REVIEW

Recevied/ Geliş Tarihi: 17.05.2024
Accepted/ Kabul Tarihi: 11.07.2024
Published / Yayın Tarihi: 31.08.2025

Aydın Dental Journal - Volume **11** Issue **2** - August **2025** (215-222)

Aydın Dental Journal

Journal homepage: http://dergipark.ulakbim.gov.tr/adj
DOI: 10.17932/IAU.DENTAL.2015.009/dental_v011i20011

3 Dimensional Printing in Prosthetic Dentistry

Protetik Diş Tedavisinde 3 Boyutlu Yazıcılar

Nilüfer İpek Şahin[1*], Emre Tokar[2]

ABSTRACT

Three-dimensional (3D) printers are used in dental clinics and laboratories, offering the opportunity to provide prosthetic dental treatment services more cost-effectively and faster compared to traditional methods. This technology addresses challenges encountered in the clinical and laboratory phases by minimizing errors associated with traditional impression taking and model production. Dental restorations such as crowns, bridges, implant-supported prostheses, removable partial denture frameworks, occlusal splints, personalized impression trays, complete dentures, models, and maxillofacial prostheses can be efficiently produced using 3D printers. As the use of 3D printers becomes more widespread, these devices are increasingly integrated into dental practices. Consequently, there is a growing demand for current information regarding this technology. The integration of 3D manufacturing technology contributes to the development of personalized treatment practices and enables customized solutions to meet individual patient needs. As the field of dentistry continues to embrace digital technology, ongoing research and development into three-dimensional printing techniques promise further advancements in treatment possibilities and greater success in results. This article aims to examine the 3D manufacturing techniques and applications used in dentistry, and to evaluate their advantages and disadvantages.

Keywords: *CAD-CAM, Computer-Aided Design, Dental Prosthesis, 3D Printing.*

ÖZET

Diş kliniklerinde ve laboratuvarlarda üç boyutlu (3B) yazıcıların kullanılması, geleneksel yöntemlere kıyasla protetik diş tedavisinde uygun maliyetle ve daha hızlı bir şekilde hizmet üretme olanağı sağlamaktadır. Bu teknoloji, geleneksel ölçü alma ve model üretimiyle ilişkili hataları en aza indirerek klinik ve laboratuvar aşamalarında karşılaşılan zorlukları büyük ölçüde gidermektedir. Diş restorasyonları, kronlar, köprüler, implant destekli protezler, çıkarılabilir kısmi diş protezi iskeletleri, okluzal splintler, kişiselleştirilmiş ölçü kaşıkları, tam diş protezleri, modeller ve maksillofasiyal protezler gibi çeşitli diş restorasyonları, 3B yazıcılar kullanılarak etkin bir şekilde üretilebilir. 3B yazıcıların kullanımı yaygınlaştıkça, bu cihazlar diş kliniklerine giderek daha fazla entegre edilmektedir. Bu nedenle de bu teknoloji hakkındaki güncel bilgilere olan talep artmaktadır. 3B üretim teknolojisinin entegrasyonu, kişiye özel tedavi uygulamalarının gelişmesine katkı sağlamakta ve bireysel hasta ihtiyaçlarını karşılamaya yönelik özelleştirilmiş çözümlere olanak tanımaktadır. Diş hekimliği alanı dijital teknolojiyi benimsemeye devam ettikçe, üç boyutlu baskı teknikleri konusunda devam eden araştırma ve geliştirme faaliyetleri, tedavi olanaklarında daha fazla gelişme ve elde edilen sonuçlarda daha fazla başarı vaat etmektedir. Bu makalede, diş hekimliğinde kullanılan 3B üretim teknikleri ve uygulamaları incelenmekte, sunduğu avantaj ve dezavantajların değerlendirilmesi amaçlanmaktadır.

Anahtar Kelimeler: *Bilgisayar Destekli Tasarım, CAD-CAM, Diş Protezi, 3D Printing,*

[1] PhD student, Department of Prosthodontics, Faculty of Dentistry, Gazi University, Ankara, Turkey
[2] DDS, PhD, Associate Professor, Department of Prosthodontics, Faculty of Dentistry, Gazi University, Ankara, Turkey
***Corresponding Author:** Nilüfer İpek ŞAHİN, **email:** nipek.sahin@gazi.edu.tr,**ORCID:** 0000-0001-6950-1645,
Emek Mahallesi, Bişkek Caddesi, 1. Sokak B Blok, No:4, Protetik Diş Tedavisi A.B.D., 06490 Çankaya/Ankara.

