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Additive Manufacturing (3D Printing) Methods and Applications in Dentistry

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ABSTRACT

Computer Aided Design-Computer Aided Manufacturing technologies (CAD-CAM) are often used in dentistry. Along with technological developments, techniques of additive manufacturing (3D) which has a lot of advantages have been improved and found a field of practice. Today, metals and metal alloys, polymer and composite, ceramic materials are produced and used through additive manufacturing techniques. With additive manufacturing in dentistry, dental implants, prosthetic restorations, maxillofacial implants and prostheses, dental models, custom trays, occlusal splints, orthodontic models and devices can be produced and used in tissue engineering. The aim of this study is to profile and evaluate the additive manufacturing methods, materials, and application fields in dentistry.

Keywords: 3D printing, dentistry, computer aided design-computer aided manufacturing, stereolithography

1. INTRODUCTION

During recent years, the tendency towards digital systems in material production has been increasing (1). After the first use of Computer Aided Design and Computer Aided Manufacturing (CAD-CAM) technologies in dentistry in 1980's by Mormann, CAD-CAM systems have become widespread with precocity (2, 3). All CAD-CAM systems are made up of 3 components. The geometry of the products turned into digital data that will be processed by the computer through numerous scanning methods. These digital data are designed by the CAD method to acquire the desired layout. Afterwards, the production of the desired material is carried out by the CAM method accordingly to the data previously created (1,4).

CAD-CAM systems have three different production concepts in dentistry, such as chairside production, laboratory production and centralised fabrication in a production centre (4). CAD-CAM systems in dentistry has been in widespread use for years with inlay, onlay, crown and bridge restorations, laminate veneer, removable partial denture frameworks, surgical guides, abutments and maxillofacial prosthesis (5).

CAD-CAM systems that is widely used in the material production in dentistry is called Substractive Manufacturing. In this method, the designed object obtained by the milling method in which additional material is abstracted from the block used for production. CAM software automatically sends the design created with CAD to the CNC (Computer Numeric Controlled) machine and locates it for the milling system of the machine (6). The accuracy of the positioning specified as 10µm. In this process, 3 axis milling system is used and the aimed design is acquired with the milling cuttlers moving over the x,y,z plain (7). This technology allows the utilizing of unmanipulable materials. It is not affected by the working conditions and has the advantage of using homogeneous materials. However, since the production is made by the removing of materials out of the solid block, the amount of waste material is a lot (1). The materials used in this system for production are metals, resin materials, silica-based ceramics, infiltrated ceramics and metal oxide ceramics (4).

The other CAD-CAM system that has been developed and used in recent years is Additive Manufacturing system. It is also called the solid freeform processing, rapid prototyping and 3D printing (1). This system has been recognised by International Standards Organisation (ISO) and American Society for Testing and Materials (ASTM) as "the process of merging the materials layer by layer, unlike the reduction method for the production of the desired material from 3D model data" (8).

Similar to the milling technique, the data is acquired by intraoral scanning. It is followed by 3D modelling with the help of CAD software; the materials are created layer by layer based on the computer generated design (Standard

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Tessellation Language) (STL). The design is usually divided into two-dimensional layers (9). Afterwards, the additional manufacturing machine carries out the production throughout x,y directions. Every layer is added after another and the material is made in three dimensions (1,10). For the production of the final restoration, procedures such as the removal of the support structures created during the production, washing and heat treatment are required (9). The thickness of the produced layers is between 15-500 microns. If the thickness of the layers is under 50 microns, the layers cannot be distinguished with the naked eye (11).

Additive manufacturing systems have advantages such as a more sensitive production in complex geometry, flexibility in design and custom designs, saving materials as opposed to conventional methods (12). The disadvantage is that with the additive manufacturing method, materials can be produced in different sizes between micro size to macro size; however, the sensitivity of the production can vary according to the method in use. The resolution, surface quality and interlaminar bonding problems may occur when post-production methods such as micro size 3D manufacturing and sintering are required. The limited materials existing for 3D manufacturing cause hardship in the usage of this technology in various industries. Thus, the development of suitable materials for 3D manufacturing and the development of the mechanical qualities of these materials are necessary (12).

