ISSN: 2469-5734

Sert and Dikicier. Int J Oral Dent Health 2024, 10:163
DOI: 10.23937/2469-5734/1510163
Volume 10 | Issue 1
Open Access

International Journal of
Oral and Dental Health

REVIEW ARTICLE

Additive Manufacturıng Techniques Used in Prosthetic Treatments

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Abstract

With recent technological advancements, manufacturing methods in dentistry have undergone significant transformations. Digital methods are now preferred over traditional techniques. Subtractive manufacturing involves obtaining the desired form by milling the material from a block through computer programs. This process is time-consuming, and due to the generation of a considerable amount of waste material compared to the desired product, it is cost-intensive. On the other hand, additive manufacturing is a computer-controlled process that allows the formation of the desired shape by layering materials.

Metals, polymers, and ceramics are commonly used in additive manufacturing. In prosthetic treatments, from temporary crowns to bridge restorations, and from removable prosthesis frameworks to abutments, additive manufacturing finds applications in various areas. Additive manufacturing offers a series of advantages over traditional methods, including precision, time and material savings, and the elimination of issues commonly encountered in conventional techniques. In prosthetic restorations, additive manufacturing techniques are increasingly becoming prevalent by leveraging these advantages.

Keywords

Additive manufacturing, 3D printing, Prosthetic treatments, Stereolitography, Digital light processing

Introduction

In dentistry, the initial digital production methods began with subtractive approaches. Subtractive production involves the mechanical erosion of material from a block through computer-controlled milling, resulting in the desired form [1]. Subtractive production offers several advantages, such as shortened production processes, a broad range of indications, brief clinical waiting times, high surface resolution, the availability of various materials, and the ability to achieve pore-free production with superior biological and mechanical properties. However, this method also presents disadvantages, including excessive material consumption, wear and tear on the milling tools over time, the impact of tool diameter on production precision, the influence of heat generated during production on the material, high waste generation, and generally high costs [2].

Additive production, on the other hand, involves the creation of the desired form in layers, with the material obtained from powder, liquid, or various polymerization methods under computer program control. This production process represents a general term for automatically producing parts by joining voxel, which are volumetric elements. Additive production begins by converting the 3D CAD model into a model with a triangular mesh (such as in STL format, although other formats like AMF or 3MF have emerged in recent years) [3,4]. After the model is segmented into layers through specialized software, it is transformed into a layered part using a 3D printer.

Additive production facilitates the design process and allows for the rapid production of parts that may be challenging to produce otherwise [5-10]. Additionally, terms such as "three-dimensional (3D) manufacturing" or "3D printing" are used interchangeably for this method. The devices used in this production process are commonly referred to as "3D printers." Additive manufacturing methods offer a range of advantages and disadvantages:

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Citation: Sert B, Dikicier S (2024) Additive Manufacturıng Techniques Used in Prosthetic Treatments. Int J Oral Dent Health 10:163. doi.org/10.23937/2469-5734/1510163

Accepted: April 19, 2024: **Published:** April 21, 2024

Advantages:

1. Reduction in Production Processes and Costs
2. Rapid Prototyping Capability
3. Production of Complex-Shaped Parts
4. Decreased Need for Data Storage
5. Wide Variety of Material Options
6. Reduction in Waste Generation

Disadvantages:

1. Removal of Support Structures Post-Production
2. Surface Quality
3. Cost of Equipment

This compilation aims to provide general information about the evolving additive manufacturing techniques, specifically focusing on their use in dentistry, particularly in prosthetic restorations. The purpose is to highlight the application of these methods and present studies conducted in this field.

Additive Manufacturıng Techniques

Due to the diverse nature of additive manufacturing technologies, it is not feasible to categorize them under a single main group. The American Society for Testing and Materials (ASTM) has classified additive manufacturing technologies into seven main headings:

1. Tank Resin Polymerization (Reservoir Photopolymerization)

- Stereolithography (SLA)
- Digital Light Processing (DLP)

2. Material Jetting (MJ)

- Photo polymer Jetting (PPJ)
- Inkjet Printing

3. Material Extrusion

- Fused Deposition Modeling (FDM)

4. Powder Bed Fusion (PBF)/Powder-Based Fusion

- Selective Laser Sintering (SLS)
- Selective Laser Melting (SLM)
- Selective Electron Beam Melting (SEBM)

5. Binder Jetting/Adhesive Jetting

- Powder Binding Printers (PBP)/3D Inkjet Printing/3D Printers
- Binder Jetting (BJ)

6. Sheet Lamination

7. Directed Energy Deposition

This classification provides an overview of the major additive manufacturing techniques, each encompassing various methods for producing objects layer by layer. It is essential to understand these techniques to explore their applications and advancements in various fields, including dentistry.

