Universidad Europea

GRADUATION PROJECT

Degree in Dentistry

INDICATIONS OF 3D PRINTERS IN FIXED PROSTHODONTICS

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CONTENTS

RESUMEN :

Introducción: Las prótesis fijas son algo esencial para restaurar la oclusión estética y funcional, y hay una gran cantidad de pacientes con dientes faltantes. Además de esto, la impresión en 3D está adquiriendo un papel importante en la técnica de fabricación desde hace mucho tiempo y, en odontología, está empezando a ser muy utilizada. Entre todas las técnicas de fabricación, algunas son muy utilizadas en odontología, como el fresado, que pertenece a la técnica sustractiva, pero la técnica aditiva, como la impresión en 3D, está cobrando cada vez más importancia ; **Objetivos:** El objetivo principal era dar una visión general de todos los posibles usos actuales de la impresión en 3D para la odontología y mostrar las limitaciones y el posible futuro de la impresión en 3D ; **Material y método:** Este estudio se llevó a cabo utilizando diferentes criterios de inclusión y exclusión y algunas palabras clave específicas. Solo se utilizaron artículos muy recientes para los resultados y la investigación se realizó en múltiples bases de datos como la biblioteca de la universidad o BMC ; **Resultados:** Para los resultados, se utilizaron diferentes bases de datos debido a la especificidad del tema. Por ejemplo, el sitio web de la biblioteca de la UEM y MDPI, BMC y Springer ; **Conclusión:** Como se ha visto durante este estudio, hay muchos usos para las impresoras 3D en prótesis fijas hoy en día. Se pueden utilizar con fines educativos para aprender la preparación de coronas o carillas, por ejemplo, pero también se pueden utilizar para hacer provisionales que también pueden servir como maquetas. Y probablemente en el futuro se utilizarán para producir restauraciones fijas definitivas como coronas gracias a las resinas que incorporan circonio.

Palabras clave: impresora 3D, prótesis fija, CAD-CAM, fabricación aditiva, sonrisa digital.

ABSTRACT

Introduction: Fixed prosthesis are something essential for restoring aesthetic and functional occlusion and there is a large part of patient with missing tooth. It is more appropriate nowadays, when possible, to use fixed prosthesis instead of removable. And apart from this fact, 3D printer is taking an important role in manufacture technique since long and, in dentistry, it is starting to be very used. Among all the manufacture technique some are very used in dentistry as milling which belong to subtractive technique but additive technique as 3D printing is getting more important; **Objectives**: the main objective was to give an overview of all the possible actual uses of 3D printer for dentistry and show the limitations and the possible future of 3D printing; **Material and method**: this study has been conducted using different criteria of inclusion and exclusion and some specific keywords. Only very recent article was used for the results and research were done on multiple database such as the library of the university or BMC; **Results:** for the results, different database has been used because of the specificity of the subject. The website of library of UEM and MDPI, BMC and Springer for example**; Conclusion**: as seen during this study, there are nowadays many uses for 3D printers in fixed prosthesis. Can be used for educational purpose to learn preparation for crowns or veneer for example but also, it can be used to make provisional that can serve also as mock-up. And probably in the future will serve to produce definitive fixed restorations as crowns thanks to the resins incorporating zirconia.

Keywords: 3D printer, fixed prosthesis, CAD-CAM, additive manufacturing, digital smile.

1. Introduction

1.1. Workflows in Dentistry

1.1.1. Conventional workflow

First, to understand everything about 3D printing, explanation about digital workflow is important. But still today, basis is conventional or partial workflow which need to be define to understand well the benefit of digital work and 3D printing(1).
Conventional workflow is the oldest workflow technique still in use today, it is going to start with the impression(2).

Impression is a vast subject but, in general, in fixed prosthesis, we are often going to make an alginate impression for the antagonist arch to the prosthesis.
The agonist arch is going most of the time to require more precise impression because alginate is not a perfect material(3).
Silicone with one step or two steps is a good option for crowns or inlays. It is going to need putty soft and fluid silicone to get the best mechanical properties of each consistency of the silicone(4).
Once impressions are done, plaster needs to be poured and in the case of alginate, it will have to be done at the clinic because alginate have a short time stability. The silicon on the other hand is enough stable in time to be sent at the laboratory with only the impression(5).

The prosthesis after the production by the laboratory and all the post-treatment to have a good finish for the crown, is going to be sent back to the clinic to be cemented in the patient mouth(6).

For the preparation of crowns, it requires specifics space to fit the prosthesis. Dentists need to use specific burs to prepare the tooth to have enough space. It will depend on the material that will be used. Metals will require less space than ceramics because for the same strength, ceramics need thickness. Usually, guide made of putty soft are used to see how much of the tooth has been removed(7).

These guide for dental preparation is a good example also of what can be done digitally using the CAD-CAM techniques(8).

1.1.2. Partially digital workflow

Partially digital workflow is an alternative to the normal full digital workflow, allowing to work partially digitally with lower coast for the clinic. The acquisition of the patient mouth is going to be done same way as for the conventional way: impression with rim-lock and alginate or silicone(9).

But instead of working on the plaster cast, either the dentist or the prosthetist are going to scan the cast with an extra-oral scanner allowing to proceed to all the rest of the steps using digital techniques(10).

The idea is simple, the process is going to start with conventional workflow until the steps of the cast is reached and then all the rest will be done following the digital workflow allowing to have advantages of digital even without intra-oral scanner at the dental chair(11).

1.1.3. Full digital workflow

In the first step, the scan of the patient mouth is necessary and for that dentists are using intra-oral scanner which allows to have a 3D file of the mouth.
Photos of the patient face smiling can be combined with the intra-oral scan. Also, facial scanner exists to combine in 3D the face with the mouth to be able to work on the design of prosthesis. CBCT also can be combined for bone evaluation in relation to tooth position(12).

When scanning something, the 3D scan can use a file specific to the brand or it can be an STL file (stand for Standard Triangle Language or Standard Tessellation Language). If the file is specific to the brand, the user will have to use the software associated to the brand. If it is STL, the file is royalty free, it can be used with most of the software. As it will be mentioned later, STL has been created in collaboration with Charles Hull who deposed the first patent of 3D printer(8,13).

