Research, Society and Development, v. 9, n. 11, e80791110632, 2020
(CC BY 4.0) | ISSN 2525-3409 | DOI: http://dx.doi.org/10.33448/rsd-v9i11.10632

Indications, materials and properties of 3D printing in dentistry: a literature overview

Indicações, materiais e propriedades da impressão 3D na odontologia: uma visão geral da literatura

Indicaciones, materiales y propiedades de la impresión 3D en odontología: descripción general de la literatura

Received: 11/26/2020 | Reviewed: 11/29/2020 | Accept: 11/30/2020 | Published: 12/04/2020

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Abstract

3D printing and digital manufacturing technologies have been largely used in dentistry in recent years and dentists and prosthetic technician are up to date and involved in the subject, following the advancement of technology. The objective of the present manuscript was to carry out a descriptive literature review, covering the processing methods, precision, types of materials used and the applications of 3D printing in dentistry. A bibliographic search was conducted in the PUBMED database (www.pubmed.gov), in which studies published from 2000 to 2020 were collected. Laboratory studies, case reports, systematic and literature reviews were included. Therefore, articles that did not address the topic in question, letters to

the editor, opinion articles, duplicate literature and texts that were not in English were excluded. According to the inclusion and exclusion criteria, 75 research articles were selected. In dentistry the most common methods of 3D printing used are: stereolithography (SLA), material jetting (MJ), binder jetting, and Laser sintering. It is important to carefully consider the limitation of each method, material and operator's skills in 3D printing for this technology to be more affordable in dentistry. Despite that, the accuracy of printing methods and materials used in different dental applications with 3D printing have been improving each day more, allowing a digital workflow with greater applicability and frequency of use in dentistry.
Keywords: 3D printing; Dental materials; Dentistry; Accuracy.

Resumo

A impressão 3D e a tecnologia de manufatura digital têm sido de grande uso na odontologia nos últimos anos onde os dentistas e técnicos protéticos têm se atualizado e se envolvido no assunto, acompanhando o avanço da tecnologia. O objetivo do presente manuscrito foi realizar uma revisão descritiva da literatura, abordando os métodos de processamento, precisão, tipos de materiais utilizados e as aplicações da impressão 3D na odontologia. Foi realizada uma busca bibliográfica na base de dados de saúde PUBMED (www.pubmed.gov), na qual foram coletados estudos publicados de 2000 a 2020. Estudos de laboratório, relatos de casos, revisões sistemáticas e da literatura foram incluídos. Portanto, foram excluídos artigos que não abordassem o tema em questão, cartas ao editor, artigos de opinião, literatura duplicada e textos que não estivessem em inglês. De acordo com os critérios de inclusão e exclusão, foram selecionados 75 artigos de pesquisa. Na odontologia, os métodos mais comuns de impressão 3D usados são: estereolitografia (SLA), jateamento de material (MJ), jateamento de aglutinante e sinterização a laser. É importante considerar cuidadosamente a limitação de cada método, material e habilidade dos operadores em impressão 3D para essa tecnologia ser mais acessível na odontologia. Apesar disso, a precisão dos métodos e materiais de impressão utilizados nas diversas aplicações odontológicas com a impressão 3D têm melhorado cada vez mais, permitindo um fluxo de trabalho digital com maior aplicabilidade e frequência de uso na odontologia.
Palavras-chave: Impressão 3D; Materiais dentais; Odontologia; Precisão.

Resumen

La impresión 3D y las tecnologías de fabricación digital han sido de gran uso en odontología en los últimos años y los dentistas y los técnicos dentales han estado actualizados e involucrados en el tema, siguiendo el avance de la tecnología. El objetivo del presente manuscrito fue realizar una revisión descriptiva de la literatura, cubriendo los métodos de procesamiento, la precisión, los tipos de materiales utilizados y las aplicaciones de la impresión 3D en la odontología. Se realizó una búsqueda bibliográfica en la base de datos de salud PUBMED (www.pubmed.gov), en la que se recopilaron los estudios publicados entre 2000 y 2020. Se incluyeron estudios de laboratorio, informes de casos, revisiones sistemáticas y bibliográficas. Por tanto, se excluyeron los artículos que no abordaran el tema en cuestión, cartas al editor, artículos de opinión, literatura duplicada y textos que no estuvieran en inglés. De acuerdo con los criterios de inclusión y exclusión, se seleccionaron 75 artículos de investigación. En odontología, los métodos mas comunes de impresión 3D utilizados son: estereolitografía (SLA), inyección de material (MJ), inyección de aglutinante y sinterización láser. Es importante considerar cuidadosamente la limitación de cada método, material y habilidades de los operadores en impresión 3D para que esa tecnología sea más asequible en la odontología. A pesar de eso, la precisión de los métodos de impresión y materiales utilizados en diferentes aplicaciones dentales con impresión 3D han ido mejorando cada vez permitiendo un flujo de trabajo digital con mayor aplicabilidad y frecuencia de uso para la odontología.

