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3D Printers and Their Use in Prosthetic Dentistry

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ABSTRACT

In recent years, the use of computer-aided design and computer-aided manufacturing (CAD/CAM) has increased considerably in addition to the traditional methods used in routine. CAD/CAM technology has many advantages. However, despite these advantages, it has a very important disadvantage such as material waste. Today, the technology that overcomes this problem is the additive manufacturing method with three-dimensional printers. This method has recently replaced the traditional subtractive computer-aided design and manufacturing technology in prosthodontics. The use of 3D printers has been increasing in recent years due to its advantages such as ease of production, time saving and material saving, freedom of design, error-free and faster production. It is also predicted that the use of this technology will increase in the future and will be the main method for digital manufacturing. The aim of this review is to evaluate the production methods of 3D printers, the areas of use in prosthodontics, the advantages and disadvantages of 3D production methods, and to review the purposes of use, materials used and developments in prosthodontics.

Üç Boyutlu Yazıcılar ve Protetik Diş Tedavisinde Kullanımı

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ÖZET

Son yıllarda rutinde kullanılan geleneksel yöntemlerin dışında CAD/CAM (computer aided design-computer aided manufacturing) sisteminin kullanımı teknolojinin gelişmesiyle birlikte hızla artmaktadır. CAD/CAM teknolojisinin birçok avantajı vardır. Fakat bu avantajlarına rağmen malzeme israfı gibi oldukça önemli bir dezavantajı bulunmaktadır. Günümüzde bu sorunun üstesinden gelen teknoloji ise üç boyutlu yazıcılar ile eklemeli üretim yöntemidir. Bu yöntem protetik diş tedavilerinde son zamanlarda geleneksel eksiltmeli bilgisayar destekli tasarım ve üretim teknolojisinin yerini almaktadır. 3 boyutlu yazıcıların kullanımı üretim kolaylığı, zaman tasarrufu ve malzeme tasarrufu, tasarım özgürlüğü, hatasız ve daha hızlı üretim gibi avantajlarından dolayı son yıllarda gittikçe artmaktadır. Ayrıca gelecek dönemde de bu teknolojinin kullanımının gittikçe artacağı söylenmekte ve dijital üretim için ana yöntem olacağı öngörülmektedir. Bu derlemenin amacı ise 3 boyutlu yazıcıların üretim yöntemlerini klinisyenlere aktarmak, protetik diş tedavisinde kullanım alanları, 3 boyutlu üretim yöntemlerinin avantajları ve dezavantajları ile ilgili değerlendirme yapmak ve protetik diş hekimliğindeki kullanım amaçlarını, kullanılan malzemeleri ve gelişmeleri gözden geçirmektir.

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INTRODUCTION

The history of 3D printers began with Dr. Kodama and continued with Charles Hull. Kodama attempted to obtain a patent for the technique he developed but was unsuccessful for unknown reasons.[1] On the other hand, Charles Hull successfully patented the stereolithography technique in 1986, which allowed for the production of 3D objects.[2] Additionally, in the same year, Hull also created the STL (Standard Tessellation Language) file format.[3]

3D designs are required for production using 3D printers. There are many programs available that can create these designs. Thanks to these programs, digital files required for 3D printing can be obtained. The digital files are typically in the STL format, which is widely used in 3D printing. The virtual object that has been designed using 3D software technology is then produced using materials such as polymers and resin composites, and undergoes heat or chemical processes.[4]

Increasing developments in computer technology and software systems have brought 3D printers to the present day. As an advanced technology, 3D software techniques allow for the production of complex and high-precision objects in various fields. 3D printers are primarily utilized in the production sector and are considered highly advanced products. They significantly reduce manufacturing preparation time, lower production costs, and facilitate the production of complex structures.[5]

3D printers, which were invented in the early 1980s, have been widely used, especially since 2010, due to their decreased production costs, making them easily accessible in many areas. 3D printers are used in various fields such as architecture, health, visual arts, space research, aviation, education, food, and automotive.[6]