Scanner are going to use a laser to point different place knowing the distance and all these points will be joined using triangles and these triangles makes the transition from a point to another creating a surface without holes. The size of the triangles depends on the space between each laser point of the scanner and the definition partially depend on the size of triangles because it is the interpretation of the software(14).

After the digital impression and the explanation about the STL file which is very important because is the universal language of 3D world, reviewing the steps of impression for digital workflow seems pertinent.

Once the scan is done, impression of the cast if necessary is possible using 3D printer. Can be useful in case of mock-up using conventional way, make the wax up on the 3D cast and then use putty silicone to make the impression for the provisional(8,15).

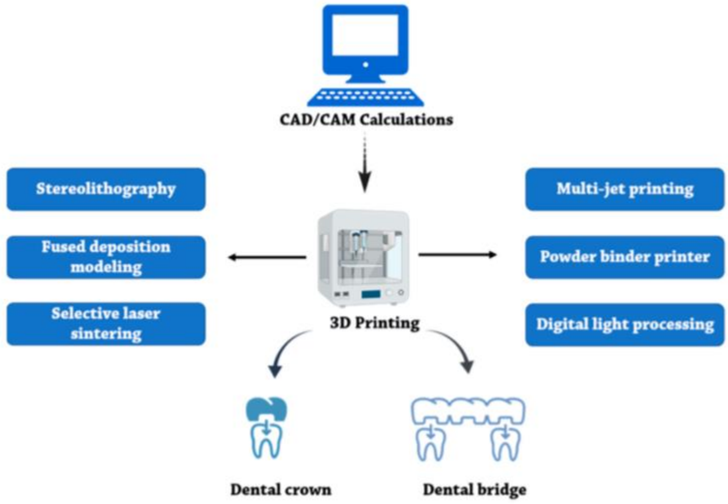


Figure 1*: The different manufacturing techniques(16).*

To resume, here are the six steps for digital workflow from DSD:

1. Patient digitalization (acquisition of all the patient data)
2. Cloud dentistry (concept in which exchange of patient data is easier)
3. Virtual treatment simulation (allows to see virtually the result and adjust it and show it to the patient)
4. Digital patient presentation and case acceptance (present to the patient the plan and can be shown the design virtually, also mock-up can be done for patient approval)
5. Guided dentistry and digital quality control (include things as 3D printed guide for crown preparation or guides for gingivectomy)(12)

1.2. 3D printing, definition, history, and technologies

1.1.1. Definition of 3D printer

There are nowadays more and more technologies available for dentist in the clinic. One of them which is becoming more and more popular is the 3D Printer, also called in more technical words stereolithography. Before going further in the subject, it is important to define the term 3D Printer(17).

Among the different process of CAM (computer aided manufacturing), there is the additive, the subtractive and the formative manufacturing(17). These are the three main category of manufacturing technique. More less all the techniques to build an object can be placed in one of these categories. Seems important to detail rapidly them to have a good idea of what can be done nowadays before to go more in detail in 3D printing which belong to the additive manufacturing(18).

The formative manufacturing consists in building object in different materials using molds. It is useful for high volume production because the coast for the molds is high but then the coast of production and speed are good. It is usually used for big volume production.
They are used in dentistry for example in prothesis for lost was technique which correspond in engineering to formative manufacturing.(15).

The subtractive manufacturing corresponds to the removal of matter from a block to manufacture an object. The machines are usually called CNC (Computer Numerical Control) because they are machine with a drill which is motorized over two or three axis and the motor are controlled by a computer and a specific software.(18).

This manufacture technique is very used nowadays in prothesis. It permits to dentist to manufacture crowns from a block of ceramic from an impression with intraoral scanner and a design done by software. Then the dentist can manufacture the crown in a block of ceramic, only the glazing and colour will require hand work(19).

The last manufacturing technique is the additive, more commonly called 3D printing, which is the most important for this work.

It consists of adding layer per layer the selected material. And depending on this material, each layer will have its own limits and advantages(15). It can be printed almost any geometry for each layer except one of the limits of 3D printing which is the anisotropic geometry of the models(20). Meaning that the model built cannot be full, there is the exterior geometry including inside some support part to conserve a certain strain. Also, for the additive technology, the stability of the impression is something important since a same part printed several times will have some variation due to the cooling differential of the wrapping during curing. In dentistry, additive manufacturing is still recent and is nowadays used to produce models, guide for different types of preparation such as veneers. Also, can be used for surgical guides for examples. For that purpose, we can either have full numeric workflow meaning, 3D scanner initially and then produce with a 3D printer a model of our scan using CAD-CAM (Computer Aided Design and Computer Aided Manufacturing and STL files, Standard Triangle Language or Standard Tessellation Language)(21).

1.2.1. History of 3D printer

Now the different manufacturing technologies have been described, it is important to see who is the inventor of 3D printing and in which condition has it been created. From the books, the very first one to work of 3D printing was Hideo KODAMA in 1981. He was working on a “Rapid prototyping device”. And Hideo KODOMA was the first person to apply for a patent describing a laser beam curing process(17).

Then, a French trio composed of Jean-Claude André, Olivier de Witte and Alain le Méhauté who's were working for the brand Alcatel and also for the French National for Scientific Research (CNRS). But neither Alcatel which is an important French firm in technologies, nor the CNRS wanted to collaborate on this project forcing the French team to discontinue their work(22).

In 1984, Charles "Chuck" Hull, who is considered as the creator of stereolithography, filed a patent for a system like the one of Hideo Kodama and the French trio.

Charles Hull, commonly called Chuck, were born in Clifton in the Colorado, and used UV light from his own industry to create the first 3D printing making the polymerization of resin with the light.

Charles Hull's patent were approved in 1986, he then created his company called 3D systems and started commercializing his first model of printer, the SLA-1 in 1988.(13).

1.2.2. First application in health and dentistry

After seeing the definition of 3D printing, the different manufacturing process, and the history of stereolithography, the first use of this technology in health and more precisely in dentistry is going to be the point of this part.

First, in the mid-1990s, a group from different countries as Canada, Wales, the United State of America (USA) and Germany worked on the use of 3D printing for the re-construction of head and neck. (14).

