

A Literature Review Of 3D Printing In Dental Prosthesis

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Abstract

3D printing is a technology of making 3D objects by stacking materials layer by layer, which is also called additive manufacturing process. Today, all clinical aspects, including patient admission, patient records collection and storage, patient diagnostic information acquisition and processing, treatment planning, obtaining data to form three-dimensional images and designing and producing restorations in dentistry, are done with the help of computers. Dental prostheses that are designed and made with the help of a computer (computer-aided design, computer-aided manufacturing) (CAD-CAM) have become popular in recent years. Technology based on CAD-CAM usually includes three stages: 1-data collection or digitization, 2-data processing (CAD), and 3-production (CAM). The purpose of this article is to provide a comprehensive review of the use of 3D printing in the manufacture of dental prostheses. The techniques were studied in terms of the main methods used, materials used, advantages, disadvantages, limitations and applications of each of them in making dental prostheses. Based on the results of this study, 3D printing has a huge transformative capacity in dentistry. Design freedom, mass customization, and the ability to print complex structures with minimal waste of material are the main advantages of 3D printing. Currently, with the help of this cost-effective technology in which the amount of wasted material is very small, casts, special trays, removable prostheses, surgical guides, implants, temporary prostheses, cast patterns, and metal frames can be produced.

Keywords: 3D printing, Dental prosthesis, Technology

INTRODUCTION

3D printing is a technology of making 3D objects by stacking materials layer by layer, which is also called additive manufacturing process. This technology is one of the central methods in the third industrial revolution and includes a combination of digital modeling, mechanical and electrical inspection, information technology, material science and chemistry. The shapes of printable materials are powder, thread and solution depending on the instrumentation, which can be placed in arbitrary three-dimensional patterns. Charles Hull first commercialized 3D printing technology in 1980. Today, due to the flexibility of this technology, it is considered as a comprehensive tool in the reconstruction of biological organs, jewelry making, steel structure design, electronics and food industries, as well as products related to the air and space industry. In the automotive and aerospace industry, the design of light 3D parts with complex and advanced geometry is available and reduces the consumption and waste of materials, costs and time (1).

Today, all clinical aspects, including patient admission, patient records collection and storage, patient diagnostic information acquisition and processing, treatment planning, obtaining data to form three-dimensional images and designing and producing restorations in dentistry, are done with the help of computers. Dental prostheses that are designed and made with the help of a computer (computer-aided design, computer-aided manufacturing) (CAD-CAM) have become popular in recent years. Technology based on CAD-CAM usually includes three stages: 1-data collection or digitization, 2-data processing (CAD), and 3-production (CAM) (2).

There are two methods for 3D manufacturing (CAM): Subtractive Manufacturing (SUM) and Additive Manufacturing (AM).

The subtractive method is based on milling the material block on a lathe. This technology reduces the length of treatment and has many advantages for dentists, patients, and laboratory technicians. Although it has disadvantages such as wasting a large amount of material, limitation in the thickness of the prosthesis, low accuracy in recording details due to the size of the milling cutter, and the high price of the equipment (3–5).

The additive method, which is known as rapid prototyping and 3D printing, is based on increasing the layers of materials. The AM has great flexibility in design and, unlike the reduction method, it has high accuracy in recording details. The amount of material wastage is negligible. AM methods have been developed for the construction of complex structures and in recent years have entered various fields, including dentistry (6).

3D printing is a layered manufacturing method that is used to make a 3D model of a wide range of structures with complex shapes. This technology was first invented in the 1980s by Charles Hull under the name of stereolithography (7,8). The 3D printing is becoming popular in various fields of dentistry, such as making dental models, surgical guides, and various dental veneers, implants, etc (7).

The additive process is an alternative to the subtractive method, in which materials are mostly based on powder or liquid to build a 3D solid model (9,10). AM methods have been developed to build complex structures. Rapid prototyping, the production of large structures, the reduction of manufacturing defects, and the increase of mechanical properties are the key factors in the development of AM technologies (7).

