European Journal of Research in Dentistry 2024; 8(1): 41-47
DOI: http://dx.doi.org/10.29228/erd.69

REVIEW / DERLEME

An Overview of Three Dimensional Printing Captured by Three Dimensional Imaging

Üç Boyutlu Görüntüleme ile Elde Edilmiş Üç Boyutlu Baskı Teknolojilerine Genel Bir Bakış

Veysel Ömer ERDİL[1], Miray TAYLAN[2], Şebnem ERÇALIK YALÇINKAYA[3]

ABSTRACT

Modern manufacturing techniques such as 3D printing allow products to be made quickly and accurately from anything. Thanks to recent advances in 3D printing technology in dentistry, dental professionals can now custom design and print temporary and permanent crowns and bridges, implants, surgical drill guides and orthodontic appliance. This review discusses the different 3D printing technologies that can be used in dentistry and evaluates the materials printed.

Keywords: Printing, Three-Dimensional, Computer-Aided Design, Computer-Aided Manufacturing, three-dimensional image, Image-Guided Surgery

ÖZ

Üç boyutlu baskı gibi modern üretim teknikleri, plastikten metale birçok materyalden yapılmış ürünlerin hızlı ve doğru bir şekilde üretilmesini sağlar. Diş hekimleri üç boyutlu baskı teknolojisindeki son gelişmeler sayesinde artık cerrahi kılavuzları, geçici ve kalıcı kuronlar ve köprüler, ortodontik apareyler ve implantlar için özel tasarımlar yapabilmektedir. Bu derlemede diş hekimliğinde kullanılabilecek çeşitli üç boyutlu baskı teknolojileri ve baskı malzemeleri ele alınmıştır.

Anahtar Kelimeler: Printing, üç boyutlu, bilgisayar yardımlı tasarım, bilgisayar yardımlı imalat, 3-boyutlu görüntü, görüntü kılavuzluğunda cerrahi

Veysel Ömer Erdil (✉)
Marmara University Faculty of Dentistry, Department of Restorative Dentistry.
veyselomererdil@gmail.com

Miray Taylan
DDS, Department of Prosthodontics, Faculty of Dentistry, Marmara University.

Şebnem Erçalık Yalçınkaya
Prof. Dr., Department of Oral and Maxillofacial Radiology, Faculty of Dentistry, Marmara University.

Submitted / Gönderilme: 18.10.2023 **Accepted/Kabul:** 28.02.2024

INTRODUCTION

Three-dimensional (3D) printing is a rapidly evolving technology. It is now widely used in the dental industry. 3D printing has benefits for process engineering as compared to conventional and subtractive methods. The production of materials such polymers, metals, and ceramics can be done utilizing a variety of methods. 3D printing was first developed around thirty years ago. It is frequently referred to as the main technology of the upcoming industrial revolution and is currently undergoing rapid development as a result of the expiration of numerous patents (Sturb et al., 2006). The transfer from its laboratory to clinical use in dentistry depends heavily on the materials possible; these materials must not only offer the requisite precision but also the required physical and biological qualities (Sturb et al., 2006; Wang & Leon, 2006)

Over the past few decades, the use of computer-aided manufacturing (CAM) and computer-aided design (CAD) in dentistry has advanced significantly. It has inspired the creation of entirely new material courses, as well as the digitisation and automation of many work processes. In dentistry, CAM and subtractive manufacturing were synonymous until recently. (Wang & Leon, 2006; Kessler et al., 2020; Soriano et al., 2017).

This review's objective is to offer a current summary of many printing techniques, including digital light processing, stereolithography, selective laser sintering, photopolymer jetting, material jetting, selective laser melting and fused filament fabrication. Special consideration is given to materials used in dentistry and their clinical applications. Thus, this review article also discusses the production stages at which 3D printing technology is used in spesific dental fields, existing 3D printing technologies and the materials utilized in these 3D printing technologies and their properties (Sturb et al., 2006; Wang & Leon, 2006; Kessler et al., 2020).