Furthermore, in dentistry, even if it is hard to find the very first use of stereolithography, the books said probably was used for fabrication of dental implant. Even if the first intraoral scanner, the CEREC (Chairside

Economical Restauration of Economic Ceramics), was sell in 1985, still nowadays all dentists don't have one at their clinic.

And to use 3D technologies in most of the cases, it is required to have the scan of the patient mouth. It can be a casted with cement and then scanned extra-orally also. Anyways, to produce a cast or a guide we need the 3D files of the patient mouth, which slowed down the development of 3D technologies. These two aspects of 3D need to be developed at the same time, nowadays there is plenty of models of scanner on the market and it easier for someone to try something new using 3D printers(21).

1.2.3. Technologies in 3D printing

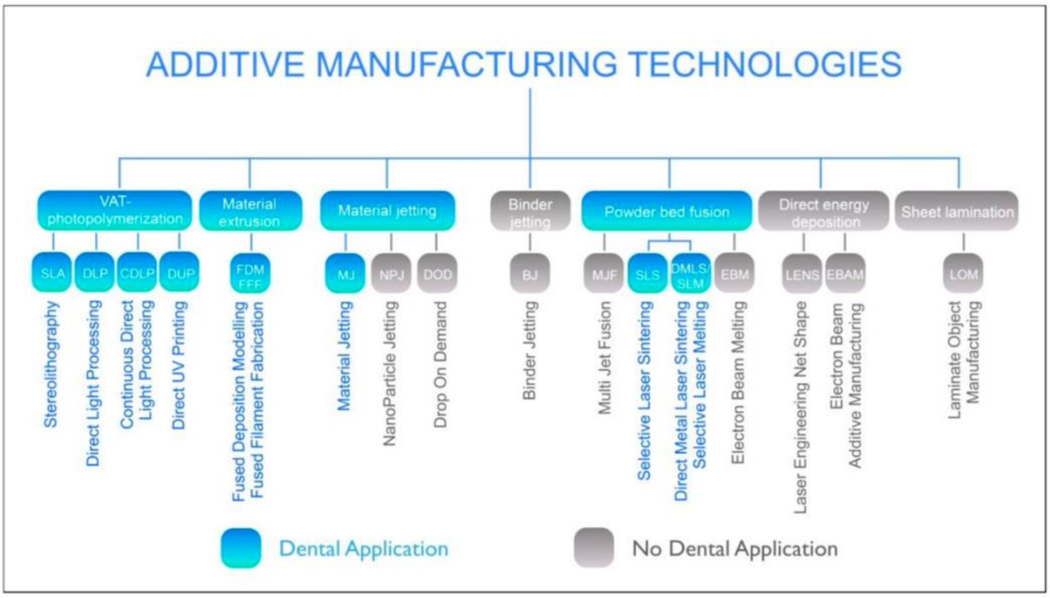


Figure 2: Overview of manufacturing process in general and for dentistry(23).

1.2.3.1. Material extrusion (FFF)

This technology is nowadays the most common to see and even more in low budget additive system. The system is very simple, a solid thermoplastic material called filament is going to be pushed by a system into an heated nozzle which is going by heat to melt the material allowing the deposit of it on a plate(24).

Into the category of material extrusion, the main technology is the FFF, standing for Fused Filament Fabrication. There is for now no other technique in the material extrusion system. This technology is also called FDM for Fused Deposition Modelling. As explained before, a filament is going to pass through a printer nozzle to get hot. Then the material is going to be deposited layer by layer on a plate. Depending on the brand, either the nozzle or the support material can move. But the more common is to have the nozzle moving over two of three axis and at the end of each layer it is going to move upward to start the next layer of material(25).

FFF have as advantage the possibility of setting all the specifications such as the build speed (depending on the precision required), the extrusion speed (by acting on the temperature of the nozzle). Also, the nozzle diameter and the height of each layer are going to be defined by the machine. It will act on the resolution of the printer depending on how fine each layers can be(24).
Another positive point is the price, the machines are about the cheapest of the market and the material is very cheap and easy to procure. Offering many possibilities.
In the limitations, the main is going to be the mechanical strength and stability due to mainly two things: the piece are going to be anisotropic meaning the model is 20% fill only and higher percentage would procure more strength but also more expensive price and longer time. And the layer per layer deposit is going to cause wrapping of the FFF parts because after each layer is deposited, while cooling, there will be shrinkage of each layer and it will cause modification of the global form of the part(15).

The part produced with FFF are going to need post processing mainly because of striae produced by the layer per layer manufacturing process. It will require a surface finish, can be either sanding or gap filling (can be filles using light curing epoxy resin)(25)

1.2.3.2. Vat polymerization (SLA, DLP)

The principle of this technology is to photopolymerize (using different techniques) the desired form from a bath of photopolymer resin. There is two main technologies in this manufacturing process: SLA (Stereolithography) and DLP (Direct Light Process)(24). SLA is the oldest and original form of 3D printing being the one created by Charles Hull. The printer is going to use mirrors (called Galvanometers) to redirect a laser beam through a vat of resin ending on the printing area plate. The laser is going to be directing by the inclination of the different mirrors and the printing plan is going to elevate after each layer is completed(18).

DLP technology is more recent than SLA and use the same principle. The laser is going to be replaced by a special projector which is going to project an image (composed of square pixels called voxels) through the vat to end on the building plan(26).

Also, there is two types of technology for the build platform, either it can be Bottom-up or it can be Top-down.

The bottom-up are going to have the light source placed below the vat. The printer is going to leave the right space between the platform and the base of the vat corresponding to the thickness of one layer. Then the platform elevate after the layer is polymerized. The Top-down is working in opposite way, the light is coming from the top and the platform is going down layer per layer. The difficulty lies in the viscosity of the resin to recover the platform after each layer(15).

This technology is having many advantages such as the rapidity of execution (mainly with the DLP system), the surface of the part is going to be very smooth compared to the previous technology FFF. It will not require much post process as other technologies. The dimensional accuracy is one of the best and therefore it is very used for jewellery of dentistry. The limitation of the system are going to be the material which does not provide strength and does not allow a long conservation in the time(15).

1.2.3.3. Power bed fusion, polymers (SLS)

Power bed fusion technology use heat source to a specific point to produce a fusion of the powder to create a solid part. Selective laser sintering (SLS) is the only common technique in power bed fusion(24).