The working system of 3D printers is based on the additive (layered) manufacturing method.[7]Additive manufacturing uses the three-dimensional (3D) geometric information of objects as the foundation for its production. This method utilizes raw materials like metal, composite, resin, and plastic, involving the addition of layers on top of each other.The term additive manufacturing is a general term that encompasses all manufacturing technologies that automatically produce parts by combining volume elements called voxels (the 3D equivalent of a pixel). With this method, the three-dimensional CAD model is converted into another type of model, a triangular lattice model.[8] Stereolithography is currently the most common method used for three-dimensional manufacturing. This method facilitates design flexibility and enables the production of materials that are otherwise difficult to manufacture quickly.[9,10]

In dentistry, 3D printers can be used to produce orthodontic digital models, surgical guides, crowns and bridges, surgical splints, dental models, personalized trays, and total, partial, or fixed prostheses, as well as temporary crowns, cast infrastructure modeling, and impression trays precisely and quickly in the clinical or laboratory environment. The production process is provided. The use of 3D printers in digital dentistry offers the opportunity to design personalized models, resulting in reduced chair time for patients and shorter durations for dental applications. This development is particularly important as it minimizes the margin of error in personalized dental designs.[11]

With the use of various printing materials, especially biocompatible resins, there has been a transition from the traditional 2-dimensional (2D) approach to 3D software technology in diagnosis, planning, and treatment methods in orthodontics. The aim is to adapt to the digital workflow in dentistry.[11]

Stereolithography (SLA) and Digital Light Processing (DLP) techniques are frequently preferred in dentistry. Another 3D printing technology is PolyJet technology. With this technology, the product is created by spraying liquid resin from hundreds of nozzle heads onto a table surface and then curing it with UV light. High precision production can be achieved with a layer thickness of 16µm. However, it is an expensive technology. [12]

Types Of Additive Manufacturing Technologies

1- Vat Polymerization : Stereolithography (SLA) and Digital Light Processing (DLP):

2- Polyjet / İnkjet

3- Powder Bed Fusion: Selective Laser Sintering (SLS) ve Selective Laser Melting (SLM) Electron Beam Melting (EBM), Direct metal laser sintering (DMLS)

4- Colour-Jet-Printing (CJP):

5- Fused Deposition Modelling (FDM)

6- Laminated Object Manufacturing (LOM)

1.1. Stereolithography (SLA)

The SLA production method is the oldest and most basic production method used in dentistry. It is superior to other methods due to its high mechanical durability and clarity. It was first introduced by Charles W. Hull in 1986 and defined as object construction by adding thin layers of material polymerized by UV light. The production steps are listed below.[12]

1. A computer program is used to create a 3D model of the requested object.
2. The software system divides the 3D CAD model into layers. (Having more layers leads to better clarity.)
3. 3.UV light catalyzes the liquid resin inside the tank, leading to the creation of the initial layer of the object.
4. The platform is then lowered to produce the next layer.
5. The process is iterated until the complete model is formed.
6. Once the process is completed, the resulting object is immersed in a solvent and then placed in the UV oven, thereby completing the polymerization and concluding the production phase. [14]

The production time varies based on the size of the item being produced.Polymerization may take one to two minutes for each layer. It is also possible to produce multiple objects simultaneously. Yet, in this instance, the objects must be of small size.Thus, an object can be completed in an average of 6-12 hours. SLA is used in the manufacture of special maxillofacial implants, clear aligners, and mouth guards. [15–17].