The materials used in the system for production are metals and metal alloys (titanium, stainless steel, aluminium, chrome cobalt, molybdenum), polymer and composite materials (thermoplastic polymers, polylactide, polycaprolactone, polyglycolide, acrylic resin) and ceramics (alumina, zirconia) (12,13).

1.1. Methods of Additive Manufacturing Technologies

1.1.1. Vat Polymerization

A. Stereolithography (SLA): Stereolithography has been developed to produce solid objects by adding a polymerisable material (i.e. UV) over each other. This system is known as the solid-form screening process and 3D printing technology. The UV light beam pre-programmed to meet the design is used to create the cross-section of the object in a surface or the layer of the UV-polymerised liquid. The object is then moved away from the liquid surface as programmed and then the next cut is created and the layer that completes the object is added. This procedure is continued until the whole object is created (14,15). This system has advantages such as having the speed to produce in a single day, anatomical diagnostic cast, prosthetic restorations, injection model and creating a master model for various metal castings, better surface quality and less use of raw materials (16). The disadvantage of this system is that the material production needs support structures. Thus, additional material is consumed, and the removal of support structures increases the post-production time (15,17). Since this technology uses light-sensitive polymer materials, the field of use is limited. It is not used for mass production. The cost of the machine is high (16).

B. Digital Light Processing (DLP): DLP system was developed by Larry Hornbeck in 1987 (15,18). DLP was accepted to the same additive manufacturing category as SLA by ASTM since they are similar (19). The main difference between SLA and DLP is the light source that is created by the arc lamp of the image or the little mirrors that are microscopically placed in the matrix over the semiconductor digital micro signal device (DMD). The liquid photopolymer is exposed to the light coming from the projector. DLP projector shows the image of the 3D model to the liquid photopolymer. Radiation passes through a UV transparent window. The process is repeated until a three-dimensional object is produced (15).

1.1.2. Powder Bed Fusion

A. Selective Laser Sintering (SLS): In this production technology, the production is carried out by sintering method by applying a laser beam (Nd-YAG) (20). The utilised materials are in powder form and laser carries out the production by sintering the powder. The advantages of this system are that the usage of support materials is not needed during production and the material produces has high durability and stiffness. There are various finishing options. The disadvantages are that the material surfaces are porous. Usage of adhesives such as cyanoacrylate may be needed to provide the connection between layers (21,22).

B. Direct Metal Laser Sintering (DMLS): This technology is used to create materials with high accuracy and better mechanical resistance. In this technology, laser beams are used to melt the metal powder and the metals are produced layer by layer. The advantages of the system are that it can produce high resistance materials has a high accuracy rate and it can produce complex morphologies productively. The disadvantage is that porosity and deterioration can be observed depending on the material (23,24).

C. Selective Laser Melting (SLM): In this production technique, contrary to the partial melting observed in SLS and DMLS productions techniques, the metal powder is completely melted. This way, the creation of porous internal structures and granular surfaces are prevented. In SLM, the materials are better bonded. Materials with advanced mechanical properties and higher densities are produced (25). The most widespread fibre laser used in SLM to process the metal powder is the CO_2 laser (26). The disadvantage of this production technique is that there are fluctuations in temperatures during production; due to this high internal tension occurs in the material produced. The materials need heat treatment post-processing (27).

D. Electron Beam Melting (EBM): A strong electron beam produces the product as a layer by using metal powder. The raw material which is under the vacuum is stored and combined by an electron beam. The advantages of this system are that it can obtain high energy levels with narrow beams, it can efface foreign materials in a vacuumed environment, it produces low energy and needs low maintenance. The disadvantages are the vacuum cost which is too expensive, and it needs maintenance. At the same time, the EBM transmit x-ray during the production (16,28).