It is using polymer powder and specific C02 laser. First the platform is going to go down to one layer height, the recoater (like a rake) is going to sweep the surface to remove the excess of powder. The bin of powder is heated to a temperature just below it fusion point, so it is easy for the laser to melt the powder. Then the process starts again, the process is similar to SLA(18).

Important things about SLS, first, their parts don’t need support structure as it is needed for FFF technology which force the designer to add support to the part for the printer to be able to work. In the case of SLS, the un-sintered powder in the back is going to produce the support needed for the parts avoiding specific design and allowing totally freedom for the designer(25).

In the advantages, moreover the point about support, the printer is economic because the remaining powder in the back can be partially reused, and a lot of parts can be made at the same time in the back.

These machines can produce strong parts in a mid-volume production and with a good accuracy. But the printer coast a lot ($250 000) and they are difficult to use. The time for heating and cooling the back of powder and the parts is very long (24h) so the production is slow(15).
In the new technologies for powder bed fusion, it is important to evoke Multi Jet Fusion – HP (MJF). It is an additive technique for SLS, two specific products are being used: a fusing agent which is going to be placed where the powder facilitate the fusion of the material. It reduces the time of heating. The second product is going to be applied on the border where the laser will heat the powder: the detailing agent. It allows the part to have smoother limits and surfaces. These two agents reduce the time of heating and of cooling(18).

1.2.3.4. Powder bed fusion, metals (DMLS, SLM, EBM)

Power bed fusion for metals is very similar to the one with polymers, a source of heat is going to produce fusion of a powder layer per layer to produce a part(24).
Direct Metal Laser Sintering (DMLS) and Selective Laser Melting (SLM) are very similar to SLS changing the polymers powder for metal powder.
DSLM and SLM are technologies very used in dentistry to produce individual metallic part as crowns or bridges. The main limitation of these machines is the size of the pieces and the price of production mainly because of the high cost of the machine itself but also of the materials(15).

1.2.3.5. Material jetting (DOD)

Material jetting is a process similar to 2D ink printing: an head printer is going to move and depose droplet of photopolymers or wax whose are going to be light cured by a specific light and the part will be built layer by layer(27).

This technology allows to print different materials on a same part, this specificity is used to print the supports of the part with a different material able to be removed during post processing.(28). Drop on demand (DOD) is a derived technology of material jetting, the principle is the same except it is having a double printer head to deposit the build material and the support material at the same time. Another difference is the way of deposit, DOD works with a single point moving while material jetting works by line(29). Also, material jetting provides parts with a smooth surface, does not require post processing. But these parts have a poor mechanical resistance and these machines are the most expensive and using very expensive materials with big loss for the manufacture of a part(15).

1.2.3.6. Binder jetting

Binding jetting is working same way as SLS. SLS use a laser to sinter powder as seen before, binder jetting uses a head with droplet of binder instead of a laser to sinter the powder. Droplets bind to powder producing layer pf the part. The part is produced as usually layer per layer until it ended and is leaved in the bin of powder to cure(25).

There are two main technologies in this manufacture process: binder jetting-sand and binder jetting-metal, one is going to use sand or gypsum to produce low price colour parts. It is also very useful to make molds with complex shape and geometries. From the lectures, doesn’t seems to be used in dentistry yet to produce part by lost wax technique(15).

Binder jetting-metal works the same, the powder is composed of metal and the drops are polymer binding agent. The process allows the production of complex shape and geometry as jetting-sand does. For the parts to be functional, they need secondary process as infiltration or sintering(30).

1.3. 3D in Dentistry

1.3.1. Oral scan, Computer-Aided Design and Manufacturing (CAD CAM)

First, as seen in part 1.1.3, everything starts with acquisition of data, scan of the mouth of the patient using intra-oral scanner or can be done using impression with alginate or silicone. Also, if the clinic work in partially digital workflow, conventional impression and plaster will be scanned and continue in digital(6,10,12).

Computer-Aided Design (CAD) is the part following the patient data acquisition and consist of designing what we want such as a crown using a computer to help us. There are many tools available on recent dental software allowing to see the patient teeth in relation with the extraoral photos or scan and sometime a CBCT. It permits to make the design with taking in consideration all the factors in an easier way, also with virtual articulators and capacity to show the contact point on the arch(8,12,31).

CAD software have in memory shapes of tooth and so they can help to place a new tooth in 3D over a preparation and adapt it depending and the shape of patient's tooth and depending also on the occlusion. The first time can be longue but once used to the soft, can be very rapid and some e-prosthetist started to appear working exclusively in digital(8).

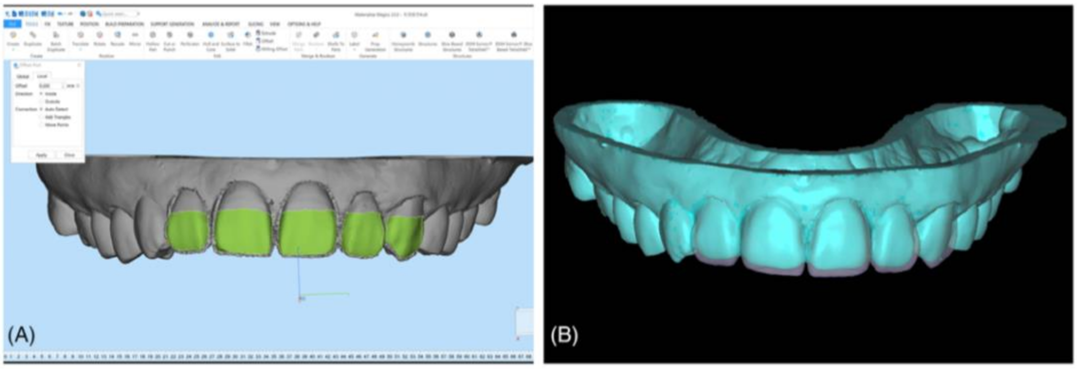


Figure 3: Example of use of computer aided design for a case of veneer(32).

Then, after designer with CAM, CAD is needed to produce any parts. Computer-aided manufacturing include many thing such as 3D printing or milling machines, more generally, it is the production of a part controlled by computer(2).