Introduction

The utilization of computer-aided manufacturing (CAM) techniques in dental practices is steadily increasing.[1] Generally, computer-aided manufacturing involves three key stages: digital impression-taking, computer-aided design (CAD), and manufacturing. CAD-CAM, an abbreviation for computer-aided design and computer-assisted manufacturing, can be categorized into two primary subgroups: subtractive and additive processes. The pioneering figures introducing CAD-CAM to dentistry were Swiss dentists Werner Mormann and Marko Bridenstine.[2] Their adoption of the technology in 1988, particularly the subtractive-based CAD-CAM, gained rapid acceptance and widespread usage.[3] Concurrently, during the same period, additive manufacturing-based 3D printing technology, developed by Charles Hull, made its mark in prosthetic dentistry applications and various other production sectors.[4] Continuous advancements in material technology have progressively enhanced the quality of products produced with this technique. In the additive manufacturing technique, layers are added one after the other from the bottom up to produce a product. In the subtractive production technique, during the production of a piece, excess material is separated and discarded, much like the production of a sculpture from a monolithic block.[5] While 3D printers are used in the additive manufacturing technique, milling machines are used for the subtractive manufacturing technique. What both technologies have in common is that the machines used for production (3D printer or milling machine) use CAD software models. In these software applications, the most commonly used digital format is the standard tessellation (STL) format.[6]

Continuous improvements in technology are pushing both manufacturing methods forward, and additive manufacturing is progressing even faster. In particular, the improvement of the quality of the materials (resins) used in additive manufacturing plays the most important role in the development of this innovative technology.[5]

Although the use of additive manufacturing is becoming more widespread in prosthetic dentistry compared to subtractive manufacturing, these two techniques have superior features and disadvantages over each other. Compared to the subtraction technique, the 3D printing technique both shortens the production time and causes less waste of raw materials. Therefore, 3D printers can be a cost-effective option for the production of temporary crowns and fixed dental prostheses.[5]

Additive manufacturing encompasses a series of advantages including unparalleled design flexibility that enables the creation of complex geometries unachievable by traditional manufacturing methods. This innovative process not only promotes the efficient production of complex parts in a single operation due to its production flexibility but also ensures material and resource efficiency by eliminating the need for auxiliary parts and minimizing waste, thus reducing overall costs. However, it faces certain limitations such as the inability to efficiently produce large-scale objects due to material strength constraints, the necessity for post-processing to address surface imperfections on printed parts and the significant initial and ongoing financial investment required for 3D printing technology.[7,8]

Additive Manufacturing Technologies Used in Dentistry

Stereolithography Technique

The Stereolithography (SLA) method involves the production process wherein UV laser solidifies photosensitive resin in thin layers.[9] In this technique, a movable platform exists within a resin tank filled with resin. The platform is positioned just below the resin to be polymerized. A computer-controlled system lowers the platform by the thickness of one layer after the liquid resin is polymerized by laser to create new layers. This process continues until the model is completed. Once finished, any remaining parts on the model are cleaned, and it is placed in an oven.[10] SLA provides rapid production and allows the creation of complex shapes with high accuracy.[11]

Digital Light Processing

Digital Light Processing (DLP) shares similarities with SLA in its manufacturing methodology, allowing for the production of high-resolution parts. Unlike SLA, which uses laser beams, DLP printers utilize visible light to solidify materials. In DLP, a thinner resin tank is used compared to SLA, resulting in reduced waste generation and a more efficient production process.[12]

Fused Deposition Modeling, Fused Filament Fabrication

Fused Deposition Modeling (FDM) or Fused Filament Fabrication (FFF), is one of the most prevalent and cost-effective 3D printing technologies.[11] Thermoplastic materials such as plastic, granules, or filament wires are used in printers utilizing fused deposition modeling techniques. The working principle of these printers involves directing the flow of plastic or metal material, which creates a solid object, to an extrusion nozzle that can open and close. The nozzle maintains the thermoplastic material just above its melting point. The nozzle is heated and moved horizontally and vertically by a mechanism controlled digitally via software. As small droplets exit the nozzle, they solidify immediately, forming a layer. Once the first layer is completed, the platform moves downward, and the extrusion nozzle constructs the subsequent layer. This method involves using support material during the model's production.[10]

