster models. During the stage of creating virtual appliance, the shape, thickness and range of acrylic base plate, fitted labial bow, and Adams clasps was designed. Wire elements were bent using cobalt-chromium alloy with 3D printing technology. The Removal Orthopadeic Functional appliance was fabricated form ClearVue resin material (3D Systems), implementing stereolithography(Fig10). Nowadays, 3D printing technology allows to manufacture wire elements, including labial bows and clasps form metal alloys and to incorporate those parts into the base plate of the appliance. The authors printed the appliance using stereolithography (SLA 350 machine – 3D Systems).

Customized Lingual brackets

3D printing is used in the process of manufacturing fixed orthodontic appliances. Additive manufacturing is a part of production of customized process of lingual orthodontic brackets..Wiechmann et al.[20] introduced 3D printing to create wax patterns of lingual orthodontic3D printing is used in the process of manufacturing fixed orthodontic appliances. Additive manufacturing is a part of production of customized process of lingual orthodontic brackets.

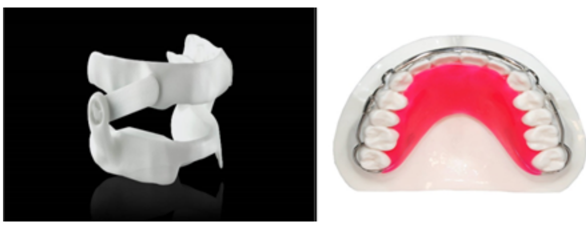
Brackets, allowing to customize the shape of bracket base. The manufacturing process begins with virtual design of each bracket, which can be customized to fit ideally to the anatomy of lingual/ palatal surface of teeth [Fig 11]. Digital design allows to customize in – out, angulation and torque values of each bracket thus, an individual bracket prescription is created for each patient. The next step employs rapid prototyping to transform virtually designed brackets into wax pattern..In order to achieve that, 3D printing technology was employed. Digital design of lingual orthodontic brackets involved creating thicker and extended bracket bases on maxillary first molars and mandibular canines to manufacture those brackets as bands. Pivots and tubes were attached to the bands, and proper tube and telescope length as well as design were planned to achieve accurate class 1 malocclusion.

Clear Aligners

In previous posts we have covered the accuracy of various 3D printers on the dental market in great detail as it pertains to the dimensional trueness of a single, static 3D printed object. However, it is also important to understand how 3D printer accuracy impacts the clinical outcome of dynamic treatments like clear aligner therapy. When fabricating a series of clear aligners to incrementally align the teeth, the dimensional inaccuracy of each 3D printed model is compounded between aligner stages thereby making 3D printer accuracy an even more important consideration. Although the directionality of the error is not necessarily consistent the magnitude of print inaccuracies between stages could be up to double that of single print. (Fig 12). 3D print-

Figure9 : Removable Essix Retainer

Figure 10 : 3D Printed Custom made Sleep Apnea appliance and Hawley's retainer



ing technology has set the basis for the use and rapid developments in the field of aligners. Manufacturing of a set of aligners for a single patient requires to perform individual digital setup, which allows to plan movements of teeth during treatment. A sequence of models, each one reflecting one single stage of treatment, needs to be fabricated to allow producing a set of aligners. Moreover, the range of tooth movement performed by an aligner ranges between 0.25 mm to 0.30 mm, thus indicating the requirements concerning the accuracy of working model fabrication. Since most quality 3D printers exhibit average dimensional inaccuracy on the order of 50-70μm, clinicians must account for the possibility of 0.1mm variance in the planned maximal activation rates[21]. As in-house clear aligner software continues to evolve, machine learning and artificial intelligence will assist in the design of more effective movement staging and activations (as products like Invisalign are already doing), but the increased accuracy of 3D prints from quality 3D printing machines will always provide an advantage for clear aligner therapy.

Occlusal Splints

Occlusal splints are used for treatment of patients presenting with temporomandibular disorders (TMD). The conventional process of splints fabrication in dental laboratory requires taking algi-nate impressions of patient's dentition,Occlusalwax bite registration, and mounting casts in articulator. Salmiet al.[22] introduced 3D printing into the process of splint manufacturing. Occlusal splints were made by the authors using stereolithography machine SLA 350 (3D Systems, USA).

3D printed splint (Fig 13) has been evaluated clinically after 1, 3, and 6 months of patient's use. The adaptation process to splint therapy has been positive and muscle tension has been relieved. No signs of tooth or splint wear has been detected after 6 months of clinical use. Moreover, the splint has been thoroughly tested following scanning and the scan was superimposed onto splint virtual design with special software. These findings indicate that 3D printing has potential to become routinely used in occlusal splints manufacturing. The printing process is highly reproducible and faster than conventional technique, thus decreases significantly the dental laboratory workload. 3D printed splint accuracy may reduce time required to trim the splint..