Fused Deposition Modelling (FDM)

Thermoplastic material is heated and produced by adding layer by layer. In this process, the printing end can use various materials simultaneously by jetting. The advantages of this system are that it can produce high resistance materials that are reasonably priced and resistant to moisture. There is more than one material colour. The disadvantages are that the mechanical properties and the surface quality are weak and the number of thermoplastics that can be used is limited. Usually, it causes bulges showing lines in every layer post production. To rid of these lines, additional processes such as polishing and sanding may be needed. Supporting materials may be needed during production and temperatures may experience fluctuations (12,29).

1.1.4. Material and Binder Jetting

A. Inkjet 3D Printing (IJP): It is one of the main methods of ceramic production in 3D. In this method, the ceramic suspension is collected over the sublayer as droplets. Then the droplets are thickened by being added layer by layer and adequate level of resistance is achieved. This method is swift and productive. Two main types of ceramics, wax essential inks and liquid suspensions are used. Wax essential inks are melted and thickened by collecting over cold raw material. Liquid suspensions are thickened by liquid vaporisation. The particle size distribution, viscosity and solid material context, extrusion speed, nozzle size and production speed of the ceramics are the determinant features of the quality of the produced material. The advantages of this system are that it can produce complex materials in less time and expense. The disadvantages are that the production process is hard, the resolution is low and the adhesion between layers is hard to protect. The sized of the materials are limited and the expense is high (12,16).

B. Polyjet 3D Printing: It is a technique in which the advantages of stereolithography (high resolution and good surface quality) and material jetting methods (high production speed and large production capacity) are combined (11). With this technique, two materials are created during production: production and support materials (30). The advantage of this technique is that it can produce multiple materials simultaneously. It is possible to produce 3D coloured materials that are hard to produce with SLA and DLP. Objects made from poly materials with various optical and mechanical properties can now be produced without the need for additional stages. The disadvantages are that contrary to other production methods, the support material has a denser structure and due to this, it requires more material use (31). The narrow production window of the utilised materials impairs the viscosity and surface tension (11).

1.1.5. Laminated Object Manufacturing (LOM)

3D models are added layer by layer through laser use. Adhesives are used to connect the layers and the production is completed by the repetition of the processes. The advantages of this system are that it can produce large-size materials, and produces fast, accurate and in high resistance. The disadvantages are that the production requires a lot of experience and time and the produced materials' surface quality and dimensional stability are low. Also, the removal of excess material post-production is time-consuming as opposed to powder bed fusion methods. Thus, it is not recommended for complex morphologies (12,16).

1.2. The Application Fields of Additive Manufacturing in Dentistry

Production of dental implants (32), maxillofacial prostheses (33), prosthetic restorations (16), occlusal splints (34), dental models (16), surgical guides (16) , custom trays (35), orthodontic models and devices (36) and usage in tissue engineering (37) are carried out by additive manufacturing methods in dentistry.

1.2.1. Dental Implants

The implants on the market offer a limited variety of design by means of length, diameter and thread parameters. Considering the personal oral and clinical conditions, custom dental implants eliminate the difference between existing standardised designs and the oral conditions of the patient (32). Implants with desired designs and features can be produced with three-dimensional production techniques (38). The 3D templates are created during implant surgery. And the implant replaces the missing tooth with a more reliable and economical method than conventional methods. The production of implants with personalised and complex geometry can be carried out in a short time with different material types. Better surface quality is obtained in dental implants with this method (16).

Osman et al. (39) evaluated the dimensional stability, surface and mechanical properties of zirconia implants and zirconia discs produced with DLP method. It is detected that the DLP method is efficient in the production of custom zirconia implants with adequate dimensional stability. At the same time, it has been reported that the mechanical properties of the produced materials show flexural strength close to the ceramics produced by conventional methods.

In the 3-year prospective study Tunchel et al. (40) carried out, the survival and success rates of additive manufacturing and the titanium dental implants produces were evaluated. It was found that in the titanium dental implants manufactured with the additive method, the general implant survival rate for single-tooth spaces in both jaws is 94.5% and the clinical results were successfully received up to three years.