Additive Manufacturing Techniques in Prosthetic Treatments

In dentistry, particularly in prosthetic restorations, additive manufacturing techniques are widely utilized. Among these techniques, stereolithography, digital light processing, selective electron processing, selective electron melting, binder jetting, fused deposition modeling, inkjet printing, and polyjet modeling stand out prominently.

These techniques find applications in various prosthetic restorations such as temporary crowns, bridge restorations, prosthetic frameworks, surgical guides, obturators, and many more. The diversity of materials, including metals, polymers, and ceramics, further enhances the versatility of these technologies.

Metal Production with Additive Manufacturing Techniques

The production method using Selective Laser Melting (SLM) exhibits the ability to manufacture Co-Cr restorations in a shorter time and at a lower cost compared to traditional and CAD/CAM milling production methods. Presently, it has become a standard process for the production of crowns and bridge prostheses using Co-Cr alloys. Additionally, long bridge restorations can be placed passively on abutment teeth or implant abutments.

This method reduces costs by shortening the production time for numerous crown-bridge restorations on a single platform. Units are subjected to a thermal treatment step before being detached from the platform, and this process can be automated in many production centers. Post-thermal treatment, detached units are manually completed. The physical and mechanical properties of laser-sintered non-casting metal alloy crowns and bridge restorations are comparable to cast restorations.

The retention force of removable partial dentures produced by laser sintering has been reported to be similar to those produced by the casting method. Additionally, a study has shown that possible small roughness is uniformly distributed across all clasps [11,12].

Ceramic Production Usıng Additive Manufacturing Techniques

The production of ceramic dental prosthetic materials using additive manufacturing techniques is still in the developmental stage, primarily concerning factors such as appropriate surface coating, mechanical properties, and dimensional accuracy. These materials have higher melting points and lower sinterability compared to other materials.

The production of ceramics through additive manufacturing can be categorized into two groups [13]:

Here's the highlighted list:

a) Indirect Technique

- Trixprinting process by Dekema (Freilassing, Germany)
- IPS e.max Digital Print Design - Ivoclar Vivadent's WaxTree (Schaan, Liechtenstein)
- Indirect 3D Printing of Ceramic by Dekema (Freilassing, Germany)

b) Direct Technique

- SLA process, for example, 3D Ceram (Limoges, France)
- DLP process, for example, Lithoz's LCM (Lithography-based Ceramic Manufacturing, LCM) (Vienna, Austria)
- Material extrusion (fusion filament fabrication, FFF; paste extrusion modeling, PEM)
- Material spraying/nanoparticle spraying, for example, XJET (Rehovot, Israel)
- Binder jetting, for example, 3D Systems (Rock Hill, SC, USA)
- SLS process (research project at the Prosthetic Dentistry Department of Munich University, Friedrich Baur Biomaterials Institute in Bayreuth, Germany, and Konzept Laser in Lichtenfels, Germany)
- Laminated object manufacturing (LOM) process

Polymer Production Using Additive Manufacturing Techniques

A significant portion of the 3D printing devices launched in the medical field in 2014, constituting the majority of additive manufacturing technology, includes polymer-based materials. Materials such as polyetherketone (PEEK) and polymethylmethacrylate (PMMA), in particular, have been produced through systems based on various material spraying and photopolymerization methods during the printing process. Polymer materials obtained through these technologies find applications in various fields of dentistry, including surgical guides, abutments, crown-bridge prostheses, temporary restorations, obturator prostheses, and others [14].

Discussion

Additive manufacturing, especially in recent years, has made significant advances in the field of dentistry. In this section, the focus is on the advantages of additive manufacturing methods compared to other techniques, and data obtained from scientific studies.

Tasaka, et al. in their study on removable partial denture frameworks produced with Selective Laser Sintering (SLS), stated that the frameworks' clasps were better than those produced with other additive manufacturing methods. However, they emphasized noticeable differences in environmental and RPI clasps arms. They warned that long and thin clasps might be distortion-sensitive when using SLS [15].

Williams, et al. in a study examining removable partial denture frameworks made using Selective Laser Melting (SLM) with Co-Cr alloy, concluded that these metal frameworks were similar in terms of accuracy, fit quality, and function compared to those produced with existing dentistry methods [16].

In another study evaluating the bending fatigue properties of Co-Cr-Mo-W alloys produced by traditional casting and Selective Laser Melting (SLM), it was reported that the bending strength of samples produced with SLM was higher than that of traditional cast samples, and the fatigue strength was twice that of traditionally cast samples [17].

In a study where 3D printing was used to produce total prostheses using a printed flask, it was stated that the compressive mucosal displacement values of the prosthesis were satisfactory compared to the original STL file. Additionally, compressive mucosal displacement was reported to be lower than that of traditionally manufactured prosthetic base plates [18].

Dehurtevent, et al. in a study comparing the physical and mechanical properties of alumina ceramics produced with SLA to subtractively manufactured ceramics, demonstrated that alumina crowns obtained with SLA had sufficient density and suitable physical properties [19].