The areas of use for this production method in prosthetic treatment are as follows:

- Temporary crown and bridge prostheses
- Wax model production
- Patient-specific model
- Obturator prostheses
- Denture bases [15-17]

Advantages:

It provides fast production, can create complex shapes in high resolution, and is relatively low-cost compared to other 3D production methods. [18]

Disadvantages:

Only light-curing liquid polymers can be used. These polymers can cause skin sensitivity upon contact with liquid and can be irritating when inhaled. Additionally, they have a limited lifespan and cannot be sterilized with heat. [15–18]

1.2. Dijital Light Processing İşleme (DLP)

Digital light processing (DLP) is based on polymerization technologyIt employs a method comparable to SLA and can be grouped in the same category, but it diverges in terms of the light source utilized. This technology includes rectangular micro-sized mirrors.[19] Microscopic mirrors provide the image for DLP. The angle of these mirrors can be adjusted, allowing them to reflect light into the projection. As the number of mirrors increases, the image resolution also increases.[20] The superiority of the DLP technique over the SLA technique lies in the fact that ultraviolet light is scanned with a single pulse, rather than scanning each layer repeatedly. Both the SLA and DLP methods operate on similar principles, but both methods can produce variable outputs. In the DLP method, the images of each layer reflected by the projector consist of pixels, resulting in the formation of small rectangular volumes at the edges of the layer.[20] The resolution of the projector directly impacts the printing quality and volume. In the DLP system, a projector is located under the resin pool instead of a UV laser. [21] Additionally, thanks to the liquid resin tank, the DLP method minimizes waste and has a high production rate due to the use of light.[15-17]

Advantages:

The advantages are as follows:

1. Time-saving: It saves time.
2. Less resin requirement: It requires less amount of resin to produce the parts compared to printers that work from top to bottom.
3. Cost effectiveness: DLP systems are cheaper compared to printers that work from top to bottom.
4. Designed for complex ceramic parts: DLP systems are designed to produce complex ceramic parts that require high precision and accuracy.[15-17]

The disadvantages of liquid resin are twofold: it can cause skin sensitivity upon contact and it can be irritating when inhaled. Additionally, it cannot be sterilized with heat.[15-17]

2. Polyjet / Inkjet

The use of liquid resin as the raw material characterizes the process as polyjet, while utilizing ink as the raw material is referred to as inkjet.This method of production allows printing objects with more than one color. [22]

2.1. Polyjet

The production steps using this method are given below:[17,22]

1- The program generates a 3D model of the requested object.

2- The 3D model has been divided into slender layers.

3- Liquid photopolymers are sprayed onto the platform.

4- The photopolymers are quickly polymerized with ultraviolet light.

On top of the support structure, a fragile support material is placed. Various materials can be used in production, including liquid resins, waxes, and rubber materials. Photopolymer spraying allows for the creation of complex shapes (up to 56-16 microns) and the formation of intricate details.Photopolymer spraying technology offers a significant benefit by enabling the simultaneous use of multiple print heads, allowing for concurrent production with different materials. [17,22]

In this printing technology, thermoplastic polymers (wax, resin, and polylactic acid) are used.

In prosthetic treatment, it is utilized to create surgical guides and anatomical and working models.

Advantages:

This technology offers numerous benefits. Firstly, it conserves time. Secondly, the clarity and quality of the produced objects are quite high. Lastly, it can be used with materials of different colors and physical properties, allowing for versatility.[12]

Disadvantages:

There are many drawbacks associated with this.First, removing the support structure can be challenging and may cause skin irritation. Second, heat sterilization cannot be achieved using this method. Lastly, the cost of raw materials is also quite high. [12]

2.2 Inkjet

This system can produce a very high level of clarity, based on the method of applying minimal ink deposits through spraying. In this system, powdered particles and ink are utilized. Therefore, the ink may include a coloring agent, binder solution, or ceramic suspension. [13]

Inkjet printing production stages are;

1- A three-dimensional model of the object has been generated.
2- 3D model is divided into layers, as in other production methods.
3- Ink is sprayed.
4- The creation of items relies on the gathering of ink droplets on dust particles and iterating this procedure in the shape of platforms.
5- Manufacturing platforms involves the ink undergoing a phase change, which varies depending on the raw material used. This can be achieved through ultraviolet light, heat, chemical reactions, or drying. [22,23] In this method; Materials such as ceramics, color agents, plaster and resin can be used.