1.2.2. Prosthetic Restorations

After the intraoral scanning is done with this method, metals and metal alloys, polymers and composites and ceramic materials can be used to produce inlay-onlay (41), temporary and permanent crown-bridge restorations (16,42), crown-bridge substructures and partial prosthesis frameworks (43), complete dentures (44) and save on time. In the study conducted by Ahlholm et al. (41) the inlay and onlay restorations were produced with milling and 3D manufacturing techniques and compared by their accuracies. The accuracy of the restorations produced with the 3D manufacturing technique was found to be almost as same as the restorations produced with the milling technique.

In a study, the accuracy of complete dentures produces by additive manufacturing was compared to the complete dentures produced by CAD-CAM milling. It was reported that the complete prosthesis produced by the milling method has higher accuracy than those produced by 3D manufacturing (45). Lin et al. (44) reported that they produced temporary removable complete denture with DLP method using a photopolymeric resin and Wilkes et al. (46) reported that they produced bridge restoration substructure that is 80% zirconia and %20 alumina with SLM method. Tahayeri et al. (42) compared the mechanical properties of temporary crown and bridge restorations produced by stereolithography technique and conventional methods. It was stated that temporary crown and bridge restorations produced by the additive technique have adequate mechanical properties of intraoral use.

1.2.3. Maxillofacial Implant and Prostheses

Titanium and polymer (Polyetheretherketone) materials were used to produce maxillofacial implants and protheses with additive manufacturing methods. The production is faster than the milling method. It has the advantage of using homogeneous and uniform materials (43,47,48).

Scollozi et al. (49) produced maxillofacial prosthesis using PEEK material in their study and provided defect reconstruction. They emphasized that this technique not only achieve a predictable correction for congenital or acquired deformities but also aesthetic expectations. Unkovkskiy et al. (33) reported that they reconstructed the maxillofacial defect by producing a nasal prosthesis with the additive manufacturing technique by using silicone material.

1.2.4. Occlusal Splints

Occlusal splints can be produced with additive manufacturing methods and used for diagnosis and treatment (34). Venezia et al. (34) produce occlusal splint with 3D manufacturing technique using acrylic resin. They stated that this production technique saves time for the physician and the patient since it is chairside, the accuracy and precision of the splint produced is high and can be reproduced when necessary.

1.2.5. Dental Models

Additive manufacturing methods have the potential to produce custom models. This model also can be used as a guide model (16). At the same time, education models in the field of medicine and dentistry can be produced with additive manufacturing techniques. Since the produced models demonstrated the anatomy well and are colourful, they can be used in education and research (50). Alshawaf et al. (51) compared in their study the dental models they produced with the SLA method and conventional stone casts. The reported that the accuracy of the models produced with the SLA method is lower than the conventional methods. In their study, Choi et al. (52) compared the fracture toughness and flexural bond strength of the artificial teeth they produced with heat cured, milling and 3D manufacturing methods after thermal ageing. It was concluded that the fracture toughness and bond strength of the artificial teeth produced by heat cured decreased significantly with ageing and the bond strength of the artificial teeth produced by milling and 3D manufacturing technique was low and not affected by aging. It has been reported that unlike milling and 3D manufacturing methods, the heat cured artificial teeth have the highest bond strength to various prostheses.

1.2.6. Surgical Guides

This technology produces high precision surgical guides. It improves the reliability of the applied surgical method and improves patient outcomes (16). Turbush et al. (53) produced bone-supported, tooth-supported, and mucosa-supported surgical guides using CBCT data for implant planning and placement protocols with the SLA technique and compared their accuracy. It has been reported that the accuracy of the mucosa-supported guides is lower than the other two techniques. In their study, Kim et al. (54) produced surgical guides with 3 different 3D printers (stereolithography, polyjet, multijet) and compared their accuracy. It has been reported that the highest accuracy is in the surgical guides produced with PolyJet technique and the least accuracy is in the multijet technique.

1.2.7. Custom Trays

Custom trays can also be produced with additive manufacturing technologies. The CAD design of the custom tray allows the control of a homogeneous area for the impression material and reduces manual procedures (35). Using the FDM technique, Chen et al. (35) produced a custom tray for a fully edentulous mandible. They found out that the custom tray produced by this method has higher accuracy than conventional production methods.