In a research comparing the accuracy of zirconia crowns produced with additive and subtractive manufacturing techniques, root mean square (RMS) ± standard deviation values were measured for different crown surfaces. The results indicated that for the outer surface of the crown, the RMS value of the 3D printing group was greater than that of the milling group. However, for the inner, marginal, and occlusal surfaces, the RMS values of the 3D printing group were lower than those of the milling group, suggesting that crowns produced with 3D printing were not significantly superior to those produced with milling ($P < 0.05$) [20].

Moby, et al. in a study aiming to determine the optimal parameters for printing PEEK materials, concluded that high nozzle temperature (150-200 °C), high printing temperature (420 °C), and 100% infill were necessary for dental restorations (42).

Limaye, et al. compared the mechanical properties of 3D-printed and CAD-CAM PEEK materials. According to the results, 3D-printed PEEK exhibited lower mechanical properties than objects produced by CAD-CAM manufacturing [21].

Guo, et al. evaluated the mechanical properties and fit of 3D-printed PEEK removable partial dentures (RPDs). According to the study results, 3D-printed RPDs had higher compressive strength than traditionally produced samples. Additionally, the mechanical properties and fit of FDM-printed PEEK RPDs primarily met clinical requirements [22].

Zheng, et al. produced 3D-printed PEEK/HA scaffold structures with different hydroxyapatite (HA) content and pore sizes using FDM technology. The study evaluated the effects of pore size, compression direction, and HA content on mechanical properties. The results showed that the mechanical properties of PEEK/HA scaffold structures were adjustable as pore size changed [23].

Mohajeri, et al. compared the marginal fit of temporary restorations obtained from PMMA using three different methods (traditional, CAD-CAM, 3D printing). The results indicated that the marginal fit of temporary restorations produced by all three methods was within an acceptable range. However, PMMA temporary restorations produced by 3D printing showed the lowest marginal fit [24].

In a similar study by Kim, et al. the accuracy of temporary restorations produced by CAD-CAM, DLP, and SLA technologies was compared. The study results showed that the accuracy of SLA and DLP produced by a 3D printer was less than 120 µm and provided clinically acceptable results [25].

Giugovaz, et al. conducted a study examining the flexural strength of aged and non-aged polymethylmethacrylate (PMMA) temporary materials produced by various methods. In the study, samples produced by CAD-CAM exhibited the highest flexural strength values, while those obtained by additive manufacturing showed the lowest flexural strength values. Additionally, additive manufacturing yielded the lowest surface roughness [26].

Takeda, et al. evaluated total prostheses produced using 3D printing. The study showed that prostheses manufactured with a 3D printer had higher mechanical strength without exposure to polymerization shrinkage, which could affect prosthetic base adaptation and correct tooth position [27].

Liu, et al. compared traditionally produced and 3D-printed trays based on the deviation in vector magnitudes of implant positions. They stated that 3D-printed trays provided more accurate implant positions [28].

Wang, et al. compared EBM with SLA in a study, observing that SLA had higher raw material utilization, faster shaping speed, high dimensional accuracy, excellent surface quality, complex structure modeling, lower cost, and easy equipment maintenance compared to EBM [29].

Kasparova, et al. compared the accuracy of models produced using EBM and SLA. The study indicated that models made with the SLA method tended to provide higher accuracy and more detailed surfaces compared to those made with the EBM method. Furthermore, models produced with EBM and SLA did not show significant differences compared to traditionally manufactured plaster models, concluding that the use of 3D models was sufficient [30].

Bukhari, et al. in a study where they produced working models with additive manufacturing, mentioned the challenge of developing a biocompatible, printable material with desired dental properties for this technology. It is known that currently approved materials by the U.S. Food and Drug Administration are limited in type and color [31].

In a study by Algabri, et al. on patients with TMD, it was determined that occlusal splints produced with CAD/CAM systems were more effective than those produced with traditional methods. The study examined the effect of both types of splints on muscle activity using 15 traditional and 15 digital splints in each group. The results showed that digital occlusal splints caused a more significant reduction in TMDs, but there were similar results in terms of muscle activity improvement between the two groups. Additionally, digital splints were reported to have a shorter clinical application time [32].

Conclusion

With advancing technology, production methods in dentistry have undergone significant changes from the past to the present. The use of digital methods has increased over traditional methods. The advantages of additive manufacturing include precision, time and labor savings, and the elimination of problems encountered in traditional methods.

Additive manufacturing techniques encompass various methods, grouped under seven main headings: Stereolithography, digital light processing, selective electron processing, selective electron melting, binder jetting, fused deposition modeling, inkjet printing, and polyjet modeling are commonly used techniques in prosthetic restorations in dentistry. While these techniques offer a wide range of applications in prosthesis production, the cost of the devices used can be limiting in some cases.

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