Use in prosthesis: It is used in model preparation, epithesis prosthesis making, ceramic infrastructure material production, temporary prosthesis making, surgical apparatus making, apnea appliance and occlusal splint making. [12,14] Advantages: It offers color printing capabilities, enables the use of diverse raw materials with varying physical properties, and has a broad range of applications.

Disadvantage: It is a high cost technology. [17.22]

3. Powder Bed Fusion

3.1. Selective Laser Sintering(SLS) ve Selective Laser Melting (SLM)

SLM and SLS are both laser-based manufacturing techniques that share many similarities. Laser light is directed onto the powder layer by reflective mirrors, thus producing the desired object.[15]

Production stages are given below:

1- A three-dimensional model of the item is generated.
2- The model is decomposed into layers.
3- In the area where the beam encounters the dust, a molten puddle of powder forms, and these pieces fuse.
4- Each level is scanned using laser light. Subsequently, the powder deposition is decreased by one layer, and a new layer of material is added on top. This sequence is repeated until the object is created.

With these technologies, it has become possible to obtain complex structures.[3] The energy of the laser light used in the SLM system is higher. The SLM method differs from the SLS method in that it completely melts all powder particles homogeneously. However, this distinction cannot be said to be clear. The reason for this is that complete melting occurs when the raw material of the product alone is used in the SLS method. If a second binding material is used in addition to this material, partial melting will occur. In essence, the disparity between these approaches arises from both technical distinctions and the resulting products.[24] While SLS is mostly used in ceramics and polymer production, SLM is used in metal production. In addition to using one material in products produced with SLS, more than one raw material can be used in the SLM method.[15,16]

Metal and metal alloy products are also used in the SLM system. Therefore, the term 'direct metal laser sintering' (DMLS) is also employed to define this process. The heat generated during the sintering of metal products obtained through SLM results in stress, which subsequently leads to shrinkage, surface irregularities, reduced physical resistance, and compromised dimensional stabilization. To mitigate these adverse effects, a secondary process known as post-processing is implemented. Typically, this secondary process involves thermal treatment. The process offers the benefit of reducing thermal stresses, preserving structural integrity, and thereby improving mechanical properties.[25]

This method can utilize ceramics, metal alloys, and wax.[26] In the field of prosthetic dentistry, it is employed for various purposes, including the production of wax models for casting, dental implants, removable partial denture frameworks, and the infrastructure of crown bridge restorations. [15]

Advantages:

Polymeric materials can be sterilized by heat, have high resistance, can produce precision parts, and can be recycled if a metal alloy is used.

Disadvantages:

There is a risk of inhaling dust, high surface hardness, detailed finishing is required, it is a slow process, and support structures are difficult to remove.[3]

3.2. Electron Beam Melting (EBM)

In the process of electron beam melting, metal alloys are used for production.[17,22] Objects are obtained by melting metal particles in layers under high pressure. The operational principle of electron beams mirrors that utilized in x-ray devices. It is formed by heating tungsten wire, and the beam is directed magnetically. The energy is very high.The reason for this is that a beam of electrons replaces light. As a result, the resulting metal is more free of voids and stronger when compared to other additive methods.[18]

The material used is metal and its alloys (Co-Cr alloys, Titanium).

In prosthetic dental treatment, it is used in the infrastructure production of implants used in mandibular and maxillary reconstruction, and fixed restorations.[12]

Advantages: Since it is produced at high temperatures, it does not require subsequent heat treatment, and the production time is short.