Material Jetting

3D printers used in the Material Jetting method follow a technique similar to that of inkjet printers. Therefore, these printers are called 3D inkjet printers.[13,14] The system contains a piezoelectric head spraying liquid photopolymer droplets, which are immediately solidified by the UV lamps.[13] The piezoelectric head is positioned on a movable platform. Once the first layer is completed, the platform descends, and the construction of the subsequent layer takes place. This iterative process continues until the model is fully constructed[14] In inkjet 3D printers (such as MultiJet, for example), various resins can be used simultaneously to manufacture multi-part objects. The support structure is automatically generated[13]. It is an efficient method that allows for the rapid production of complex structures.[15] However, the main disadvantages of this method include poor resolution and poor coherence between layers.[16]

Powder Bed Fusion Laser Sintering

Laser-based manufacturing techniques such as Selective Laser Melting (SLM) and Selective Laser Sintering (SLS) rely on directing laser energy through mirrors onto a powdered material substrate to create solid objects.[9] The heat generated by the laser beam striking the surface brings the powder together in the desired form, producing three-dimensional components from CAD data. Beneath the layer of powder in the system, there is a movable platform. After scanning the designated area through the scanning system, the first layer is formed, and the platform descends by the layer thickness to enable the formation of new layers. This process is repeated until the entire solid object is created. Once the sintering process is complete, the station is allowed to cool for a brief period. The produced part is then cleansed of dust using brushes and vacuum cleaners. Since the powder that undergoes sintering in these printers serves as the support material outside the sintered powder, there is no need for additional support material.[10] Laser sintering can create detailed and precise structures, with the level of detail depending on the precision of the laser and the fineness of the powder. Metal, plastic, and ceramic objects can be produced through laser powder shaping.[17]

In manufacturing, SLS is generally preferred when using polymers or ceramics, while SLM or Direct Metal Laser Sintering (DMLS) is used when working with metals. The produced objects do not require additional curing (hardening).[10]

Materials Used in 3D Printers

Metals and Metal Alloys

The three-dimensional production of metals involves melting pure metal using laser or electron beams. The molten metal is then added layer by layer and hardened. CoCr, Ni-Cr, and titanium alloys are examples of materials used in additive manufacturing. The additive manufacturing method enables high-precision and rapid production.[18]

Metals and metal alloys are used in strengthening restorations and incorporation into frameworks. These type of materials are used mainly by SLS and SLM technology.[19]

Composites and Polymers

Polymers exist in the form of thermoplastic filaments, reactive monomers, resins, or powder. The advantages of producing polymer-based materials through three-dimensional printing include the ability to create the designed geometry with high accuracy and cost-effectiveness compared to other traditional manufacturing methods. Polymers are considered the most commonly used materials in additive manufacturing due to their material diversity and adaptability to various methods.[18,20]

The usage of polymer materials produced through additive methods is currently limited due to their low durability. Ongoing research aims to improve the mechanical properties of polymers through different methods and materials.[18,20]

Ceramic Materials

Ceramics are widely used in dentistry due to their positive features such as biocompatibility, high mechanical and optical properties, chemical stability, and thermal conductivity.[11,21] However, ceramics are fragile, and there are challenges in the production processes.

In dentistry, ceramics can be produced using traditional methods as well as subtractive and additive CAD/CAM methods. Ceramic components are traditionally produced using manufacturing methods such as injection molding, press molding, strip casting, and gel casting. Desired morphologies are created from a binder or binder-less powder mixture. Materials like zirconia and alumina are used in the additive manufacturing of ceramics. After production, the ceramic structure needs to be sintered at high temperatures to densify it. However, these production techniques have limitations due to long processing times and high costs.[11,22]