In case of 3D printing, the software should slice the parts in layer of less than a millimetre for the printer to know layer per layer what to print. Also, the soft can help us to design the support, it is additive materials in strategic place to support the previous layer that can be removed at the end of the impression. These are examples of setting needing care for a good impression(15).

1.3.2. 3D printing in dentistry: technologies and setup

The main technology used in dentistry is Vat polymerization using liquid resin because this technology as seen previously is the one offering more capacity and advantages for dental clinic(8).

Also, FFF technology, using filament could be used but it presents less advantages and even if it present lower cost, problems about dimensional stability are a problem for a use in dentistry. Other plastic technologies are still now not really developed for dental application in clinics. Still some brands as Leonardo or Cubicon develop filament 3D printer(33).

SLA and DLP machines do not allow much setting, unlike FFF that we will see right after, Vat machines automatically choose the layer height and other parameters depending on the material and are determined at the slicing step.
These depends mainly on the capacity of layer height and the light source resolution(15).

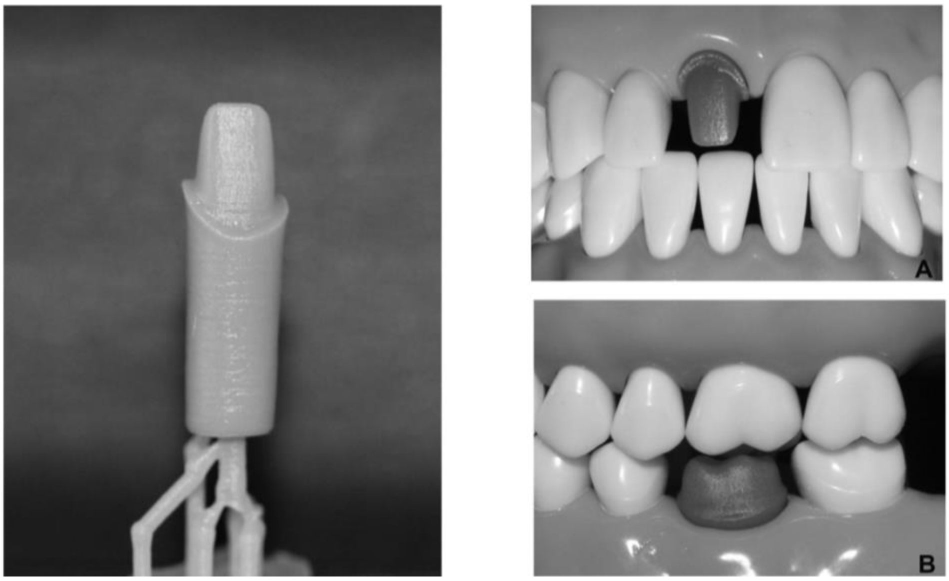


Figure 4: Example of 3D printed teeth for cast for educational purpose(34).

On the other hand, on FFF printers, many parameters can be changes by the user. The build speed, which depend on the extrusion speed and the nozzle temperature can be set by the user and from these setting will depend on the resolution and speed of the part production(18).

And for metal impression, the main technology is laser sintering, as seen in the part 1.2.3.4, it allows impression of 3D of metal, permitting fabrication of bases for crowns or fixed full metallic bridges for example. The machines are very expensive and most of the time not accessible for private clinic.

The setting also of the machine are very complex and require a real knowledge(8).

1.3.3. Materials for dental 3D printing

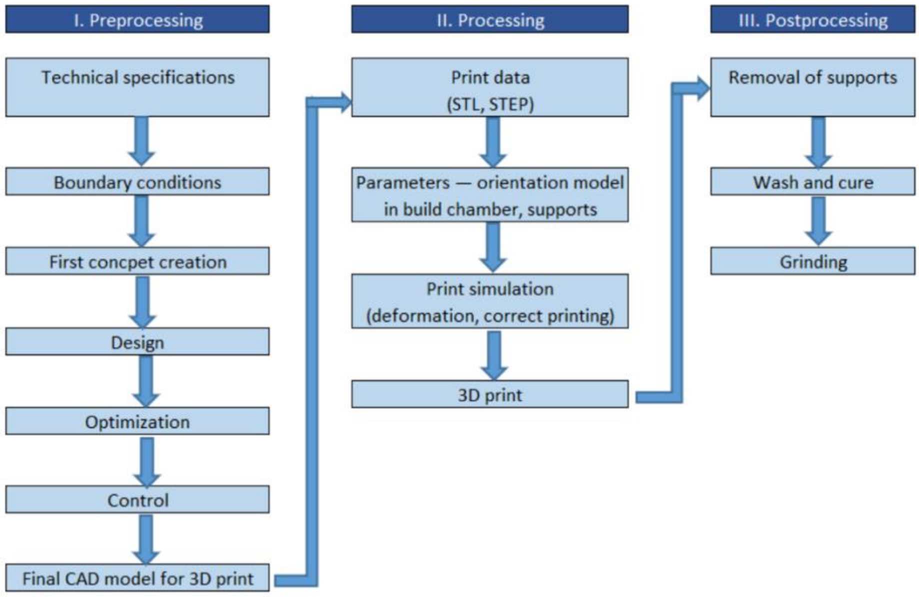


Figure 5: Integral steps of processing for 3D printing(26).

Materials for the main type of 3D printers used in dentistry will be seen in this part because, there is so many different materials and technology, sound better to focus on the most used ones.

First, for the FFF technology, which is using filament of different materials, the most used in dentistry are ABD and PLA which are cheap and efficient materials.

PLA is the most common because of it easy to print but the ABS is having better mechanical properties than PLA even if it is more difficult to print and more expensive(15).

For the technologies using metals such as laser sintering or other technologies, for addition impression, the most used is cobalt-chromium because it is possible to print it and it is already the most used in dentistry for traditional way of building removable prosthesis(8).

For Vat polymerisation technologies, resins in liquid forms are used, allowing it photopolymerization. Classic resins can be used if the case does not require biocompatible material, like the Formlabs grey or the Somos prototherm which resist high temperature. Specifically for dental use and biocompatible, brands such as Detax freeprint, Visijet e-stone, Formlabs dental resins. These are biocompatible and have a good resistance to abrasion but more expensive(15).

2. Objectives

2.1. Provide to dentists a clear comprehension of the actual additive manufacturing technologies, 3D printing, and what uses can they provide to their clinic in the process of fixed prosthesis.