Disadvantages: Accuracy is low, cost is high. There is a risk of inhalation of dust, and also a risk of explosion during processing.[12]

4. Colour-Jet-Printing (CJP):

In this method, powder is used as the main structure. The nozzle combines dust deposits with liquid drops, layer by layer. The dust pile gradually descends, and the object is formed in layers. A thin layer of dust forms on the object. The object is supported by uninfiltrated powder. Thus, no support material is required. The resulting objects are useful in the form of working models and visual prototypes. Their accuracy is not high, and these products have a fragile structure. As a final process, surface hardness and durability are increased by infiltrating epoxy resin or cyanoacrylate into the resulting object. The advantage of this approach is that items can be manufactured in any preferred color.[3]

It is mostly used in model preparation in prosthetic dental treatment.[19]

Advantages: Color printing can be achieved using safe materials without requiring a support structure, and it is relatively fast. [3]

Disadvantages: The resulting object is not durable enough and cannot be manipulated directly.[3] Moreover, although it is cheaper than other methods, it is still costly. Sterilization cannot be achieved with both liquid and heat. Its accuracy is insufficient to be used in prosthetic treatment applications.[19]

5. Fused Deposition Modelling

This method is the oldest 3D printing method.[20] It is mostly used by low-cost 3D printers. There are more than one techniques in this method. The techniques are basically based on sending materials through the nozzle. In this method, thermoplastic materials are generally used. Another method involves removing the raw material from the hopper using a pressure injector. The layers of the object are formed by sending the molten material through the tip and then hardening it.[16] The production of the object is thus finished. The supporting part is dissolved and melted with various solutions. Different raw materials with different thermal and mechanical properties can be used.[18] The object obtained has a porous structure, enabling it to gain properties similar to the elastic modulus of tissues. For this reason, its mechanical properties are similar, which is considered an advantage.[27]

In this method, thermoplastic polymers and ceramics are used. In prosthetic dental treatment, they are used in wax model making, anatomical model making, custom tray fabrication, and surgical model making for facial reconstruction.[14,19]

Advantages:

Some materials can be sterilized with heat, products with high porosity can be obtained, they are low to medium cost, and some materials can be sterilized with heat.[3]

Disadvantages:

They have variable mechanical durability, their production is delicate, and they are limited in reflecting details. [3]

6. Laminated Object Manufacturing (LOM):

This method includes layered manufacturing and ultrasonic manufacturing.[27] The method is based on separating metal strips layer by layer and then joining them using ultrasound welding. The process heat used is low compared to other methods and allows the creation of different shapes. It is possible to bond different materials to each other with sheet lamination.[27]

Advantages:

It utilizes less energy than alternative methods because the metal is not melted, but rather separated into layers.

Disadvantages:

Laminar objects, which are mostly used in the production of visual or aesthetic models, are not suitable for structural use.[27]

Application Areas of 3D Printers in Prosthetic Treatment

3D production is an advanced design and manufacturing method that has significantly evolved in recent years and has diverse applications in prosthetic dental treatments.

Its results can be predicted in advance, in saving time for doctors, patients, and technicians. The usage of is anticipated to rise in the coming years. [13]

In prosthetic treatment, the applications include:

- Production of ceramic restorations
- Model acquisition
- Personal trays production
- Surgical guide production for implant placement
- Temporary crowns and bridges preparation
- Total prosthesis production
- Occlusal splint preparation
- Production of epitheses and obturator prostheses
- Wax modeling
- Can be used in metal infrastructure production

Additive Manufacturing and Ceramics

- Zirconia and alumina with SLA method,
- Material extrusion method, in the production of feldspathic porcelain and zirconia,
- Powder bed fusion, in feldspathic porcelain production,
- Inkjet printing, for zirconia production,
- Binder spraying method is utilized in the fabrication of feldspathic porcelains during production.[15]

Studies have reported that fissure machining of zirconia restorations obtained by the SLA method can be processed much more clearly and accurately than the subtractive method. Implants consisting of zirconia material obtained by the DLP method have sufficient dimensional clarity and accuracy.[28,29]

Zirconia produced by the 3D production method is not only monolithic but also used as an infrastructure material. It has sufficient bond strength with porcelain. In the current literature, both monolithically produced and self-glazed zirconias are included. The binder spraying method is implemented to minimize or eliminate potential drawbacks associated with the surface polishing process of zirconia in uncertain scenarios.[26]