Palabras clave: Impresión 3D; Materiales dentales; Odontología; Precisión.

1. Introduction

Digital manufacturing process consists of digitizing a 3D model, designed in a computer software or scanning a real patient, either by the direct method, where the oral cavity is scanned, or by the indirect method, by scanning an impression or a model. The data obtained by the scanners is converted into an STL (stereolithography) format compatible with the computer software (Park & Shin, 2018). There are two processing methods in 3D manufacturing: subtractive manufacturing and additive manufacturing. The subtractive manufacturing process is based on milling the material, as is the CAD / CAM system (Liu, Leu, & Schmitt, 2006), which is used for the manufacture of dental prostheses such as fixed prostheses, removable prostheses and implants, which their effectiveness has already been proven (Goodacre et al., 2012; Hada et al., 2020; Kanazawa, Inokoshi, Minakuchi, & Ohbayashi, 2011; Katase, Kanazawa, Inokoshi, & Minakuchi, 2013; Y. De Zhang, Jiang, Liang, & Hu, 2011). The additive manufacturing process also known as rapid prototyping, is based on the addition of the material, as is 3D printing, which creates objects making one layer at a time, thus adding several layers to form an object, allowing the manufacture of more complex structures, which are difficult to mill. Generally, techniques based on material jet and photopolymerization are used in these devices for three-dimensional printing, to produce surgical guides and diagnostic models (Andonović & Vrtanoski, 2010; Keating, Knox, Bibb, & Zhurov, 2008; Liu et al., 2006).

CAD / CAM (Computer-aided design / computer-aided manufacturing) technology has been widely used in dentistry, mainly for the execution of restorations such as fixed prostheses, inlays, individual crowns, prostheses on implants, total prostheses, etc.(Chung et al., 2018; Kattadiyil, M.T.; Goodacre, C.J.; Baba, 2013). This technology provides a series of advantages for the prosthetic technician, dentist and patient, allowing to develop treatments in less time, reducing the number of clinical visits, through techniques with durability, efficiency and economy, in comparison with traditional methods (Kim, T.H.; Varjao, 2016; Pereyra, N.M.; Marano, J.; Subramanian, G.; Quek, S.; Leff, 2015). However, this technology has certain limitations, such as: great loss of material during milling, limited thickness of the restoration, lack of precision in the level of detail due to the size of the milling bur, and the high cost of acquisition and maintenance of the equipment (Azari & Nikzad, 2009; Strub, Rekow, & Witkowski, 2006). Thus, 3D printing is becoming popular in various disciplines of dentistry, such as in the manufacture of dental models, surgical guides and occlusal devices, also focusing on studies in the area of dental prosthesis, to improve technical factors and their effect on general quality, and the mechanical properties of 3D printed prostheses (Abduo, Lyons, & Bennamoun, 2014; Liu et al., 2006; Tahayeri et al., 2018; Van Noort, 2012).

In addition, the methods for additive manufacturing have certain advantages, which can give an easy solution to the difficulties that arise during the grinding of materials, since it can create fine details, such as undercuts, voids and complex internal geometries, which the subtractive manufacturing method limits. Nowadays, there is a great variety of additive manufacturing techniques, which is an ideal fact for dentistry, since it has always intended to make pieces tailored to the patient (Van Noort, 2012), which will be reviewed later in the present study.

Due to the use of 3D printing and digital manufacturing technologies in dentistry in recent years, it is important that both dentist and the dental technician are up to date and involved in the subject, following the advancement of technology. Therefore, the objective of this article is to carry out a descriptive literature review, covering the process, the different methods that exist, the precision, the types of materials used and the different applications of 3D printing in dentistry.

2. Methodology

2.1 Source Selection

Following the methodological guide line from Pereira A.S. et al. (2018), a bibliographic search was carried out in the health database PUBMED (www.pubmed.gov), in which studies published from 2000 to 2020 were collected. In the first stage, the list of retrieved articles was examined by reading the titles and abstracts. In the second stage, the studies were selected by reading the entire content. Experimental, case-control, randomized controlled and cohort studies, laboratory study, case reports, systematic reviews and literature review were included. Therefore, articles that did not address the topic in question, letters to the editor, opinion articles, duplicate literature and texts that were not in English were excluded. According to the inclusion and exclusion criteria, 75 research articles were selected.

3. Literature Review

3. 1 3D printing process in dentistry

To obtain an object by 3D printing, it needs a sequence of steps for its manufacture. First, data acquisition must be obtained, which can be carried out by means of non-contact or contact scanners. Generally, techniques such as computed tomography, cone beam computed tomography, magnetic resonance imaging and laser scanning (extra oral or intraoral scanner) can be used. Soon after, data processing is performed using specific CAD software where the object's virtual design is carried out. An STL file with the completed drawing is imported into the printer software, where construction variables and parameters for slicing and adding support structures are specified to generate the information needed to control the 3D printer. Continuing with additive manufacturing, creating the object using the slice file on the 3D printer. Finally, follow the post-processing, cleaning of the object and post-curing procedures, for the completion of the polymerization process (Fahad, Dickens, & Gilbert, 2013; León & Özcan, 2017; Revilla-León & Özcan, 2019; León, Sadeghpour & Özcan, 2020).