3D Printing Techniques used in Digital Dentistry

Stereolithography Printers

The first commercially available 3D printing technology is stereolithography (SLA). Using highly cross-linked polymers, this manufacturing technique uses photoinduced polymerization to produce multilayer structures (Fig. 1), (Fan et al., 2020). This technology can be categorised into different groups based on the type of platform movement and laser movement. Regardless of these classifications, printing involves three main steps: exposure to light or laser, platform movement, and resin refilling. The typical example of additive manufacturing, which makes use of layer-by-layer modeling, is stereolithography. The SLA equipment completes the printed object under the direction of a 3D digitized model that serves as a template for the fabrication process. When resin is exposed to ultraviolet light, which causes the resin monomers to undergo free radical polymerization (FRP), the layers are joined from the bottom up. As each layer is polymerised, the resin platform descends by a distance equal to the thickness of one layer, building up the next layer until the 3D digital model is printed (Sakly et al., 2014; Jain et al., 2013; Lipson & Kurman 2013).

Figure 1: Creality Halot-One SLA Printer

Digital Light Processing Printers

The Digital Light Processing is a photocuring technology which is similar to SLA process. The materials used are liquid photosensitive resins that go through photocuring and then layer by layer build the 3D printed item. The initial layer forms on the build platform. The build platform may be moving upward or downward depending on where the UV source is located. Subsequent layers are constructed above the preceding layer. The DLP 3D printer uses a digital projector screen to flash the image of the current layer across the build platform or the preceding layer through a transparent bottom or top of the resin tank. The construction platform moves up or down in accordance with the thickness of a layer after each layer has dried to complete the portion (Fig. 2) (Sakly et al., 2014; Jain et al., 2013; Cuan-Urquizo et al., 2019).

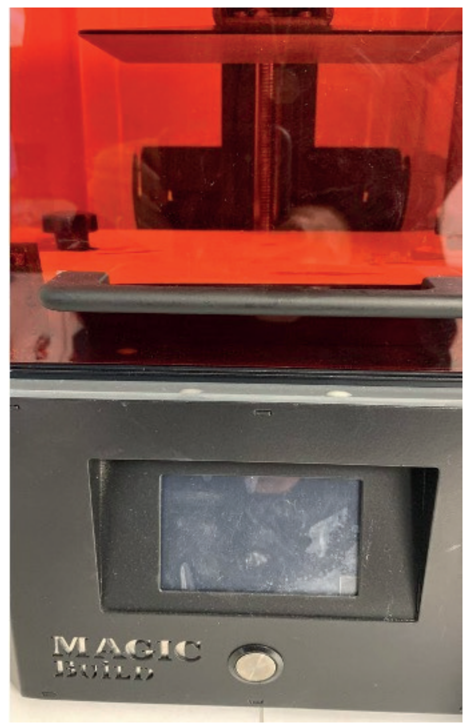

Figure 2: Magic Build DLP Printer

Fused Deposition Modeling Printers

The term "fused deposition modelling", sometimes known as "fused filament fabrication", refers to a procedure for softening metal alloys, composite materials, and polymers that was developed more than 20 years ago. FDM is the second most popular 3D printing method after SLA (Jain et al., 2013). This method is significantly less expensive than the other additive manufacturing techniques (Cuan-Urquizo et al., 2019). The strand extrusion principle serves as the basis for this method, which involves delivering the required type of thermoplastic material to the extruder in the form of strands. Layer by layer, the heated viscous plastic is placed by an extrusion head after softening, producing the digital model (Soriano et al., 2017; Taylor et al., 2017). The most widely used FDM filaments are thermoplastic polymers and their composites, including low melting temperature metal alloys like bronze metal filament and acrylonitrile-butadiene-styrene, polycarbonates, and polysulfones (Cuan-Urquizo et al., 2019). To make (nano)composite filament, polymers may be loaded with metal nanoparticle reinforcement to enhance various characteristics, such as thermal resistance and mechanical qualities.