Ceramics can be employed as raw materials for Selective Laser Sintering (SLS). Nonetheless, their elevated melting points and limited plastic characteristics pose challenges in the SLS fabrication process compared to polymers and metals. Ceramic production with the SLS technique mainly involves two primary approaches: direct ceramic SLS and indirect ceramic SLS. The first of these, the direct technique, fuses ceramic powders to produce the sintered end product. The second technique requires a binder phase in a polymer structure to combine the ceramic powders. The produced material is then sintered.[15,29]

Model Making and Personal Tray Production with Additional Manufacturing

Patient models are tools that convey the details of the patient's oral soft and hard tissues. In the conventional method, the model is obtained by taking an impression of the inside of the mouth with a measuring spoon or tray using impression materials. With the latest developing technologies, it has become possible to produce personal measuring trays with 3D printers. [30]

In a study, models were produced with 3D printers, and their accuracy rates were calculated. As a result, they reported that this rate was high. [31]

Another research endeavor focused on examining the precision of dental models created using affordable 3D printers to generate lifelike dental models and minimize expenses for dental students in their preclinical education. The wax models obtained in this study were scanned, and then the models were obtained with a 3D printer. There was no notable variance detected in the dimensions of the resultant models during the assessment.($p \geq 0.05$). [32]

In a research investigation carried out by Chen and colleagues, in addition to personal measuring spoons produced with conventional methods, it has been found that the accuracy rate of those produced with a 3D printer is higher.

Epitheses and Obturator Production with Additional Manufacturing

In a study, it has been shown that 3D printers are faster and cheaper in the long run compared to conventional production techniques in the production of metal infrastructures for removable partial dentures and fixed dentures.[33]

In another study, they aimed to use cone-beam computed tomography (CBCT) as an alternative to the traditional measurement technique in intraoral maxillectomy defects and to produce bulb sections of obturator prostheses with the SLA method and compare their dimensional accuracy. They reported that in these cases, it seems possible to produce bulbs that are sufficiently compatible with the defect area, thanks to 3D modeling created with CBCT images.[34]

Kortes et al. conducted a study where they diagrammed the digital workflow of surgical obturator production with 3D printers.[46] (Figure 5).

Additive Manufacturing and Temporary Prostheses

Peng et al.[35] reported in a study that digitally produced temporary crowns were more successful than those produced using traditional methods. Mai et al. [39] reported high compliance with temporary crowns produced by 3D printing, especially in the occlusal regions. The repair process of these materials or whether they are suitable for repair with conventional materials is unclear. Data on the changes in the mechanical properties of these materials in the mouth over time are still very lacking.[37]

In another study, the fracture strength of fixed temporary prostheses produced from PMMA using 3D printing, CAD/CAM, and conventional methods was examined. While the highest breaking strength was found in the CAD/CAM group, the lowest breaking strength was shown in the group produced with a 3D printer. However, no statistically significant difference was found between the groups. In the same study, the samples were also evaluated in terms of surface roughness, and the highest surface roughness was found in the samples produced with a 3D printer.[38]

Another study included 34 patients with 34 premolars needing prosthetic rehabilitation: a total of 68 temporary crowns were fabricated from PMMA material, 34 by CAD/CAM and 34 by 3D printing. Immediately after fabrication, milled and printed provisions were scanned with a desktop scanner to obtain STL files that were added to the original CAD design to determine occlusal accuracy. A second occlusal comparison was made by scanning both temporal types after the samples were placed intraorally with the Trios scanner; intraoral scans were obtained to compare temporary STL files before and after occlusal adjustments. Upon completion of this study,the data obtained showed that the dimensional accuracy of the occlusal surfaces of temporary crowns produced with 3D printers was better compared to those produced with CAD/CAM. When comparing the results obtained, it was found that intraoral scans played a significant role in occlusion and in the production process. It was also determined that the 3D printing technique could be effectively used to manufacture temporary PMMA crowns.[39]