2.2. Develop the indications and limitations of the different 3D printing technologies and their materials in dentistry.

2.3. Understand the future of 3D printing in dentistry, mainly about the impression of ceramics for definitive fixed prosthesis.

3. Material and methods

This work has been done researching articles through different database with specific criteria and key word. The main database used are the website of the library Crai Dulce Chacon, PubMed, Google scholar, books, and articles from the library of university and thesis from Spanish and French universities. Many books about prosthesis and engineering from the library of UEM were used as articles about history of 3D printing for the introduction.

Search strategy: for this research, keyword was used in the following way using the PICO system and a table from which a query box in PubMed were used.

The following research question have been formulated after the table and still following the PICO system: To examine the different 3D printing systems about precision, gain of time and the price for machine and material for the preparation of prosthesis in patient requiring fixed prosthesis.

PICO	List of terms
Patient	Fixed prosthesis, crown, bridges, implants
Intervention	Provisional, mockup, preparation guide, impressions, waxup, CAD, CAM, Digital impression
Comparison	Different brands of 3D printer, materials, and their applications
Outcome	Application of printing and it precision

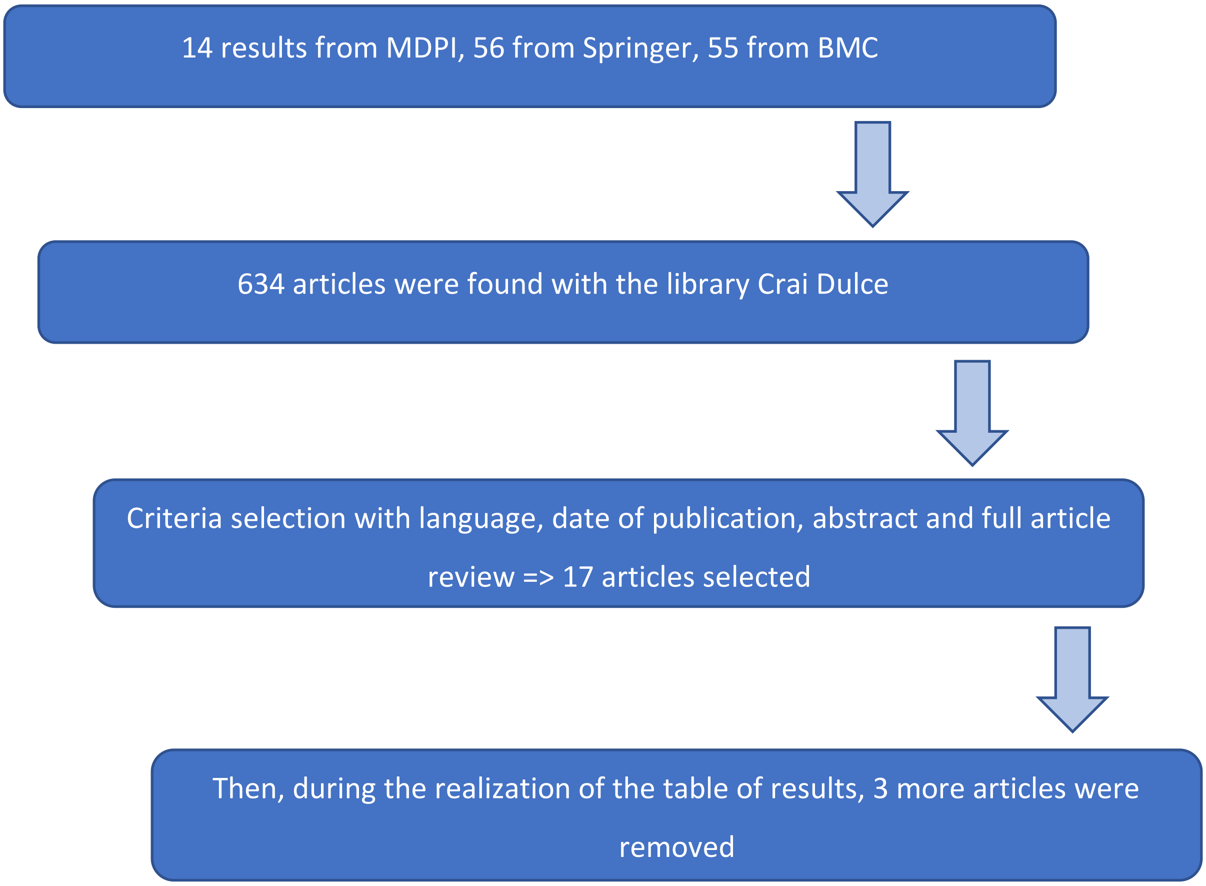
The final Querybox used on PubMed is the following one (using the system of inclusion OR, AND, NOT): (((((((fixed prosthesis) OR (crowns)) OR (bridges)) AND (3D printing))) AND (CAD-CAM)) AND (brands) (digital impression)) OR (wax-up)) OR (mock-up).

Eligibility criteria: for the selection of articles, criteria selection was used.
Inclusion criteria: articles in English, French and Spanish and published in the last 10 years. The articles need to be complete and available in PDF. Articles older than 10 years are excluded except for the introduction. Also, books are used, and older books might be used since there less publication of books. Articles, books, and thesis about the use of 3D printing in fixed prosthesis were used, also some about the CAD-CAM process and about the engineering for manufacturing process in conventional and digital ways.

Exclusion criteria: Every article in language else than French, Spanish or English, old articles or non-relevant due to change of technologies in 3D printing.

All the different articles and books and thesis used to make this research were uploaded on Zotero to manage the production of a Bibliography in Vancouver style that you can find at the end of the work.

4. Results



To obtain this article list, it was necessary to use multiple data base because of the complexity of the subject: use of 3D printers in fixed prosthesis.

It was very difficult to make research for articles since it was needed very different articles such as articles about the 3D impression of tooth for teaching coronal preparation for student. But also, articles about full digital workflow in case of implant crown rehabilitation.