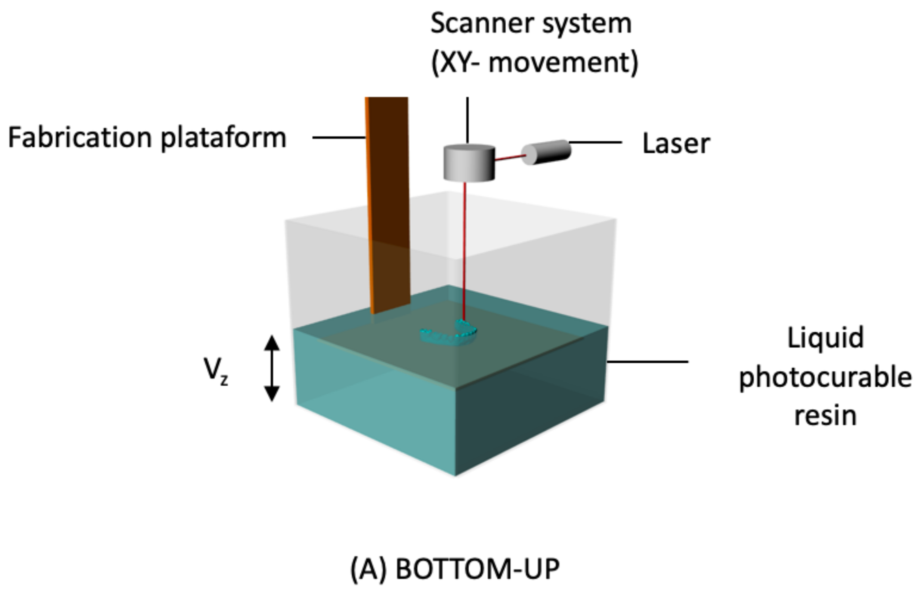
3.2 Additive methods during printing

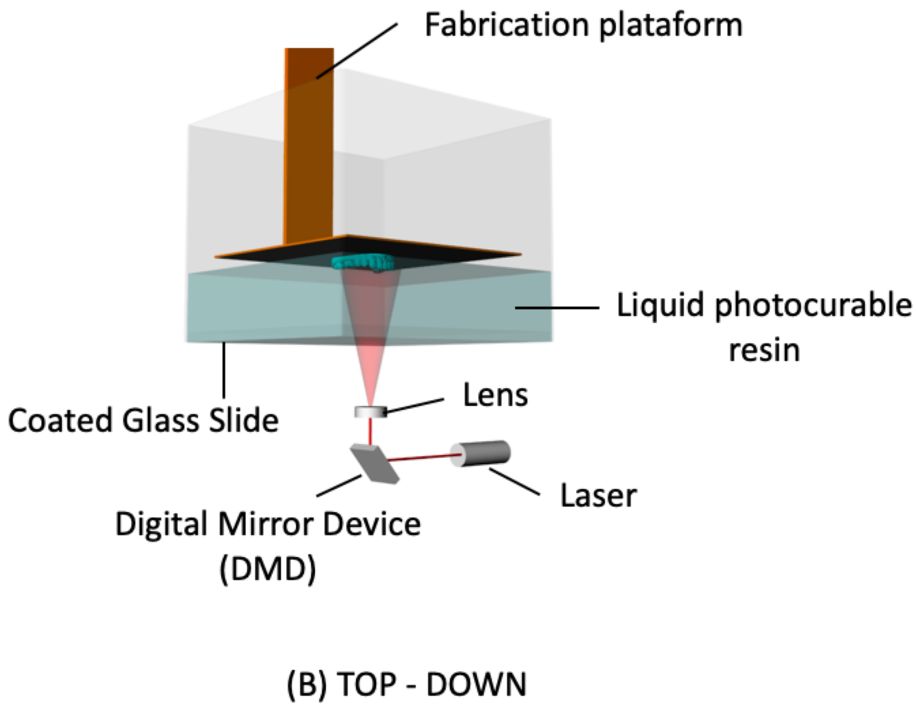
According to the ASTM (American Society for Testing and Materials) the additive manufacturing process, also called as 3D printing or rapid prototyping, is defined as the process of joining materials to create objects from 3D model data, usually layer by layer.

This process is based on creating cross-sections from a 3D computer file, where each cut or slice is printed on top of each other creating a 3D object, thus reducing material waste. 3D printing originated from rapid prototyping, which is a rapid production of the model through additive layer manufacturing. It was a process that began to be used in the year 1980, for the manufacture of prototypes, models and foundry molds (Van Noort, 2012). In 1990, the method was introduced to general medicine, producing 3D models, improving the diagnosis and planning of the operation and reducing surgical risks, and their uses in the dental area were expanded. Nowadays additive manufacturing is used for a much wider range of applications saving material and making parts with complex geometries. So, it is a method that can provide an ideal solution in the dental field (Kessler, Hickel, & Reymus, 2019).