Selective Laser Sintering

In the process known as selective laser sintering (SLS), the fusing of the raw material powder is induced using a laser beam. The platform will be lowered to allow room for the laser to sinter the subsequent layer of powder after the laser has made a solid layer out of the powder. Because the surrounding powder acts as support, this particular kind of structure construction eliminates the need for extra material support during printing (Olakanmi et al., 2015). SLS can be used to produce metal frameworks, multipurpose study models, and drilling and cutting guides. The utilization of autoclavable materials, mechanical functionality of the printed object, and a decrease in production cost with an increase in production volume are all benefits of SLS. The health risk connected with inhaling the raw material's powder, the initial high cost of setup, and the requirement for additional supplies like compressed air for SLS to function properly are the drawbacks of this printing technology (Tolochko et al., 2002).

Cone Beam Computed Tomography

This part will specifically focus on cone beam computed tomography and how it is used in conjunction with 3D printers. Although conventional radiography is still widely used today, converting the morphology of three-dimensional hard structures into two-dimensional radiographs may lead to inadequate examination and inaccurate diagnosis. These shortcomings prompted researchers to improve three-dimensional imaging systems. Cone Beam Computed Tomography imaging system was used for the first time for radiotherapy, angiography and mammography in 1982. Since the 1990s, it has been possible to add three-dimensional imaging to the existing 2D imaging system. The use of cone beam computed tomography (CBCT) in dentistry has seen a significant surge. Its applications include the diagnosis and treatment of anatomical and pathological structures within the oral and maxillofacial area, evaluation of the temporomandibular joint, implant design, and several other matters. (Karslıoğlu et al., 2022; Windisch et al., 2007).

The use of CBCT in dentistry has rapidly changed radiodiagnostics in dentistry, allowing dentists to make three-dimensional diagnoses. The CBCT units currently in use are capable of three-dimensional imaging of hard tissues in the head and neck region with excellent high resolution (Karslıoğlu et al., 2022).

USAGE OF 3D PRINTERS IN FIELD OF ORTHODONTICS

The developing use of 3D printers has also led to great developments in the field of orthodontics. One of the most important of these developments is the use of technology that will change the concept of orthodontic appliances with 3D printers. With this technique; one can produce orthodontic instruments used in active orthodontic treatment such as various removable orthodontic appliances (hawley etc.), dental arch expansion appliances, space holders, arch wires, clear aligners, brackets, transfer trays for orthodontic treatment for indirect bonding, lingual bracket systems. In addition, it offers opportunities to make orthodontic treatment applications fast and easy by providing models produced for treatment planning and diagnosis and the production of surgical splints and surgical guides for orthognathic surgery patients (Suryajaya et al., 2021).

Obtaining a Dental Model

In orthodontics, where dental models and impressions are widely used, the traditional method of impression-taking has begun to give way to intraoral scanning devices and 3D digital model-taking technology. The production of models makes treatment faster, easier and more comfortable for both the dentist and the patient. Advantages of digital models; no need for physical storage, easy access to data, digital diagnosis or treatment simulations, patient comfort, ability to send to laboratory, no risk of breakage, wear, deterioration or loss, less labour required (Suryajaya et al., 2021).

Orthodontic Appliances

There are many processes involved in the manufacture of orthodontic appliances, both in the clinic and in the laboratory. The production of appliances using traditional methods consists of long, challenging and less comfortable stages for both the patient and the clinician. Recently, 3D printer application in the production of orthodontic appliances has brought benefits such as rapid treatment planning, easier planning and patient comfort. Digital applications open up new possibilities for indirect bonding (IDB) (Dong et al., 2020).

Orthodontic Treatment Provided by Clear Aligners

The first clear aligners were developed for the final stages of orthodontic treatment or simply to treat minor irregularities in tooth position. As a result of developments in the field of clear aligners, they have also begun to be used in the treatment of moderate to severe malocclusions. Many materials have been used in the manufacture of clear aligners, but limited work has been done to introduce new materials. The manufacturing process of 3D printing technology bypasses physical creation of the dental model and the clear aligner can be created directly from electronically stored 3D data (Zinelis et al., 2022).