1.2.8. Tissue Engineering

Tissue engineering is the process of tissue production using a combination of cells and materials. Cells can accumulate on a 3D tissue scaffold or can be allowed to proliferate without

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a tissue scaffold (13). The tissue scaffold must direct and stimulate tissue regeneration and should be biodegradable (37). In scaffold-free tissue engineering, polymeric support structures are required for the movement of blood and nutrients. This application can be used in dental tissue regeneration where the pulp cavity can be filled with cells and microstructured biomaterials (55). Shuai et al. (56) reported that they produced bone tissue scaffolds using nano-hydroxyapatite with the SLS method.

1.2.9. Orthodontic Models and Devices

With the additive method, the orthodontic model, devices used in the treatment of irregularities in teeth and jaws can produce. The dentist can scan with the intraoral method and design an orthodontic model and device, and finally produce this device with additive manufacturing technologies (57). Jindal et al. (57) compared the accuracy of thermoplastic-based aligners produced by the traditional method and resin-based aligners produced by the 3D method. They reported that the resin-based aligners produced with the 3D method have high geometric accuracy, better mechanical properties and they shorten the processing time.

1.3. Materials Used with Additive Manufacturing Methods

1.3.1. Metals and Metal Alloys

Metal and metal alloys can be produced by traditional casting, milling technique and additive manufacturing. 3D manufacturing of metals consists of melting metallic raw material (powder or wire) using an energy source such as a laser or electron beam. The molten material is solidified by adding layer by layer. With additive manufacturing, high accuracy and fast production can be achieved (12).

Although well-designed studies have been conducted on the properties of titanium alloy produced using SLS (especially Ti_6Al_4V), little has been produced on other materials that can be produced using the same technology. Additive manufacturing techniques such as direct metal laser sintering (DMLS) have been used to overcome the difficulties encountered during the production of high hardness materials such as CoCr (cobalt-chrome) with traditional casting and milling techniques. The shrinkage during casting and the high hardness of CoCr making it difficult to produce by milling technique were eliminated by DMLS technology (58). In their study, using the titanium alloy with SLM method, Kanazawa et al. (59) produced a maxillary complete denture infrastructure, evaluated their hardness and microstructures, and concluded that they were suitable for clinical use.

Uçar et al. (60) compared the internal fit of CoCr alloy crowns produced by laser sintering technique and traditionally produced CoCr alloy and Ni-Cr alloy crowns. As a result, no significant difference between the 3 crown materials and internal fit between the crowns has been found.

In a study evaluating the metal-ceramic bond characteristics of Co-Cr alloys produced by casting, milling and selective laser melting methods, the oxidation surface and interfacial characterization and composition before porcelain application were evaluated and the ceramic bonding strength was assessed by 3-point bending test. It was concluded that the oxidation surface and thickness of CoCr alloys depend on the different manufacturing techniques used. The bond strength was found to be 37.7 ± 6.5 MPa for casting restorations, 43.3 ± 9.2 MPa for milling restorations and 46.8 ± 5.1 MPa for SLM restorations. Statistically significant differences were reported between the 3 groups that were tested (61).

Revillia-Leon et al. (62) produced and compared titanium frameworks for complete arch implant-supported prostheses using SLM and EBM additive manufacturing technologies. The implant-prosthesis discrepancy did not show a significant difference between SLM and EBM additive manufacturing technologies. Titanium frameworks produced by additive manufacturing have been reported to be a clinically acceptable implant-prosthetic discrepancy.

1.3.2. Polymer and Composite Materials

Polymers are considered to be the most widely used materials in 3D manufacturing due to the variety of materials and ease of adaptation to different methods. Polymers are available in the form of thermoplastic filaments, reactive monomers, resin or powder for 3D manufacturing. The advantages of producing composite materials with 3D manufacturing are that they identify the geometry with high accuracy and are more cost-effective than other traditional production methods. Since the durability of polymer materials produced by additive manufacturing is low, their usage areas are limited. Researches aimed at improving the low mechanical properties of 3D-produced polymers and leading to the development of various methods and materials for the production of improved polymer composites with better performance are being conducted (12,63). It has been reported that adding fibre to polymer materials can increase the mechanical properties of polymers (64).