Additive manufacturing technology has been categorized by ASTM into seven processes according to its printing method: stereolithography (SLA), material jetting (MJ), material extrusion (ME) or fused deposition modelling (FDM), binder jetting, powder bed fusion (PBF), sheet lamination and direct energy deposition (ASTM, 2009). Figures 1-2 show schematic drawing of the commonly used Additive Manufacturing Technologies. Figure 1 (A) the light source is applied directly to the polymer, while figure (B) the light source is reflected to the material causing the model to be suspended on the fabrication platform. In figure 2 it is possible to observe an example of a 3D printer with emphasis on the three axes of movement, basically regardless of the printer model this system is will present (Yao, Wang, & Mi, 2017); (Tamay et al., 2019). It is possible to observe that for each dental indication there are parameters and specifications for printing process (Table 1).

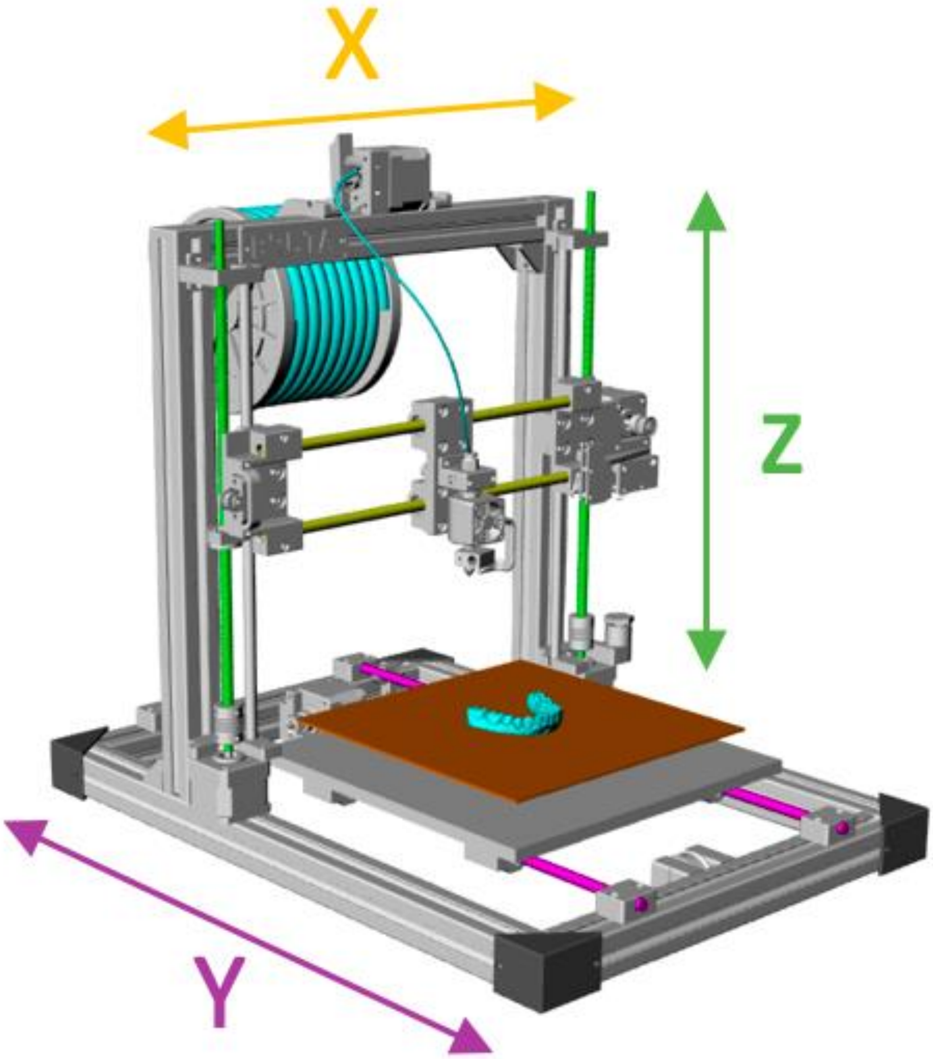
Figure 1 - Schematic of two kinds of SLA approaches. (A) Bottom-up setup. In the top-down setup (B), every newly fabricated layer is underneath the previous layers and the polymerization of the light sensitive material is performed by irradiation from underneath.





Source: Authors.

Figure 2 - Schemes Fused deposition modeling (FDM), the position of the nozzle moves in x-y plane to create the desired pattern. Once a layer is completed, the nozzle moves upwards along the z-axis, a predefined distance to print the next layer.



Source: Authors.

Table 1 - Additive methods and materials used in dentistry.