3D Printed Photocurable Shape Memory Resin for Clear Aligners

Direct 3D printing of aligners has been developed to overcome the disadvantages of the traditional vacuum thermoforming manufacturing process. The photocurable resin TC85, a novel material for 3D printing of clear aligners, was compared with the thermo-mechanical and visco-elastic properties of a thermoplastic known as polyethylene terephthalate glycol. Dynamic mechanical analysis was carried out to investigate the mechanical behaviour of the two materials at 37°C and 80°C respectively. In addition, a U-bend test was used to assess the shape memory properties of the two materials and the shape recovery ratio was calculated for 60 min at 37 °C (Melkos, 2005).

Recently, attempts have been made to directly 3D print clear aligners using a biocompatible material in order to solve the challenges that come with traditional production methods. This approach requires less time and effort and produces fewer geometric errors. Numerous studies have evaluated the accuracy, fit and clinical viability of direct 3D printed clear aligners. However, few studies have investigated the mechanical and physical properties of the 3D printed materials (Fig.3), (Melkos, 2005).

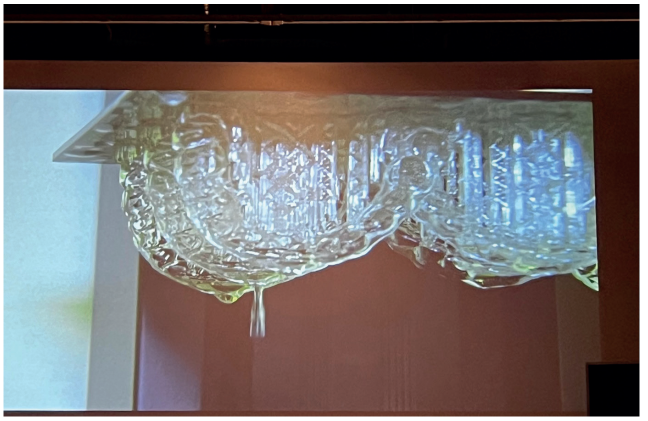

Figure 3: Graphy Shape Memory Clear Aligner printing stage

In order to enhance the predictability of clear aligner performance and treatment results, it is critical to understand the viscoelastic properties of creep and stress relaxation in addition to physical parameters such as static mechanical properties. Force degradation occurs when clear aligners are worn for extended periods of time and are frequently placed in the mouth. The clear aligners are made of viscoelastic polymers, which have properties halfway between elasticity and viscosity (Dupaix et al., 2005). As a result, the behaviour of clear aligners changes significantly over time under constant load (Fig. 4), (Fang et al., 2013).

Figure 4: Graphy Shape Memory Clear Aligner curing stage

3D PRINTERS IN ORAL SURGERY

As technology develops, three-dimensional software and printing technologies are being used in the surgical field of dentistry, as well as in many other fields. Three-dimensional printing technology, particularly cone beam computed tomography (CBCT), has been developed alongside advanced 3D imaging techniques such as magnetic resonance imaging (MRI) and computed tomography (CT), and can be used in all areas of dentistry. This technology reduces the risk of complications that can occur during and after surgical procedures by providing guidance during surgery, as well as superior diagnosis and treatment planning. (Windisch et al., 2007)

Preoperative Planning

The use of anatomical models is of great importance in preoperative planning, especially in orthognathic surgery applications. Orthognathic surgery is defined as surgical procedures performed in conjunction with orthodontics for correction of dentofacial deformities in patients with severe skeletal mismatch as a result of congenital or acquired deformities and who have completed their growth development (Oberoi et al., 2018; Bayramov et al., 2022).

Surgical Education and Simulation

Anatomical models produced by three-dimensional printers can also be used for training purposes and can be shared between specialists for information exchange (Windisch et al., 2007). Models can be used to evaluate complex anatomy and to test new manipulation and surgical techniques. They can be used as a tool in obtaining informed consent for surgery by making it easier for the patient to understand the surgical procedures and have a positive effect on patient satisfaction (Windisch et al., 2007).