Applıcations of 3D Printers in Prosthetic Dentistry

Crowns and Bridge Restorations

For resin-based three-dimensional additive methods in crown and bridge restorations, SLA and DLP methods are applied. In additive methods significantly less material is utilized compared to milling systems, resulting in minimal material loss. Permanent physical models can be generated from virtual three-dimensional models within a virtual environment using either milling machines or three-dimensional printers. Various clinical and experimental studies have demonstrated the satisfactory clinical performance of this technology in producing both fixed and temporary crowns, as well as zirconia crown restorations.[23-25]

The accuracy values of zirconia crown restorations obtained with 3D printers in four regions (outer surface, inner surface, crown edge, and occlusal inner surface) were compared with those obtained through milling (CAD/CAM) and reported no statistically significant difference between them. According to these results, they suggested that 3D printing could be suitable for producing zirconia crowns.[26]

After the adoption of additive manufacturing methods, such as SLS and SLM for metal and metal alloy productions, 3D printers have become a common alternative to traditional casting and grinding methods for producing metal frames.[27]

In a study comparing conventional casting, milling, and SLM methods for three-unit implant-supported Co-Cr restorations, researchers found that restorations produced with the SLM method exhibited lower stress and strain values and demonstrated the best marginal fit. The researchers concluded that these findings suggest restorations produced with the SLM method offer higher dimensional accuracy.[28]

Dental Model Production

Additive manufacturing finds another important application in the production of anatomical study models, facilitating detailed examination of complex anatomy and enabling preoperative surgical planning.[29] These models serve multiple purposes, including diagnosis, preoperative planning, and as surgical references. Moreover, Additive manufacturing technology has been instrumental in producing models for surgical planning and simulation in oral and maxillofacial surgery for over twenty years.[30]

Colored models produced by 3D printers offer valuable tools for education and research purposes. However, in a study comparing models produced with the SLA method to conventional gypsum models, it was reported that the SLA-produced models exhibited lower accuracy compared to traditional methods. Despite this finding, the use of 3D printing technology continues to hold promise in anatomical modeling and education.[31]

Subsequent studies have partially supported this finding. Nevertheless, due to the clinically acceptable accuracy of fit, 3D-printed casts may still be utilized as definitive master casts to fabricate implant-supported fixed dental prostheses.[23]

Removable Partial Denture Frameworks Fabrication

During the preparation of Removable Partial Denture (RPD) frameworks using digital workflow, either impressions or models are scanned using an intraoral or extraoral scanner. The designs created in CAD software are then saved in STL file format. These digital data are subsequently transferred to 3D printers for the fabrication of personalized structures. Digital methods offer several advantages over conventional ones. In conventional methods, distortions in wax modeling and investment can occur during the processes, potentially leading to problems in the fit of castings.[32]

The most common complications encountered in the clinics due to the use of Removable Partial Dentures are mucosal lesions and residual ridge resorption, both of which are pressure-related. RPD frameworks produced with 3D printers provide a more balanced distribution of chewing pressure. Customized optimal denture designs using CAD/CAM manufacturing techniques are expected to reduce pressure-induced mucosa lesions and long-term ridge resorption.[33]

Complete Denture Fabrication

Owing to the development of digital techniques and systems, it's now possible to complete permanent full prostheses in just 2-3 clinical appointments. The successful integration of intraoral scanners in edentulous jaws has facilitated a fully digital workflow for complete dentures.

Both clinical and laboratory protocols of commercially producing companies now incorporate a combination of manual and digital procedures. These protocols aim to deliver complete dentures to patients in only 2 clinical appointments, utilizing CAD/CAM or rapid prototyping technology

The first photopolymerized resin complete denture using 3D laser lithography was produced in 1994.[34] In the following years, many researchers have contributed to the development of this field with studies focusing on various aspects such as the utilization of intraoral scanners in edentulous jaws, digital teeth arrangement, and the creation of virtual patient models.[35,36] Most of the systems on the market use milling techniques (CAD/CAM) for the production of complete dentures.[37]

Complete dentures printed in one piece using 3D printing are typically used as trial prostheses for transitional prostheses or to record maxillo-mandibular relationships. In recent years, the use of 3D printers in the production of permanent complete dentures has also rapidly increased.[38] Although DLP technology is the most commonly used rapid prototyping method for producing complete dentures, other technologies such as SLA and PolyJet technology (also known as Multijet Modeling Printing or MJP) are also employed for this purpose.[39]

Occlusal Splints

The conventional workflow for producing occlusal splints typically involves taking alginate impressions, obtaining working models, and fabricating the splint after obtaining interocclusal records with interocclusal wax. However, errors can arise during impression-taking and gypsum model fabrication processes, and milling processes consume a significant amount of material.