Polymer material production with additive manufacturing technique is slower compared to traditional methods such as milling technique and injection moulding. However, with this method, CAD-guided production of many material systems with complex morphology and properties is provided (11).

Additive manufacturing techniques used in the production of polymer and composite materials are SLA, SLS, FDM and IJP. The most used method to produce polymer composites and thermoplastics with low melting points is FDM (63). However, the materials used must have good physical properties and must be environmentally friendly. Polymers commonly used in additive manufacturing are polymers such as Acrylonitrile butadiene styrene (ABS) and polylactic acid (PLA). ABS has good mechanical properties but gives an unpleasant smell during production, PLA is environmentally friendly, but its mechanical properties are poor (65). Photo polymeric resins can polymerize when activated by UV light in the SLA method (11). Also, the thermomechanical properties of photopolymers still need improving. The molecular structure and sequence of the polymers produced depend on the thickness of the layers due to UV exposure and variable density (12).

Selective laser sintering is the second most used method in polymer production. Polymers used in production by selective laser sintering include polystyrene, polyamides, and thermoplastic elastomers (12).

PLA-based composite materials are used in the production of tissue scaffolding in additive manufacturing (12). Senatov et al. (66) have created PLA-based hydroxylapatite scaffolds with a porosity of 30% for bone implants. A combination of PLA and bioactive CaP has been produced by additive manufacturing to create a 3-dimensional biocompatible scaffold for various tissue engineering applications (32).

With the latest technological developments, the usage of silicone material in the production of facial prostheses has begun. Jindal et al. (67) reported that the mechanical properties of the produced prosthesis depend on the composition of the silicone material.

1.3.3. Ceramic Materials

The ceramic material is widely used in dentistry due to its positive properties such as biocompatibility, good mechanical and optical properties, chemical stability, and thermal conductivity (1, 68). In addition to its positive features, it has disadvantages such as fragile structure and difficulty of production processes. The ceramic material can be produced in dentistry using traditional methods (69), substractive manufacturing and additive manufacturing (1) techniques.

Ceramic components are traditionally produced by manufacturing methods such as injection moulding, die pressing, tape casting, gel casting, etc. The desired morphologies are created from a powder mixture with or without binders (69). After production, the components must be sintered at high temperatures to densify. However, these manufacturing techniques cause limitations in terms of long processing times and high costs (70). The high melting points of ceramics make it difficult to melt under normal heating methods. Although it is possible to melt some ceramics, this process may cause a new phase formation. During cooling, thermal shock can occur, leading to cracks. On the other hand, various factors (sintering temperature and duration, particle size and distribution, the content of binders) related to the production stages of ceramic materials and the properties of the raw materials used affect the porosity. The increasing porosity negatively affects the mechanical properties of the final product (1).

The production of ceramic components by milling technique is extremely difficult due to their extreme hardness and brittleness. It is difficult to obtain good surface quality and dimensional stability with this method. Milling tools are subject to severe wear. Failures such as cracking and breaking can be seen in ceramic materials (70).

The production of ceramics with 3D printing techniques was first performed by Marcus et al. (71) and Sachs et al. (72) in the 1990s. To date, a wide variety of 3D manufacturing techniques have been developed for ceramic production, with material science and technological developments (70). In the production of ceramics with 3D manufacturing methods, Inkjet 3D manufacturing technique, powder bed fusion and SLA methods are frequently used (12). Inkjet 3D manufacturing method is considered as the main method of producing dense ceramic that will not need post-production processes. Inkjet 3D manufacturing requires a stable suspension with controlled rheology that flows easily, does not clog, and has an effective drying process (73).