Thus, the data base of the UEM, library CRAI Dulce Chacón was used with very precise keyword as: Dental fixed prosthesis 3D printing and VAT polymer resin or dental student education 3D or drilling template aesthetic 3D and tooth preparation and dental and 3D printer or additive manufacturing. Allows to obtain 634 results, parameters as the date less than 5 years, the language in English and a lecture of the title for a first selection and then the lecture of the abstract of the preselection allowed to obtain a selection of 10 articles.

Also, database as MDPI, BMC, and Springer allowed with simple keywords as: Dental 3D printing and Fixed prosthesis and Additive manufacturing and application to obtain shorter list of results. 14 results on MDPI and 56 for Springer and 55 for BMC. For these databases, a lecture of the title first for a preselection and then a lecture of the abstract of the preselection allowed a selection of 7 articles.
And during the realization of the table, after reading again all the abstract to resume them and after to resume all the conclusion of the 17 articles, 3 of them were removed because for example, one about the use of 3D mesh for implant surgery and bone and soft tissue graft was considered too far from the subject even if very interesting. Another one was too like another article from MDPI so the best of them have been selected and the last removed was mainly about dental splint even if the keyword corresponded to the research, splints are removable, so the article had to be removed.

Here is the final table with information about the 14 articles selected for the result and discussion. As information, can be found the title, the author and the date, a resume of the abstract, the technologies used and its application and finally, a resume of the conclusion of the articles.

NB	Article Title	Author / Date	Abstract resume	3D Technology used	Application of 3D	Conclusion
1	3D Printing in Digital Prosthetic Dentistry: An Overview of Recent Developments in Additive Manufacturing(23).	Schweiger J; Edelhoff D; Güth JF / 2021 May(23)	This article examines the use of 3D printing in the dental industry, evaluating its current applications and future potential for dental restorations. It also discusses the impact of 3D printing on traditional dental laboratory services.	Laser sintering, Filament based, Light based resins, Material jetting	Metal crowns and bridges, clasp-retained metal framework, Model, Template drilling stents, Custom impression trays, Occlusal splints, Training models, Graphic 3D models, Multilayered crowns, Muffling, Ceramics printing	3D technologies offers nowadays great alternative to conventional technique and can help where there were no solutions before in many dental fields and in the future with impression of multilayered ceramics.
2	A Review of Vat Photopolymerization Technology: Materials, Applications, Challenges, and Future Trends of 3D Printing(26).	Pagac M; Hajnys J; Ma QP; Jancar L; Jansa J; Stefek P; Mesicek J / 2021 Feb(26)	This manuscript reviews three popular 3D printing techniques: stereolithography, digital light processing, and continuous digital light processing. These techniques use ultraviolet light to solidify light-	This article focus on all the technologies using liquid resins such as: SLA, DLP, CDLP, CLIP	Does not focus on the use of 3D printers but on the different materials that can be use for SLA 3D printer in the dentistry	This article discusses the advancements in photopolymerization 3D printing for rapid prototyping, customized products, and serial production. The future of photopolymerization lies in material development for medical applications

			curable resin into 3D structures.			and modern designing methods.
3	A review on Vat Photopolymerization on 3D-printing processes for dental application(35).	Andjela L; Abdurahmanovich VM; Vladimirovna SN; Mikhailovna GI; Yurievich DD; Alekseevna MY / 2022 Nov(35)	This study provides a critical review of research conducted on Vat Photopolymerization for use in dentistry, highlighting the need for further research in areas such as mechanical properties, biocompatibility, antimicrobial properties, accuracy, and surface properties of 3D-printed resin-based dental parts.	Technologies based on liquid resins, mainly SLA	The articles does not treat about uses of 3D printer but about the mechanical properties of 3D parts, the biocompatibility and antimicrobial properties, the accuracy, and surface properties for printed parts	The authors found that most of the research conducted so far has used SLA and DLP 3D printers, and there is a need for more exploration of DUP and CDLP processes. However, the lack of information due to trade secrets and missing protocols and standards is a significant obstacle for future research.

4	A stereolithographic template for computer-assisted teeth preparation in dental esthetic ceramic veneer treatment(32).	Gao J; Li J; Liu C; Fan L; Yu J; Yu H / 2020 Dec(32)	This article describes a digital dental esthetic ceramic veneer treatment workflow using a stereolithographic template for teeth preparation. A case study of a 33-year-old woman with dental fluorosis is presented preparation template is created using a stereolithographic technique.	Resin 3D printer (type SLA)	Guide for veneer preparation (for depth control depending on the digital waxup)	In this clinical report, a workflow is presented for a digital-focused dental esthetic veneer treatment that involves using a stereolithographic template to prepare the teeth. The use of this template enables precise control over the depth of reduction for the labial and incisal preparation, which simplifies the procedure.
5	Clinical Outcome of Fully Digital Workflow for Single-Implant-Supported Crowns: A Retrospective Clinical Study(36).	Gianfreda F; Pesce P; Marcano E; Pistilli V; Bollero P; Canullo L / 2022 Jul(36)	In this study, a fully digital workflow was used for single-tooth implant rehabilitation, utilizing intraoral scanners, computer tomography, Computer-Aided Design and Computer-Aided Manufacturing (CAD-CAM), and 3D models.	PMMA	Surgical guide and Models	Digital protocols and planning have reduced the number of clinical sessions needed, and CAD-CAM technology has simplified the process of managing changes. However, more research is needed to assess the potential benefits and limitations of a fully digital workflow.

6	Dimensional Accuracy of Dental Models for Three-Unit Prostheses Fabricated by Various 3D Printing Technologies (37).	Yoo SY; Kim SK; Heo SJ; Koak JY; Kim JG / 2021 Mar(37)	This study examined the accuracy of 3D-printed dental models for three-unit fixed prostheses, particularly at margin and proximal contact areas.	DLP, MJP and SLA	Comparison for cast impression with different technologies	The study found that MJP casts were more accurate than DLP and SLA casts. The conclusion was that DLP, MJP, and SLA techniques can be used for adjusting and determining the fit of fixed prostheses before delivery.
7	Flexural Strength of 3D-Printing Resin Materials for Provisional Fixed Dental Prostheses(38).	Park SM; Park JM; Kim SK; Heo SJ; Koak JY / 2020 Sep(38)	In this study, the flexural strength of 3D-printed provisional restorations was compared to conventionally fabricated and milled restorations. Three additive manufacturing technologies, DLP, SLA, and FDM, were used to manufacture three-unit fixed dental prostheses.	DLP, SLA, FDM	Bridges 3 pieces	This in vitro study found that the experimental groups DLP and SLA had higher flexural strengths compared to the CV negative control group. However, there was no significant difference in flexural strength between the DLP and SLA groups and the SM positive control group.