The purpose of this article is to provide a comprehensive review of the use of 3D printing in the manufacture of dental prostheses. The techniques were studied in terms of the main methods used, materials used, advantages, disadvantages, limitations and applications of each of them in making dental prostheses.

Different print methods

Additive manufacturing technology is classified by the American Society for Testing and Materials (ASTM) into seven processes according to the print method (11,12):

- 1) Vat photo polymerization
- 2) FDM (Fused Deposition Modeling)
- 3) PBF (Powder Bed Fusion)
- 4) Binder jetting or three-dimensional printing (3DP).
- 5) Material jetting or inkjet printing
- 6) DED (Direct Energy Deposition)
- 7) Manufacturing of laminated objects (LOM)

1) Vat photo polymerization

A) Stereolithography (SLA)

This method is one of the first AM methods that was discovered in 1986 (13). This method is based on light polymerization and uses UV light or an electron beam to initiate the chain reaction of resin and monomer. The raw materials are in liquid form and include photopolymers such as polyamides, elastomers, pure polymer resins, composite resins, and ceramic + resin slurry (12). The construction platform is located in a tank of liquid photopolymer. By moving the construction platform up and using laser radiation, polymerization is done and the first layer is made. To make the next layers, the construction platform moves down and sinks into the tank so that the surface of the built layer is covered by liquid polymer, and polymerization is done again with the movement of the platform. This process continues until all the layers are made and the 3D model is completed. To increase the strength, final processing by heat or photo curing may be needed (6). Printing by SLA has high quality and resolution, but this method is time-consuming and expensive, and the materials that can be used in it are very limited. On the other hand, the resin is sensitizing and causes inflammation due to contact with the eyes and skin (14). The energy of the light source and the amount of exposure are the main factors that control the thickness of each layer (13). In dentistry, SLA is used to make implants, casts, full removable prostheses, temporary veneers, cast models, and metal frames.

B) Digital light processing (DLP): The printing process and the materials used in it are the same as SLA, with the difference that in SLA, a laser is used for polymerization, but in DLP, a digital projector is used. The speed of this method is higher compared to SLA (15).

C) Continuous digital light processing (CDLP): The printing process and the materials used in it are the same

as the previous two methods, with the difference that LED or oxygen is used for polymerization. This method is faster than SLA and less expensive than DLP (15).

2) Fused depositing modeling (FDM)

The filament is heated until the material becomes semi-liquid and the desired model is made layer by layer. Acrylonitrile butadiene styrene (ABS), polylactic acid (PLA), and polycarbonates are the most commonly used materials. The main feature of this method is the thermoplastic property of the polymer, which causes the layers to be connected during the printing process, and after printing, they turn into a solid state at room temperature. The melting point of the material should be low, and after melting, its viscosity should be enough to be smooth and come out of the nozzle easily. On the other hand, it should be strong enough to support the next layers (16,17). Layer thickness, diameter, filament orientation, and porosity are the most important factors that affect the mechanical properties of the printed material. Low cost, high speed, and easy processing are the most important advantages of FDM. Low mechanical strength, layered appearance, low surface quality, and low variety of thermoplastic materials are some of the limitations of this method (18). The evolution of fiber reinforced composites has increased the mechanical strength of the FDM printed model (19). The orientation of the fibers, the bond between the fiber and the matrix, and the presence of porosity are the main challenges in using these composites.

3) Powder-Bed Fusion (PBF):

In this method, a thin layer of powder is spread on a plate and then packed. The powder in each layer is connected by a laser or connector. These plates are layered on top of each other to make the final 3D product. Then, the powder additions are removed by vacuum, and if needed, the final processing of the details is done by infiltration, coating, and sintering. The distribution and size of the powder particles in the density of the printed area, is the most important effective factor in this method. In powders with low melting temperatures, a laser is used to connect the layers. In the powder with a high melting temperature, a liquid binder is used (20). The most important limitations of the powder bed fusion method are the slow and time-consuming process, high cost, and high porosity when using the binder (14,20).

A) SLS (Selective Laser Sintering):

SLS can be used to print different polymers, metals, and alloys. In SLS, the laser does not completely melt the fabric, and the surface heat of the powder grains causes the layers to join together (21).