With the SLA method, the moving beam polymerizes the ceramic suspension containing light-sensitive substances. Thus, stratified production of a three-dimensional object is possible. As a result, a material consisting of an organic matrix containing ceramic powder particles is produced. This part is also called the green body. The additive manufacturing of ceramics is a three-step process. Once the green body has been produced, a two-step thermal process (debinding and sintering) is required. In the debinding process, the organic matrix is burned at temperatures up to 550 ° C. In the first step, the diluent evaporates. Thus, porosity are formed in the green body. The porosities then facilitate diffusion and evaporation of the pyrolyzed polymer components. The burning of the organic part and the sintering procedure leads to weight loss and volume shrinkage (74).

Another additive manufacturing technique used in ceramic material production is selective laser sintering (SLS). However, heating during fusion and cooling down to room temperature after production can cause thermal shock and cause cracks in the ceramic (73).

Ceramics are often used in dentistry in crown and bridge restorations, endodontic posts, orthodontic brackets, dental implants, and abutments (1, 75). Materials such as zirconia and alumina are used in the additive production of ceramics.

1.3.4. Zirconia Ceramics

Zirconia, a polycrystalline ceramic is generally stabilized by 3 mol% yttria (3Y-TZP) for dental applications. Zirconia ceramics can be stabilized in tetragonal or cubic phases depending on the additive used (Y_2O_3, MgO, CaO), its concentration and temperature during heat treatment (1). Its components and additives have positive properties such as hardness, abrasion resistance, high texture compatibility due to post-production sintering procedures and heat treatments (76,77). 3Y-TZP ceramics, which are frequently used today, are used in the construction of dental crowns and especially long bridge restorations in the anterior and posterior region (76,78). It has been reported that zirconia is biocompatible with oral tissues and osteoconductive. Bone formation becomes easier as a result of the contact between the zirconia ceramic and the bone. Studies also emphasize that zirconia does not cause allergic reactions or taste changes (79-81).

Ebert et al. (82) reported that using zirconia ceramic suspensions, they created crowns-sized dense three-dimensional components with inkjet 3D printing technique (Inkjet 3D printing). It has been observed that the failure rate of the produced and sintered samples is low. With this study, it was possible to obtain samples with a density of 96.9%, comparable to the 3Y-TZP traditionally produced by cold isostatic pressing.

Lian et al. (83) reported that they successfully produced zirconia ceramic, while Cheng et al. (84) reported that they successfully produced the yttria-containing zirconia ceramic using the SLA method. Moin et al. (85) reported that they successfully produced the root analogue implant with zirconia ceramic using the DLP manufacturing method.

1.3.5. Alumina Ceramics

Alumina ceramics, also called aluminium oxide (Al_2O_3), are used in endodontic posts, orthodontic brackets, dental implants, crown and bridge substructure production and ceramic abutments (75). According to the US Food and Drug Association (FDA), high purity alumina should be used. High purity alumina generally has 99.99% purity and has been developed as an alternative to metal alloys for dental applications (1).

Maleksaeedi et al. (86) produced the alumina material with high density and improved mechanical properties using vacuum infiltration inkjet 3D manufacturing method. It has been reported that the properties of the materials produced by this technique are highly dependent on the appropriate suspension concentration, the thickness and size of the produced material, and the complexity of the morphology.

Uçar et al. (87) compared the fracture mechanics, microstructure, and elemental composition of alumina-based on stereolithography with the alumina ceramics produced by pressing and CAD-CAM methods. They compared the flexural strength of these materials using In-Ceram alumina and alumina-based on stereolithography. They concluded that SLA-based alumina is a promising technique for ceramic production in dental applications.

2. CONCLUSION

Additive manufacturing can be made thanks to the materials and techniques developed with the use of CAD-CAM applications in dentistry. Production carried out using metals and metal alloys, polymer and composite materials and ceramics with additive manufacturing. With additive manufacturing in dentistry, dental implants, prosthetic restorations, maxillofacial implants and prostheses, dental models, custom trays, surgical guides, occlusal splints, orthodontic models, and appliances can be produced and used in tissue engineering. Since additive manufacturing techniques have new and many advantages, research is being done on them. The mechanical and biological properties of the restorations produced with this technique should be examined and evaluated in detail before oral use in the clinic.

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