Surgical Operation Instruments Used in Preoperative Surgical Planning

The use of three-dimensional printers in the treatment of tissue loss due to trauma or tumour surgery, or in reconstruction procedures for plastic surgery, has brought many benefits. For example, functional planning and execution can be achieved when restoring an anatomically complex area. In particular, the use of three-dimensional anatomical models in the evaluation of the bone defect for grafting, together with the identification of the ideal donor site, can provide an excellent match for the graft material (Thankappan et al., 2008). Another advantage of anatomical models is that they allow appropriate reconstruction plates to be shaped on the model prior to surgery (Windisch et al., 2007; Thankappan et al., 2008)

Instruments Used During Surgery

Anatomical models or surgical instruments produced by three-dimensional printers can be used both preoperatively and intraoperatively, thus contributing in many ways to the treatment process. Although a wide variety of 3D printers and printing materials are used to produce anatomical models and surgical instruments, it is recommended that sterilisable materials are used so that the model can be used for guidance during surgery (Thankappan et al., 2008; Schmauss et al., 2013; Ursan et al., 2013).

3D PRINTERS IN ENDODONTICS

Educational Use of 3D Printed Models

The use of 3D printing in dentistry can produce high-resolution resin models, with a resolution range of 16-32 µm for each layer, automatically and by layering. Rapid prototyping of replicas of natural teeth is very promising and has particular potential for inclusion in endodontic training. It also allows standardisation of specimens, which is important for laboratory studies such as root canal instrumentation, filling and retreatment (Patel et al., 2019).

Guided Non-Surgical Endodontics

Pulp canal obliteration is a gradual narrowing of the canals and a more apical position of the roots as a result of caries, orthodontic treatment, systemic disease, trauma or increased dentin production due to age. As a result of pulp canal obliteration, perforations of calcified canals during access and canal preparation increase by up to 75% (Anderson et al., 2018). 3D-printed guides may be useful for canal localisation during nonsurgical endodontic treatment, where there is a significant risk of procedural errors, including root perforation, which can seriously compromise the outcome of treatment (Cvek et al., 1982; Amir et al., 2001).

Guided Surgical Endodontics

The effective performance of endodontic microsurgery (EMS) necessitates the precise implementation of osteotomy and root tip resection, which should be guided by anatomical landmarks and preoperative radiographs or measurements obtained using cone beam computed tomography. The osteotomy may deviate from the ideal due to operator failures in clinical scenarios where proper orientation, angulation and preparation depth are difficult. Advances in magnification systems and materials have made EMS a predictable procedure (Syngcuk et al., 2006).

3D PRINTERS IN PROSTHODONTICS

The prosthetic rehabilitation of teeth and jaws is influenced by 3D technology at every stage. The development of intra-oral scanners allows digital optical impressions to be taken of the patient's dental arches, significantly reducing chair-side time. The dentist can now interact with a dental laboratory by digitally exchanging patient data or printing the required prosthesis or component in the office, thanks to the evolving trends of the digital revolution. (Vasamsetty et al., 2020; Lee et al., 2017)

Fixed Prosthetic Restorations

A 3D temporary bridge and crown resin must not only be biocompatible, but also have mechanical properties that can withstand the high occlusal forces. To achieve sufficient polymerisation and the ideal mechanical performance of the material as designed by the manufacturer, an ideal post-polymerisation process is required in which the photosensitive resin receives the necessary UV light at the right wavelength. It has been observed that the biological, mechanical and degree of polymerisation of the final printed resin improves with post-curing time and temperature. (Vasamsetty et al., 2020; Bayarsaikhan et al., 2022)

Removable Dental Prostheses

Recent advances in digital dentistry have enabled the successful use of digital technology to produce removable prostheses. Prosthesis manufacturing methods, materials and processes have been modernised and made more efficient with 3D printing. (Aanadioti et al., 2020) Dentca created the first 3D printed denture in 2015. The dentist can send a digital or traditional impression, together with details of the jaw relationship, to the dental laboratory during the working day. The prosthesis base is created using CAD design software with the teeth in occlusion. A printed try-in prosthesis is an option and clinical modifications can be made by grinding the acrylic and then rescanning. The finished prosthesis and teeth are fabricated separately and then bonded together. Dental professionals can also print prosthesis internally as open source softwares and printers become more cost-effective. (Aanadioti et al., 2020)