B) SLM (Selective Laser Melting)

Unlike SLS, SLM is only used for special metals such as steel and aluminum. In SLM, the powder is completely melted and connected, which increases the mechanical strength (21). This method is used in prosthetics to make metal frames.

C) EBM (Electron Beam Melting)

Unlike the above two methods that use a laser, EBM uses a beam of electron energy that is guided by electromagnetic coils (15).

4) Three-dimensional printing, or binder jetting:

This system is similar to the powder bed system (PBF) except that a liquid binder is used to connect the layers to each other. First, a layer of powder is deposited on the bed, and then it is aligned with the roller. Then, according to the information obtained by CAD, the binder drops are spread on the powder bed. The chemical properties of the binder, the shape and size of the powder particles, and the reaction between the binder and the powder play an important role in the 3DP process (12). The amount of porosity in this method is higher than using a laser (4,14).

5) Material jetting or inkjet printing:

It is a photopolymer injection system that makes the whole three-dimensional object layer by layer through several nozzles. The chemical basis of the material is similar to vat photopolymerization and it is cured by ultraviolet light. This method is used to make ceramics with a complex structure in tissue engineering. In this process, a

stable suspension of ceramics, such as zirconium oxide powder in water, is pumped by a nozzle onto a substrate and deposited. The drops form a continuous pattern that provides sufficient strength to support the next layers (22).

The two main types of ceramics include wax-based ink and liquid suspension. Ceramic particle size, solution viscosity, nozzle size, and print speed are factors that affect the quality of the final product (23). This method can also be used to make casting patterns.

6) Direct Energy Deposition (DED):

They are used to make alloys. Raw materials are melted and then deposited and connected together. The difference between this method and SLM is that powder is not used in this method, and higher energy is needed to melt raw materials. Compared to SLM, DED has lower accuracy and lower surface quality, but it has the ability to make models with less complexity. This method is faster and cheaper (24).

7) Laminated object manufacturing (LOM):

In this method, the materials are in the form of sheets that are cut layer by layer by laser or mechanical methods, and then they are connected. In this method, composites, ceramics, and metals can be used. Depending on the type of material, it requires final processing. LOM (without processing) has a lower surface quality and its dimensional accuracy compared to other methods of powder bed is less (25).

A Comparison of 3D Printing Methods

Among the various methods, FDM is one of the most common 3D printing technologies due to its low cost, simplicity, and high speed. It was originally used for 3D printing of polymer filaments, but it has been adapted to many other materials. The mechanical characteristics and quality of parts printed by FDM are lower compared to powder bed methods such as SLS and SLM.

Adjacent powders in powder bed methods are melted and connected together or bonded by auxiliary adhesives, which leads to more accurate separation, but incurs more costs and has a slower process.

In DED, an energy source (laser beam or electron) is used to melt metal powders, but compared to SLM, a powder bed is not used and raw materials are melted in layers before deposition like in FDM, and a much higher amount of energy is needed for the melting of metals. Inkjet printing is relatively fast and is used for 3D ceramic printing, but it requires heat treatment after processing.

When choosing the right printing system, the availability of materials, the medical properties of the materials, the required time, and the desired resolution of the printed item should be considered. A problem that needs further research is the limitation of the available materials, especially when moving beyond conventional polymers, as well as improving the speed of printing and post-processing. Despite the advantages of the AM method, there are problems that require more research and development to use this technology in different industries (Table 1).

Table 1: Common AM methods, advantages, disadvantages, and applications in dentistry.