Additive Manufacturing Process	Description	Type of material
Stereolithography (SLA)	Following the CAD design, a solid object is created by printing thin layers of a material curable by ultraviolet light. The ultraviolet light laser is focused on the surface of a tank containing acrylic resin, as the light beam scans and polymerizes each layer when it attracts the object to the liquid surface, repeating this process layer by layer until the model is complete (Van Noort, 2012).	Photopolymerized resin
Digital light processing (DLP)	It is similar to SLA technology. Its main difference is the source of digital light projection (high power LED). The constructed layers are illuminated using a light mask that is created by a digital micro-mirror device (DMD), which consists of hundreds of thousands of micro-mirrors. Each mirror represents one or more pixels in the projected image. The number of mirrors corresponds to the projected image resolution (Groth, Kravitz, Jones, Graham, & Redmond, 2014; Melchels, Feijen, & Grijpma, 2010; Mitteramskogler et al., 2014)	Photopolymerized resin
Material jetting (MJ, PP)	In the jet of material or polyjet printing (PP), a liquid resin is injected selectively from hundreds of nozzles and polymerized with ultraviolet light, allowing the use of different materials that allow different colors or hardness (rigidity) in the same printing (Katkar, Taft, & Grant, 2018; Stansbury & Idacavage, 2016).	Slurry
Binder jetting	Plaster material, such as a dust bed, is often used. A print head provides color and a layer-by-layer binder. The powder supports the piece. The completed part generally needs some kind of post-processing because the part is quite fragile (Katkar et al., 2018).	Powder
Laser sintering (Selective laser sintering, Selective laser melting, Direct metal laser melting- SLS/SLM/DMLS)	In SLS / DMLS, the layers are built sequentially by melting powder particles using a CO_2 laser beam that traces a path in a powder bed based on the desired CAD design. In each layer, the laser raises the temperature to the melting point, which melts the powder particles. The process is repeated until the object is completed. SLM, is based on the melting of the powder instead of sintering it (Vandenbroucke & Kruth, 2007).	SLS: Resin, metals, and ceramics SLM/DMLS: Metals

Source: Authors.

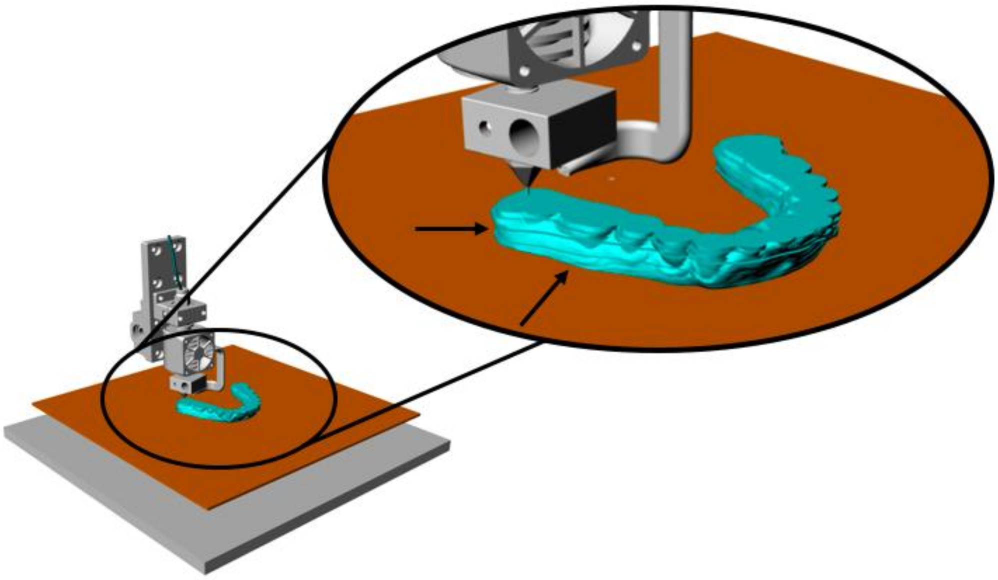
3.3 Advantages and limitations of the Additive process

The main advantages of the 3D printing process are: Flexibility, due to the variety of machines available, passivity during the laying of prosthetic parts, low percentage of waste of the raw material.(Barazanchi, Li, Al-Amleh, Lyons, & Waddell, 2017).

It is possible to observe the inhomogeneous interposition of the printed layers causing a visible effect on the surface printed model, named Staircase effect. Printers with this type of limitation are unsuitable to manufactory specimens for dental use that require high precision (Figure 3); because the layer-by-layer process in additive manufacturing can leave a ladder effect on the final material, but if the layer thickness is adjusted to the highest resolution, the ladder effect can be reduced, however the object's printing time would significantly increase (Masood, Rattanawong, & Iovenitti, 2003). Limitation in the manufacture of ceramic structures, due to the fact that porous structures produced by the additive technique may require extensive post-processing, which causes shrinkage (Denry & Kelly, 2014). Difficulty in reproducibility, since some machines still do not reproduce with precision and reproducibility when using them in dental applications (Abduo et al., 2014). Support structures are needed, as extra steps need to be added when placing support structures that may be needed for use during the manufacturing phases (Liu et al., 2006); There is still a limitation of some machines to use in dentistry, such as FDM, because their low precision and speed, and the thickness of the material's nozzle, which can affect the quality of the printed object (Krar S, 2003). Although these printers are not adapted for dental applications, some companies (3D Systems, Rock Hill, SC; Stratasys, Eden Prairie, MN) are focusing their production on additive technology specifically for dentistry (Barazanchi et al., 2017).