Surgical Templates For Orthodontic Miniscrew And Miniplates Placement

Orthodontic miniscrews and miniplates are used as a source of intraoral maximal anchorage. Loading of miniscrews or plates allows to minimize reaction forces acting on teeth and also, broadens the scope of possible tooth movements. Regarding force control, miniscrew stability and anatomical limitations including limited space for miniscrew placement, risk of root damage, perforation of maxillary sinus or neurovascular damage in miniscrew insertion, a factor of crucial importance for correct miniscrew positioning. Various techniques have been developed to ensure proper miniscrew placement trajectory and localization, but according to the contemporary research data, the following methods do not guarantee sufficient precision.

Wang et al. described a technique of orthodontic miniscrew placement using a 3D printed surgical template[23] . The authors applied superimposed CBCT and dentitionscan data, which were

Figure 11 : Customised 3D printed Lingual Brackets

Figure 12 : 3D Printed Clear Aligners

Figure 13: 3D Printed Occlusal splints

Figure 14: Adaptation of the mini-plate. (a) Placement of the drill guide, (b) Pilot holes made on the STL model, (c) Adaptation of themini-plate, (d) Mini-plate secured with fixation screws, (e) Transfer-jig.

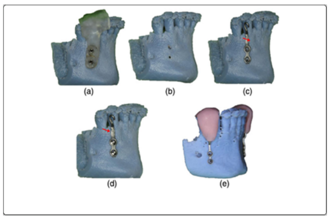
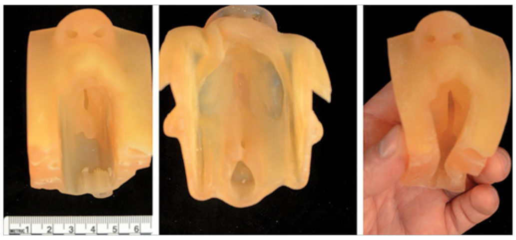


Figure 15: The soft 3D printed models which allows deform under slight pressure with enough elasticity to spring back into shape, similar to real soft tissue.



imported into CAD software to design virtual surgical template. The template was 3D printed with ABS material (acrylonitrile butadiene styrene) using FDM 3D printing machine. The template was subjected to clinical evaluation following fabrication. The template had a good fit to the surface of oral mucosa (mean gap size of 0.3 mm), good holding power, and fitting adoption to patient's teeth, ensuring sufficient stability during miniscrew insertion. In order to manufacture surgical templates with high accuracy and ability of intraoral application, it is necessary to use high resolution 3D printers and biocompatible printing materials. Time and workload required to design and manufacture the template need to be considered in routine clinical use.Miniplates may be used as well as a source of maximal anchorage in orthodontics.Miniplates are a certain alternative to orthodontic miniscrews, their range of applications include different orthodontic treatment procedures such as maxillary molars intrusion, open bite treatment, maxillary molar distalization, or maxillary protraction or impaction..(Fig 14) Precise miniplate placement and good adoption to the bone surface allows to decrease failure rates, and enables the orthodontist to apply required mechanics.The main advantage of this technique is precise determination of the final position of an orthodontic miniplate prior to the surgical procedure, which significantly reduces the time needed for surgery and simplifies the process.

Cleft Palate And Cleft Lip

Three-dimensional printing is impacting surgery and patient management in a wide variety of ways, including design of bespoke implants as well as presurgicalplanning,creation of scaffolds for soft-tissue defects, and creation of prosthetics. In regard to cleft palate pathology, 3D virtual modeling is being used for reproduction of palatal musculature mechanisms in adults as well as to simulate velopharyngeal closure (Fig. 15) for research purposes[24]. The creation of some conservative methods of treatment for cleft palate, the use of distraction osteogenesis, has also been evaluated and put into practice using 3D modeling. None of the above uses have gone so far as to print a full reproduction of a patient with cleft palate.

Conclusions

3D printing technology has become more widely used in orthodontics and the scope of possible applications is still expanding with upgradation. Available literature gives many examples of various 3D printing techniques and materials in a wide range of its applications in dentistry especially Orthodontics. 3D printing technology and material used in a certain clinical situation depends on building a broad basis of scientific evidence from both in-vitro and in-vivo studies, which allows to draw conclusions about accuracy, costs effective, clinical efficiency, and further Future new methods 5D Printing technology can easily create a sophisticated andcurved structure which requires a lot of strength[25]. But available literature is limited in database. Scientific and manufacturers with recommendations applications of digital printing technology are to be followed in order to minimize risks and help to achieve clinical goals.With the addition of a 3D printer, the orthodontist can achieve a completely digital workflow. Eliminating traditional impressions and stone models not only reduces storage requirements and time in the office, and also enhances clinical practice efficiency, improves appliance fit, allows model reuse, and results in more satisfied patients.

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