AM technique	Materials	Advantages	Disadvantages	Use in dentistry
Stereolithography (SLA)	-Acrylate photopolymer - Plastic -ceramic	-High accuracy -flat surface -Appropriate mechanical strength -Accurate recording of details	-High cost -The need for final processing -Residual monomer toxicity	- Wax patterns -Zirconia fixed prosthesis -Removable prosthesis -Temporary cover - Metal frame
Selective laser sintering (SLS)	-polymer - Metal -ceramic	-High accuracy - High strength and hardness - Chemical resistance	- Porosity - Lower surface strength compared to SLA	-Metal cover and framework

Selective laser Melting (SLM)	-Metals and metal alloys - Stainless steel - Cobalt chrome alloy - Nickel chrome alloy - Titanium alloy (Ti-6Al-4V)	-High accuracy -Accurate recording of details -Mechanical characteristics comparable to SLS	-Need high energy to melt the powder	-Metal framework
Fused Deposition Modeling (FDM)	- Polylactic acid (PLA) -Acrylonitrile butadiene Styrene (ABS) - Polycarbonate - Polyesters Composites	-Relatively cheap -High construction speed - High strength	-Composites must be in the form of filaments	- Special tray -Complete denture with use of ABS or polycarbonate

Materials: Three categories of materials, including metals, ceramics, and polymers, are used in 3D printing.

Metals and alloys

The techniques used to print these materials are DED and PBF. Metals such as stainless steel, aluminum alloys, titanium and its alloys, and nickel-based alloys are made by these methods (26).

Polymers and composites

Due to their high diversity, they are the most common materials used in 3D printing. Polymers are used in the form of thermoplastic filament, powder, monomer and resin.

Polymers and Composites

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FDM is the most common method used to make composites (14,17).

The low strength of polymers is the biggest challenge in their use. Elements are added to the polymer to increase its reinforcement, and composites reinforced with particles, fibers, and nanomaterials have been produced so far (14).

Particle Reinforced Polymer Composites

Due to their low price, they are widely used to increase the strength and improve the mechanical properties of the polymer matrix. Particles can be added to the powder in the SLS method, to the liquid in the SLA method, and to the filament in the FDM method.

The tensile coefficient has been improved by adding glass particles (27), iron and copper (28), wear resistance by adding aluminum and aluminum oxide particles (29), and dielectric conductivity by adding ceramic particles (30,31) and tungsten (32).

Fiber Reinforced Polymer Composites

These materials are used in the FDM method. Polymer balls and fibers are first mixed in a mixer and then fed to an extruder to make filament. In the powder bed fusion method (33).

Short fibers of glass (34) and carbon (35–37) are usually used to improve mechanical properties. Fiber orientation and porosity of the final composite play an important role in strength and mechanical properties (38).

Nanocomposites

Nanoparticles of carbon (39), graphite (40), ceramics (41), and some metals are effective in improving mechanical, electrical, and thermal properties. Studies have shown that an increase of 5% by weight of titanium dioxide nanoparticles (42) and 10% by weight of nanocarbon (43) increases the tensile strength by 13.2% and 39%, respectively.

Ceramics

The most common methods for 3D printing of ceramics are SLA, PBF, and inkjet. SLS can also be used, but the possibility of cracking is very high (44).

Application of 3D Printers in Dental Prostheses:

Printers are used in various fields of dentistry, including tissue engineering, implants, maxillofacial surgery, and prosthetics. One of the first uses of CAD-CAM was the creation of accurate anatomical models and surgical guides to help surgeons simulate the surgical procedure before surgery. In 1987, Brix and Lambrecht (45) made the first anatomical models using lathes. Lathes were limited to making complex models. In 1992, Klein et al (46) introduced a method based on stereolithography.

Implants can be made by the SLM method using titanium powder, which is biocompatible. Absorbable implants are also made of calcium and phosphate. Some studies used tricalcium phosphate and hydroxyapatite to make implants and reported acceptable results (47,48).

In tissue engineering, by 3D printing, scaffolds can be made according to desired dimensions, and the amount of porosity, surface texture, and overall design can be controlled. It is also possible to add ossification stimulating factors such as BMP-2 and BMP-7 to stimulate cell attachment and proliferation, blood supply, and nutrition. Direct printing of cells to make tissue eliminates the need for scaffolding. Cells are deposited in layers. Of course, this method needs more investigation and study and can be useful for the reconstruction of the dental tissue where the pulp cavity is filled by cells (49–51). The emergence of 3D and digital technology has had a significant impact on tooth reconstruction and prosthetic work, which will be discussed in detail below.