By utilizing intraoral scanners and three-dimensional printers, multiple splints can be produced simultaneously, resulting in both time and material savings. However, it's important to note that the mechanical properties of the materials used in 3D printers may not be as robust as those of conventional resin materials used for milling. Therefore, caution should be exercised in their long-term use.[40]

In a study comparing the performance of occlusal splints produced using 3D printers, CAD/CAM, and traditional methods in a chewing simulator, it was found that 3D printed splints showed lower wear and bending resistance. This study suggested that occlusal splints obtained with 3D printers could be clinically used for up to one month.[41] In a similar study, it was observed that resin and polyamide splint materials used for 3D printers were subject to less wear than traditional resin materials used for milling.[42]

In another study comparing the wear resistance of resin splints produced with 3D printers, CAD/CAM, and conventional cold acrylic, it was reported that there was no statistically significant difference between them.[43]

Preparation of Custom Impression Trays

Precision in impressions is crucial, especially in implant-supported prosthodontic restorations and fully edentulous cases, to ensure stability, retention, optimal function, and continuous oral tissue health of the restorations.[44]

One of the most important criteria for impression precision is the stability of the impression tray in the mouth. When precise and stable impression trays are used, there will be a more homogeneous thickness and sufficient space for the impression material.

In a study, digital design and a three-dimensional printer were utilized to produce a splinted framework and a custom tray for a full-arch implant impression in a fully edentulous patient with 6 implants in the upper jaw. The authors concluded that this application could reduce laboratory steps, costs, chairside time, and the number of impression copings as laboratory analogs needed.[45]

In another study, custom tray applications in full edentulous cases of the lower jaw were produced using CAD design and FDM compared with conventional custom trays. It was found that the compatibility of the models with the 3D-printed custom trays was much higher than with conventional trays.[46] The ability to produce these special trays quickly and with high precision through 3D printing techniques makes them increasingly popular.

Prosthetic Rehabilitation of Maxillofacial Deformities

In cases where prosthetic rehabilitation of maxillary deformities presents significant challenges, 3D printers play an effective role in reducing errors arising from conventional impression-taking and model production.

To determine anatomical details in the digital workflow, various computer-aided medical imaging methods such as computed tomography

(CT), cone beam computed tomography (CBCT), magnetic resonance imaging (MRI), laser surface scanners, intraoral optical scanning systems, and spectrophotogrammetry techniques can be utilized. Recent advancements in technology enable the integration of computer-aided medical imaging and digital impression data in CAD/CAM systems. The combined use of these techniques and devices effectively eliminates errors that may occur during the conventional impression-taking process.[47]

The significant advantages of the digital workflow completed with 3D printers include time savings compared to traditional techniques, shortened laboratory stages, and the ability to store prosthetic designs in a digital environment. As a result, the time spent at the chairside for adapting the prosthesis is significantly reduced.[48]

Conclusion

In conclusion, the utilization of three-dimensional printers in prosthetic dental treatment presents a promising and cost-effective avenue compared to traditional manufacturing methods. The application of additive manufacturing technologies to prosthetic dentistry has provided significant advantages in terms of design flexibility, production efficiency and material savings.

As technology advances, further research and development will likely address current limitations and enhance the capabilities of three-dimensional printing in prosthetic dentistry. The ongoing refinement of materials, processes, and digital workflows will contribute to the continued integration of additive manufacturing technologies into routine dental practices, ultimately benefiting clinicians and patients.

Ethical Approval

Ethical approval is not necessary for this study.

Conflict of interest

The authors have no conflict of interest to declare.

Sources of Funding

No funding was received for this study.

Authorship Contributions

Conception: N.İ.Ş. Design: E.T. Supervision: E.T. Materials: N.İ.Ş., E.T. Data Collection and/or Processing: N.İ.Ş. Analysis and/or Interpretation: N.İ.Ş., E.T. Literature Search: N.İ.Ş. Writing Manuscript: N.İ.Ş. Critical Review: N.İ.Ş., E.T.

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