Although the additive manufacturing processes are versatile allowing the printing of different 3D models, some dental structures may be inadequate when made with a process that has not been thoroughly evaluated for that indication. Thus, is recommended that the dental applicability follow an additive manufacturing process already reported in the literature for a specific indication, and that future studies should be made evaluating the reproducibility of dental models with pioneering processes (Table 2).

Figure 3 - Schematic of Staircase effect for the layer-by-layer nature of additive manufacturing.



Source: Authors.

Table 2 - Advantages and disadvantages of additive manufacturing processes in dentistry and dental applicability reported in the literature.

Additive Manufacturing Process	Advantages	Disadvantages	Dental applicability
Stereolithography (SLA)	-High accuracy -Smooth surface finish -Possible transparent objects -Good mechanical strength -Fine build details -Low tolerance	-Expensive -High material cost -Only photopolymerized material -Post curing required -Single material vat	-Resin pattern (Eggbeer, Bibb, & Williams, 2005; Wu, Wang, Zhao, Zhang, & Gao, 2012) -Complete Denture shell try-in (Maeda et al., 1994) - Fixes prosthodontics (Crown) (Alharbi, Osman, & Wismeijer, 2016a, 2016b) -Occlusal splints (Vasques, Mori, & Laganá, 2020)
Digital light processing (DLP)	-Fast -Smooth	-Only photopolymerized	-Resin pattern (Eggbeer et al., 2005) -Coping for casting (Hoang, Thompson,

	surface finish -Possible transparent objects -Fine build details	material -Post curing required -Single material vat	Cho, Berzins, & Ahn, 2015) -Mock-up (Sancho-Puchades, Fehmer, Hämmerle, Dent, & Sailer, 2015) -Fixes prosthodontics (Crown) (Osman, Alharbi, & Wismeijer, 2017)
Material jetting (MJ, PP)	-Fast fabrication -Low material cost -Multicolored material is possible Wide material options	-Large tolerance -Low mechanical strength -Rough surface finish -Layers may collapse during -Build process	-Complete Denture try-in (Chen, Wang, Lv, Wang, & Sun, 2015; Inokoshi, Kanazawa, & Minakuchi, 2012) - Crown and tooth model (Wang, Shaw, & Cameron, 2006) -Fixes prosthodontics (Crown) (Ebert et al., 2009) -Coping and 3-unit ceramic (Silva et al., 2011)
Binder jetting	-Fast fabrication -Low material cost -Multicolored material is possible	-Large tolerance -Low mechanical strength -Rough surface finish	- Individualized flask for Complete Denture (Sun, Lü, & Wang, 2009) -Teeth models (Chang, Lo, & Jiang, 2015)
Laser sintering (Selective laser sintering, Selective laser melting, Direct metal laser melting- SLS/SLM/DMLS)	Printed object with 100% density is possible	-Expensive -Thermal distortion	SLM: Crowns and metal frameworks (Z. Huang, Zhang, Zhu, & Zhang, 2015; Pompa, Di Carlo, De Angelis, Cristalli, & Annibali, 2015; Quante, Ludwig, & Kern, 2008), Removable partial denture frameworks (Bibb, Eggbeer, & Williams, 2006; Williams, Bibb, Eggbeer, & Collis, 2006) DMLS: Co-Cr three-unit- Fixed prosthodontics frameworks (Kim, Kim, Kim, & Kim, 2013; Örtorp, Jönsson, Mouhsen, & Vult Von Steyern, 2011), Copings Co-Cr (Ucar, Akova, Akyil, & Brantley, 2009), Cast base metal dental alloys (Akova, Ucar, Tukay, Balkaya, & Brantley, 2008)

Source: Authors.

3. 4 3D Printing Accuracy

It is important to know the differences of certain terms that are present in the additive manufacturing processes, which are: resolution, precision and veracity. Resolution is specific to each technology and printer, and is defined on each x, y and z axis in µm or dots per inch (dpi), where the z axis normally corresponds to the layer thickness. Precision is the function of a 3D printer to manufacture objects with exact 3D dimensions, or how close the printed objects are to one another. And veracity, is the discrepancy between the actual dimensions of the desired object and the printed object (Puebla, Arcaute, Quintana, & Wicker, 2012).