The 3D Printing Casts

One of the first uses of 3D printing is making casts from digital molds. Baghani et al (54) investigated the accuracy of intraoral and extraoral scanning of the complete jaw arch. Different studies have been conducted to compare the accuracy of printed casts, casts prepared by the usual method, and casts obtained by milling. In the study of Patzelt et al. (55), the casts obtained by the SLA method were more accurate than the casts made by a lathe (milled cast). Although the casts obtained by milling also had acceptable accuracy from a clinical point of view. According to the study by Jeong et al. (56), printed casts were more accurate than milled ones. According to the study of Al-Imam (57), the usual gypsum casts were more accurate than the SLA casts. In the studies of Alshawaf (58) and Paspaspyridakos (59), the casts obtained from 3D printing were less accurate than the usual acetone casts. According to the results of the reviewed articles, it can be concluded that casts made of acetone have the highest accuracy, followed by casts made by SLA and milling, respectively. However, all three methods have acceptable clinical accuracy.

In a laboratory study, Jang et al. (60), in 2019, investigated the marginal and internal compatibility of three-unit fixed prostheses made on 3D printed models using digital light processing and evaluated their accuracy compared to a normal casting model. They concluded that the quality of fixed prostheses made on 3D-printed models is lower than on conventional casts, but the printed casts have acceptable clinical accuracy, which shows that improving the accuracy of 3D printers is necessary for their use in prosthetics.

Making Special Molding Trays

By using digital methods, special trays can be made in less time, with higher accuracy, and with uniform spacing for molding materials. These special trays have been reported in many studies (61). According to the results of Sun et al.'s study (62), the molds taken in special trays had a more uniform thickness. Liu et al. (63) investigated the effect of the thickness of the printed layers on the mechanical properties of the printed trays using the FDM

method. According to the results, with the increase in thickness, the bonding of the molding material to the tray first increases and then decreases, and at a thickness of 0.4 mil, it has the highest value. As the layers' thickness increases, the bending and tensile strength decrease, but its dimensional accuracy remains constant from 0.1 mm to 0.4 mm and then decreases at 0.5 mm. Therefore, the average thickness of the layers provides the best mechanical properties.

According to the results, special trays can be printed with high precision by the FDM method. The thickness of the print layers is very important and the best thickness is 0.4 mm.

Fabrication of Complete Removable Denture

In 1994, Maeda et al. (64) introduced a method to fabricate a complete removable prosthesis using light-curing resin and an SLA machine. So far, new and diverse methods have been introduced to fabricate prostheses, and numerous studies have been conducted on the accuracy of this method. They compared the methods with common reduction and traditional methods (65–67). According to the study by Davda et al. (65), dentures printed by SLA are superior in terms of precision and accuracy compared to the usual methods. In most studies, making prostheses using CAD/CAM is a reliable method, and these dentures have similar or better compatibility, biocompatibility, and mechanical properties than conventional methods. However, the possibility of using AM techniques to produce permanent prostheses is questionable. According to the results of the study by Kalberer et al. (67), the internal surface (intaglio) of prostheses made by a milling machine was more accurate than those printed by SLA. According to the study by Yoon et al. (68), milled dentures were better in terms of trueness than dentures made by DLP, but there was no significant difference in terms of textural surface compatibility. The DLP method was similar to the milling method and slightly better than the usual method. Therefore, prostheses made with digital methods are superior to those made with common traditional methods, and among digital methods, milled prostheses are better than SLA.

Construction of Temporary Restoration

Different AM methods for the construction of veneers, temporary bridges, and fixed implant prostheses have been described in studies (69,70). In addition, there are various studies that compare printed temporary restorations with normal and milled specimens. According to the results, these restorations have acceptable mechanical characteristics and marginal compatibility, and the marginal gap in SLA restorations was lower than in milled restorations (71,72). Nevertheless, more studies are needed on the biocompatibility and durability of polymers used in AM.