Additive Manufacturing and Metal Infrastructure Manufacturing

The additive manufacturing method allows for the preparation of fixed partial denture infrastructure using metal alloys. In conventional methods, first, the inside of the patient's mouth is measured, and then the patient model is obtained. Subsequently, after wax modeling, investment, and wax elimination, the casting process of the restoration is completed. All stages require technical precision and a significant amount of time. Each of these stages significantly affects the marginal fit of the restoration. Additive manufacturing provides the opportunity to eliminate all these steps.[40]

In a thesis study, it was discovered that the edge clearance values of substructures created using the SLM method were slightly lower than those produced by the casting method, although the difference was not statistically significant ($p > 0.05$). Upon analyzing the edge openings of the metal ceramic restorations, it was found that the average edge openings of the final restorations manufactured through the SLM method (31.29±5.56) were significantly lower than those obtained by the lost wax method ($p < 0.01$).[40]

Additive Manufacturing and Complete Denture Prostheses

In a research investigation by Prpić and collaborators, a comparison was made on the flexural strength and surface hardness of complete denture bases produced via three different CAD/CAM systems, three distinct traditional heat polymerization methods, a 3D printing technique, and a polyamide material. The study revealed that two sets of CAD/CAM materials displayed the highest surface hardness values, while another group featuring polyamide material exhibited the lowest surface hardness values. Furthermore, the research indicated that materials printed using 3D printing technology showcased the lowest levels of flexural strength. Overall, the study's findings suggested that CAD/CAM materials possessed superior mechanical characteristics in contrast to heat-polymerized and 3D printed acrylics. [41]

In another study, the fit measurements between the denture tissue surface and the plaster model of denture base produced with the 3D printing technique were compared with those produced with the conventional method. The two groups did not show any statistically significant difference. Thus, this study indicates that using 3D printing to create a complete prosthesis seems to be clinically acceptable.[42]

Alharbi et al.[43] In an in vitro study, the bond strength between the tooth and the base material of total dentures produced by conventional methods was compared with dentures produced by 3D printing. The fact that cohesive fracture is dominant in prostheses produced by conventional methods suggests that there is a stronger bond strength between the teeth and the resin base in this group. The observed failure modes indicated that both fabrication techniques exhibited satisfactory bond strength.

Lo Russo et al.[44] In an in vivo study, they performed intraoral scanning of edentulous patients. Ten mandibular and ten maxillary edentulous arches were scanned, and half were produced with CAD/CAM and the other half with a 3D printer according to the appropriate workflow. The accuracy rates of the inner surfaces of the prostheses were compared. The maxillary and mandibular denture base group produced with the CAD/CAM technique showed better clarity on its entire inner surface compared to 3D printing.

CONCLUSION

3D printers will have a huge impact on dentistry in the future. Intermediate restorations made using 3D printing have been reported to yield good results and are considered clinically usable. However:

- In total dentures created with 3D printers, there is a bonding issue between the 3D printed denture base and the denture tooth, necessitating further verification regarding strength and deformation. Furthermore, some studies have indicated that the compatibility of the prosthesis with the tissue is high.
- Custom trays produced with 3D printers have shown clinical utility, with some studies suggesting that they are more adaptable than conventionally manufactured ones. Nonetheless, challenges related to design time and effort persist.
- The utilization of 3D software technology holds the promise of enhancing prosthetic manufacturing methods, materials, and processes. While fixed section restorations have shown favorable edge fit, there are still notable voids in the available literature regarding 3D printing technology, with several studies awaiting validation. Moving forward, comprehensive research efforts will be essential for further exploration in this domain.

Ethical Approval

Since sources obtained from humans or animals were not used in this study, ethics committee approval was not obtained.

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Conflict of Interest

The authors declare that they have no competing interests.

Author Contributions

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