Dental Models

The use of additive manufacturing techniques can be used to create custom models. This model can also be used as a reference model. At the same time, additive manufacturing techniques can be used to create educational models for the medical and dental fields. The models produced can be used for research and teaching. They are colourful and clearly illustrate the anatomy. A study compared dental models made using the SLA method with traditional stone casts. It was claimed that the accuracy of the SLA model was inferior to that of the traditional method (Alshawaf et al., 2018). Demiralp et. al. compared the prosthetic teeth made using heat curing, milling, and 3D printing techniques after thermal aging for flexural bond strength and fracture toughness. (Demiralp et al., 2021)

APPLICATIONS OF 3D PRINTING IN RESTORATIVE DENTISTRY

Indirect Composite Resin Restorations: Inlay and Onlay

In recent times, there has been a growing acceptance of 3D printed composites as feasible materials for the purpose of single tooth restorations. Studies comparing the efficiency of these restorations with subtractive procedures in terms of fatigue, time and cost are lacking. There are also no studies on marginal adaptation, which is crucial because many clinical failures, such as stain retantion, recurrent caries and water absorption, which affect the quality of the restoration, begin or are noticed at the transition between tooth and restoration. (Daher et al., 2022)

As they offer acceptable marginal adaptation with time and cost advantages, three-dimensional printed composites may be a suitable material for long-term temporary restorations. (Daher et al., 2022)

APPLICATIONS OF 3D PRINTING IN PERIODONTOLOGY

Periodontal Splint

The masticatory function of mobile anterior mandibular teeth can be enhanced with periodontal splinting, which also lowers the possibility of unintentional extraction.

Instead of ceramics and metal, polyetherketoneketone, a high-performance thermoplastic resin, has also been used. In a previous study, the antibacterial properties of PEKK and the accuracy and efficiency of digital technology ensured that the splint had no negative impact on oral hygiene or periodontal maintenance during two years of follow-up (Qian et al., 2023). The procedure provided a personalised, biocompatible and aesthetically pleasing method of stabilising mobile teeth. Qian et al. found that the PEKK splint functioned well clinically, with good stability and retention two years after delivery (Qian et al., 2023). Plaque buildup, composite resin fracture, complicated prosthodontic fabrication processes for partial dentures, or difficulty modifying or adjusting metal splints intraorally are all downsides of periodontal splints of various designs and materials (Qian et al., 2023; Patel et al., 2017).

Surgical Guide for Crown Lenghtening (Gingivectomy and Bone Resection)

Crown lengthening is a procedure used to expose the tooth structure, in order to restore the proper biological width that corresponds to the physiological dimension from the junctional epithelium and connective tissue attachment to the alveolar crest or for esthetic purposes. By using digital workflow, a surgical guide is designed digitally with a software program to perform crown lengthening. A digital design of the new tooth shape and a cone beam computed tomography scan are used to create standard tessellation language (STL) files, which are then converted from DICOM files to the STL format. Surgical planning of the crown-lengthening procedure is done by superimposing these files (Bayarsaikhan et al., 2022; Polat et al., 2022).

Based on the above-mentioned recent literature review, it appears that 3D technologies will play a popular role in future dental practices. It is obvious that 3D printing technology will be more widely used in dentistry in line with developments in artificial intelligence and technological improvements by overcoming barriers such as current R&D costs, user unfamiliarity with the products and higher financial costs of materials.

How to cite this article: Erdil VÖ, Taylan M, Yalçınkaya ŞE. The Modern Dental Era: Three Dimensional Printing, Captured by Digital Imaging. European Journal of Research in Dentistry, 2024;8(1) : 41-47. DOI: http://dx.doi.org/10.29228/erd.69