Printing Castable Patterns

There are currently several commercial castable polymers for AM technologies. By using these polymers, patterns can be made for all kinds of restorations and converted into metal and lithium disilicate restorations with the usual casting methods (54). Inlays and onlays made by printed patterns had acceptable internal and marginal conformity. (73,74) Kim et al. (75) compared the internal and marginal conformity of cast patterns, SLA printed and cut by a milling machine. According to the results, the internal and marginal concordance of SLA patterns was clinically acceptable and slightly better than casting. In milled patterns, the amount of marginal gap was greater. Khaledi et al. (76) compared the marginal concordance of frames cast from patterns cut by a lathe and printed by SLA and polyjet. According to the results, although all three methods had clinically acceptable concordance, the discrepancy and marginal gap were significantly less in the polyjet method. Alikhasi et al. (77) compared fixed prosthetic frameworks based on implants made from patterns printed by inkjet printing, patterns cut by a lathe, and conventional wax patterns. According to the results, although the adhesion of all three methods was clinically acceptable, the printed patterns had less adhesion than the cut ones.

The Fabrication of Metal Frameworks for Fixed Prosthesis and Removable Partial Prosthesis

Mechanical properties, internal and marginal compatibility, and dimensional accuracy of metal frameworks made by AM were investigated in studies. According to the results, the mechanical properties of Cr-Co frameworks printed by SLM are better than those produced by turning or casting machines (78). In Akçin et al.'s study (79),

implant-based prosthetic frameworks made by SLM had the same characteristics as cast frameworks and were better than frames cut by a lathe. Chen et al. (80) investigated the matching of partial frames made by the SLM method. In simple and uncomplicated frames, there was no significant difference between the SLM method and casting. According to the results, in general, the printed frames of partial fixed and removable prostheses have acceptable clinical grip, stability, and characteristics. In fixed prostheses, SLM frames were similar or slightly better than castings, but in removable prostheses, the lack of seating of SLM frames was greater than castings. However, in complex frames, the matching of cast frames was slightly better. In addition, in Ye et al.'s study (81), the lack of seating of occlusal rests in SLM frameworks was more than cast frames. Although both the SLM and EBM methods were clinically acceptable.

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Manufacture of All-Ceramic Fixed Prostheses

The wide use of ceramic materials in dentistry can be attributed to a set of characteristics such as excellent biocompatibility, chemical stability, suitable mechanical properties, and high aesthetics. However, due to the brittle nature of ceramic, it is challenging to produce it with suitable mechanical properties. Ahangari et al. (82) compared the fracture resistance of two types of alumina ceramic copings. According to the results, the fracture resistance of Turkom-Cera ceramic copings is comparable to that of In-Ceram Alumina.

Shayegh and colleagues (83) investigated the effect of repeated firings of porcelain on the edge seam and internal compatibility of zirconia frames. According to the results, zirconia was not affected by the porcelain firing cycle due to its high mechanical properties and strength as well as complete sintering, and for the compatibility of zirconia frames with dental implant abutments today, ink jetting and stereolithography methods are used to make zirconia (84). It has been shown in the studies that using the above methods, it is possible to produce zirconia parts with post-sintering density (in the range of 96.9% to 99%), high dimensional accuracy, and mechanical properties similar to zirconia in the usual way (85). Through techniques such as FDM, it is possible to print alumina parts with a density of 99%, with a homogeneous structure and improved mechanical properties (86). According to the results of Dehurtevent et al. (87), it is possible to print alumina by SLA with the same density and bending strength as the subtractive method.

Advantages

Among the main features of AM are customizations, the use of various materials, and easy and fast production. In addition, in this method, unlike reduction methods such as machining and turning, the amount of material wastage is small and almost no material is thrown away. The quality of the prostheses made with this method is reported to be higher than the usual methods, and due to its many advantages, it can replace them.

Challenges

Despite the many advantages that exist, this method also has limitations, the most important of which is the high cost. In this method, materials are made layer by layer, and the thickness of each layer is very important. If the thickness of the layers is not suitable, the model will not be integrated and it will be staggered.