Different factors can influence the results and the accuracy of additive manufacturing. The thickness of the printing layer, laser intensity, laser speed, printing angle and printing orientation, software, shrinkage between layers, amount of supporting material, post-processing procedures, as well as the appropriate settings for these parameters, are the variables to take into account for obtaining good results during 3D printing (Puebla et al., 2012; Urrios et al., 2016). As for the structures produced, their precision is influenced by the shapes or geometries that are being replicated, the manufacturing methods and the materials used in each process (Barazanchi et al., 2017).

There is a wide variety of studies in the literature that analyze these parameters in the results and precision in 3D printing. However, due to the different protocols, technology used, printer parameters and the 3D printing polymer material used, it is difficult to compare the results of the studies of how these factors can affect the accuracy and veracity of printed objects (Revilla-León & Özcan, 2019).

One study has analyzed the accuracy of implant analog positions on complete edentulous maxillary casts using 4 different additive manufacturing technologies (multijet printing-MJP1, direct light processing-DLP, stereolithography-SLA, multijet printing-MJP2), compared with conventional dental stone cast using a coordinate measuring machine (CMM). They concluded that the results of one of the multijet printing systems and direct light processing additive manufacturing technologies were similar to conventional dental stone for the fabrication of the definitive casts for implant prostheses, affirming that the conventional dental stone could be accurately duplicated using some of the additive manufacturing technologies tested (Revilla-León, Gonzalez-Martín, Pérez López, Sánchez-Rubio, & Özcan, 2018).

Another recent study evaluated the accuracy by the impression orientation of resin denture bases for 3D printing, demonstrating that the impression orientation significantly influences the printing accuracy. They evaluated three orientations (0, 45 and 90 degrees) in samples with established measures of length, width and thickness. They concluded that specimens with 90 degree orientation showed the lowest error rates for length, and 45 degree specimens showed the highest error rates for thickness (Shim, Kim, Jeong, Choi, & Ryu, 2020). On the other hand, Hada et al, in 2020, also assess the veracity and precision of dentures printed on photo-polymer resin, with the same directions, performed with stereolithography (SLA), showing that the veracity and precision of the prostheses printed using SLA also depends of the direction, with 45 degrees being the direction with greater precision compared to those of 0 and 90 degrees (Hada et al., 2020).

In 2019, Zhang et al compared the accuracy of 3D printed dental models using 3 types of DLP printers (EvoDent, Encadent and Vida HD) and an SLA (Form 2) printer with different layer thicknesses (20, 25, 30, 50 and 100 µm). Where they concluded that for DLP technology the ideal layer thickness is 50 µm and the printing accuracy using SLA technology increased with the decrease of the layer thickness. It was also shown that DLP technology showed the highest printing precision with a layer thickness of 100 µm, and the type of printer EvoDent had the highest printing precision with 50 µm, being the Form 2 printer with the lowest precision with a 100 µm layer thickness 100 µm layer(Z. chen Zhang, Li, Chu, & Shen, 2019).

Homsy et al., in 2018 compared in an in vitro study the fit accuracy of lithium dissilicate glass-ceramic inlays fabricated with conventional, milled, and 3-dimensional (3D) printed wax patterns, where the marginal and internal fit accuracy presented better results in subtractive milling of wax patterns than of others process studied, and the wax patterns printed in 3D process showed similar values to those of the conventionally waxed inlays (Homsy, Özcan, Khoury, & Majzoub, 2018).

3.5 Printing materials and their mechanical properties

Due to the large number of methods that offer additive technology for the manufacture of structures, it allows a wide variety of raw materials to be used through this layered process of additive manufacturing. In the dental field for 3D printing, materials are generally used with a combination of binder / powder material such as polymers (including resins and thermoplastics), ceramics and metals (Barazanchi et al., 2017).

Depending on the type of material used in printed dental restorations, the resistance and reproducibility of this restoration may vary (Tahayeri et al., 2018; Tymrak, Kreiger, &

Pearce, 2014). Also, the mechanical properties of the printing materials can be affected by the printing orientation, depending on the additive method used. For example, in the SLA method, the printing orientation significantly influences the compressive strength of printed composite resins (Alharbi et al., 2016a). In the study by Shim et al, in 2020, the resistance and reproducibility in three impression orientations (0, 45 and 90 degrees) of polymethyl methacrylate resin (PMMA) was evluated for the manufacture of a 3D printed denture base, in which it was concluded that samples printed at 0 degree had the greatest flexural strength, followed by 45 and 90 degrees (Shim et al., 2020).

Another study evaluated chipping and r indirect tensile fracture resistance of teeth printed on a 3D printing resin material (Dentca 3D printing denture teeth resin), compared with conventionally prefabricated resin denture teeth. They showed that the teeth printed on resin did not differ and were inferior in resistance to chipping when they were purchased with four types of conventional artificial teeth, also presenting simultaneous fracture of two cusps in the tensile fracture resistance. It was concluded that the manufacture of dental teeth with resin materials by 3D printing can be applicable in a clinical dental context (Chung et al., 2018).