The powder bed and stereolithography methods are time-consuming compared to inkjet printing and fused deposition modeling. In addition, 3D printing methods, such as powder bed (SLS, SLM), have high resolution but incur more cost for materials and more energy for processing. The long processing time and higher cost of 3D printing are the main challenges that prevent mass production. One of the main problems of 3D printing is creating a vacuum between the material layers. The additional porosity created by AM can be very high and reduce the mechanical performance due to the reduction of surface bonding between printed layers. The amount of vacuum formation strongly depends on the 3D printing method and consumables. In methods that use filament materials such as FDM, the formation of empty spaces is more common and is one of the main defects that lead to low mechanical properties. In the 3D printing of a composite using the FDM method, increasing the thickness of the filament reduces the porosity, but the cohesiveness of the composite decreases, which leads to a decrease in tensile strength and an increase in water absorption. Higher porosity of printed parts is not always a disadvantage and is considered an advantage of AM in applications where porosity is controlled, such as the design of porous scaffolds

in tissue engineering.

Discussion

This review study has been done with the aim of introducing additive manufacturing methods and the current use of its various techniques in the manufacturing of dental prostheses. The American Society for Testing and Materials (ASTM) has classified additive manufacturing technology into seven processes according to the printing method.

In dental prostheses, the four stereolithography methods (Stereolithography (SLA), Selective Laser Melting (SLM), Fused Deposition Modeling (FDM), and material jetting (inkjet)) have been used to make surgical guides, implants, casts, special trays, removable prostheses, cast patterns, metal frames, and fixed prostheses.

SLA is the most common method used in prosthodontics to make casts, complete dentures, temporary prostheses, and cast patterns. Previous studies compared SLA accuracy with conventional and milling methods. In the study of Patzelt et al. (55), the casts obtained by the SLA method were more accurate than the milled casts. Although the casts obtained from the milling method also had acceptable accuracy from a clinical point of view. According to the study by Jeong et al. (56), printed casts were also more accurate than milled ones. According to the study of Al-Imam et al. (57), the usual gypsum casts had higher accuracy than the SLA casts. In the studies of Alshawaf (58) and Papaspyridakos (59), the casts obtained from 3D printing were less accurate than the usual acetone casts. The reason can be related to the polymerization process, which causes shrinkage and thermal dimensional changes related to polymerization and may lead to distortion of SLA molds. The angle of making SLA plasters can also affect the dimensional accuracy.

According to the study by Davda et al. (65), dentures printed by SLA are superior to conventional methods in terms of precision and accuracy. According to the results of the study by Kalberer et al., they were more accurate than printed SLA, which may be due to shrinkage before the final polymerization of the printed denture, because polymerized resin is used in milling, but non-polymerized resin is used in printing and requires final polymerization.

Kim et al. (75) compared the internal and marginal conformity of cast patterns, SLA printed and cut by a lathe. According to the results, the internal and marginal conformity of SLA patterns was clinically acceptable and slightly better than casting. The marginal gap was more in milled patterns.

The SLM method is used to print the metal frame of the prosthesis. The mechanical properties of Cr-Co frameworks printed by SLM are better than those produced by the usual casting method or by milling (78). In the casting process, completely homogeneous alloys are not obtained, which leads to the construction of frames with weaker areas and reduces the clinical success. Both milled and SLM frames show more homogeneity, which may explain some of the observed stiffness differences. The surface roughness of SLM frames is a challenge and can complicate the accuracy of internal and peripheral matching. The surface of the SLM frames is probably influenced by the control of the molten metal resulting from the laser irradiation. The laser beam can melt the powder adjacent to the main structure and cause nodules and surface roughness.

Based on the findings of this review, it can be concluded that AM creates a great change in the field of dental prostheses manufacturing. However, its use is still limited. Developments are necessary to overcome technical and material limitations. Most of the findings are based on laboratory studies. Long-term clinical studies are needed before various 3D printing techniques are fully implemented in the manufacturing of dental prostheses.

Conclusion

3D printing has a huge transformative capacity in dentistry. Design freedom, mass customization, and the ability to print complex structures with minimal waste of material are the main advantages of 3D printing. Currently, with the help of this cost-effective technology in which the amount of wasted material is very small, casts, special trays, removable prostheses, surgical guides, implants, temporary prostheses, cast patterns, and metal frames can be produced.

Ethical Considerations

All ethical principles are observed.

Authors' contributions

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