Tahayeri et al., in 2018, compared the mechanical properties and the optimization of 3D printing of a temporary material for crowns and bridges (NextDent C&B) printed with the SLA printer, with conventionally cured provisional dental materials (Integrity®, Jet®). They observed that within the parameters for printing, the layer thickness had no significant effect on the mechanical properties of the 3D printed temporary resin, having a higher stress peak than Jet® acrylic and a lower elastic modulus than Integrity®. In conclusion, the commercially available 3D dental restorative material and the 3D printing system used allow sufficient mechanical properties for the intraoral use of a provisional restoration (Tahayeri et al., 2018).

3.6 3D printing applications in dentistry

To As previously described, the existence of the wide variety of additive manufacturing techniques and materials used in these processes, has been widely used for applications in the medical and dental fields (Barazanchi et al., 2017). Polymers represent the vast majority of materials used in additive manufacturing, being biocompatible and approved for placement in the mouth. Therefore, they are allowed to be applied in surgical guides and other tools, such as in the production of medical model implants, abutments, and tissue replicas with CT-imaged. Also, 3D printed ceramic and metallic fabrications are being used for implants, crowns, bridges, among other direct applications in dentistry (Stansbury & Idacavage, 2016). In the area of prosthodontics, these polymers allow to be applied for 3D printing, in printed models (such as diagnostic models, definitive models for dental prostheses, definitive models for implant supported prostheses), complete dentures, printed castable patterns for cast or pressed restorations, and custom impression trays. (Revilla-León & Özcan, 2019).

The manufacture of printed models by additive manufacturing are generally created for conventional aspects of the manufacture of a restoration, whether fixed prostheses on teeth or on implants, to add coating material, create contact point and occlusion contacts, among others. Although today it is not always necessary to print a master model(Birnbaum NS, 2008; Dawood, Marti, Sauret-Jackson, & Darwood, 2015). In an in vitro study, Jang et al., in 2019, evaluated the marginal and internal fit of a three-unit fixed prosthesis manufactured in 3D printed models by digital light processing and its precision compared to a conventional model stone cast. They came to the conclusion that the adjustments of the fixed prostheses made in the models printed in 3D were inferior to those of conventional model stone cast, but the printed molds presented an acceptable clinical precision, suggesting that it is necessary to improve the accuracy of 3D printers for their application for dental prosthesis (Jang et al., 2020).

3D printed models for diagnosis or treatment with orthodontic aligners are also widely used in additive fabrications, having precision, reliability and reproducibility, when compared to conventional model stone cast. However, there may be a limitation to the moment of extraoral digitization due to the lack of identification of reference points. (Aragón, Pontes, Bichara, Flores-Mir, & Normando, 2016; Ender & Mehl, 2013). In the same way, the 3D printing of mouthguards could provide a better geometry in terms of stress reduction during traumas. (Borges et al., 2020). As well as the impression of occlusal splint temporomandibular disorders (Vasques et al., 2020).

In the area of implantology, the use of additive technology is to perform surgical guides that facilitate planning and reduce the risk of surgical complications. (Lal, White, Morea, & Wright, 2006), also as the manufacture of implants with complex geometries with rough surfaces that can increase the osseintegration of the implant (H. L. Huang, Hsu, Fuh, Lin, & Chen, 2010). In the study by Yeung et al., In 2019, the accuracy and precision of 3 implant systems were analyzed using surgical guides printed in 3D with a stereolithographic printer in the office. They concluded that the clinician should be aware of the limitations of adjustment and the depth of placement of the printed guide with stereolithographic flatbed printer, stating that different implant-guided surgery systems have strengths and weaknesses revealed in the dimensional displacement and angulation of the implant (Yeung, Abdulmajeed, Carrico, Deeb, & Bencharit, 2020). Further geometries previously obtained only with reductive technology (Melo Filho et al., 2019) will be improved with the aid of the three-dimensional impression.

The maxillofacial prosthesis represents a clinical challenge yet to be discussed (Villefort et a., 2020). However, the use of additive manufacturing in facial prostheses and cranial construction has increased, allowing the planning of procedures and the exact manufacturing of the necessary prostheses, before carrying out an invasive procedure. All this thanks to the advancement of transmission-based scanning methods (CT and MRI) that increased the scanning of structures with high precision (Hatamleh & Watson, 2013).

4. Final Considerations

Additive manufacturing is a technology that has been studied for several years, favoring its use in dentistry to minimize laboratory and clinical work times. It is important to carefully consider the limitation of each method, material and operator’s skills in 3D printing to become more affordable in dentistry. Despite that, the accuracy of printing methods and materials used in different dental applications with 3D printing have been improving each day more, allowing a digital workflow with greater applicability and frequency of use in future dentistry.

Future studies are suggested evaluating the printing materials structural and mechanical properties, as well as their behavior during thermal and mechanical aging. Structures three-dimensionally printed indicated to support the chewing loads must be evaluated for their ability to dissipate the stresses. Regarding the structures of long-term usages should be evaluated for their dimensional stability and wear resistance.

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