8	The step further smile virtual planning: milled versus prototyped mock-ups for the evaluation of the designed smile characteristics(39) .	Lo Giudice A; Ortensi L; Farronato M; Lucchese A; Lo Castro E; Isola G / 2020 Jun(39)	In this study, the trueness of mock-ups was investigated. Digital smile design/digital wax-up were performed to enhance the aesthetic of maxillary anterior region, and ten milled mock-ups and ten prototyped mock-ups were obtained.	SLA	Mockup for aesthetic maxillary anterior region	From this research, the prototyped showed good results compared with the milled mockup and a better direct fitting after clinical tests. But from the 3D study on prototyped mockup, the matching was greater with milling techniques.
9	The Use of 3D Printed Tooth Preparation to Assist in Teaching and Learning in Preclinical Fixed Prosthodontics Courses(34).	Boonsiriphant P; Al-Salihi Z; Holloway JA; Schneider GB / 2019 Feb(34)	The article describes an innovative technique for teaching tooth preparation for fixed dental prostheses in preclinical fixed prosthodontics courses.	SLA	Impression for prepared tooth for educational purpose	The article highlights the advantages of using 3D-printed tooth preparations in dental education. These models are faster and cheaper to produce than traditional ones, and they help students compare their work to ideal standards.
10	Three-dimensional printing in contemporary fixed prosthodontics: A technique article(40).	Bukhari S; Goodacre BJ; AlHelal A; Kattadiyil MT; Richardson PM / 2018 Apr(40)	This article discusses the use of 3D printing in dentistry to create a die-trimmed cast and replicate gingival tissue and implant analogs.	SLA, PMMA	Impression of cast and removable gingival part in the implants and crown prosthesis	The article discusses the potential impact of 3D printing. It presents an example of 3D printing being used to create a definitive cast, demonstrating the technique's capabilities.

11	3D Printing of Dental Prostheses: Current and Emerging Applications(16).	Fereshte Rezaie; Masoud Farshbaf; Mohammad Dahri; Moein Masjedi; Reza Maleki; Fatemeh Amini; Jonathan Wirth; Keyvan Moharamzadeh; Franz E. Weber; Lobat Tayebi / 2023 Feb(16)	This review article discusses the use of three-dimensional (3D) printing in the fabrication of dental prosthetics. The article explains how 3D printing works, its advantages and disadvantages, and the various materials that can be used for dental applications.	Stereolithography, Fused deposition modeling, Selective laser sintering, Multi-jet printing, Powder binder printer, digital light processing	Crowns, Bridges, Interim restoration, intracoronal restoration, Inlays, Surgical guides,	3D printing has the potential to revolutionize the production of dental prostheses by creating more comfortable and natural-looking options while reducing production time and cost.
12	Digital dental workflow for a smile makeover restoration(41).	Agnini, A.; Apponi, R.; Maffei, S.; Agnini, A / 2020(41)	The article describes a new approach to dentistry using digital technology. This allows for more precise treatment planning and better outcomes using new ceramic materials.	PMMA AND SLA (Working with a third part laboratory in Madrid)	Casts, guide for gingivectomy and guide for veneer preparation, mockup	The article discusses the importance of a successful smile makeover and its positive impact on a patient's life. It emphasizes the need for careful planning, minimally invasive tooth preparation, and the correct choice of materials for restorative outcomes.

13	A report on a diagnostic digital workflow for esthetic dental rehabilitation using additive manufacturing technologies(42).	Rewilla-León, Marta; Sánchez-Rubio, José Luis; Besné-Torre, Adriana; Özcan, Mutlu / 2018(42)	The article explains a new digital approach to dentistry that avoids traditional cast manufacturing by using intraoral scanning, CAD design, and 3D printing.	DLP	Cast and mockup and silicon index 3D printed	This report outlines a digital workflow that begins with extraoral photographs, video documentation, and intraoral digital impression taking. This is followed by CAD design of the diagnostic digital wax-up generated using facial data. A 3D-printed silicone index is then created, incorporating the diagnostic mock-up.
14	Three-dimensional printing of temporary crowns with polylactic acid polymer using the fused deposition modeling technique: a case series(43).	Kim EK; Park EY; Kang S / 2022 Nov(43)	The article reports on the clinical application of 3D printing of temporary crowns using polylactic acid (PLA) and fused deposition modeling (FDM) printing. The temporary crowns were assessed for comfort, fracture, and dislodging and maintained until the permanent prosthesis was ready.	FDM	Unitary temporary crowns	This study was limited to single-tooth restorations in the posterior region due to the accuracy limitations of oral scanning. Objective data is required to evaluate PLA 3D-printed crowns since patient assessments in this study were subjective.

5. Discussion

First, this discussion is going to be organized by uses of 3D printer. Different application of 3D printing will be seen and when possible, compared with other articles.

5.1. Provisional bridge and crowns

In this section, provisional for fixed prosthesis made from 3D printer will be seen and compared.

Park and Sang-Mo (38) made a very detailed comparison of 3D printed cast using different technologies. It is admitted 3D printed cast are already an alternative to conventional cast. They noticed that the use of additive manufacturing reduces the C02 footprint, the loss of material and the price of the cast. They concluded that the DLP and SLA technologies had better physical resistance than conventional technique.

While in the article from Kim, Park and Kang, 5 patients were followed for 5 provisional crowns made out with 3D technologies. They have been using PLA because it is a cheap and biocompatible material working with FDM printer because this technology is cheaper and easier to handle than SLA system which are the favourite nowadays.
They explained that even FDM which is the most basic technology was enough to produce cast.

And Fereshte Rezaie, et al.(16), made comparison between different materials for 3D printing and conventional technique but also after using cast made by 3D printing and by milling technique to compare all the parameters.
They considered material for the conception of provisional crowns such as classic ones as resins for SLA but also thermoplastic polymers, PMMA and ceramics for provisional and definitive crowns but in the article of Park and

Sang-Mo they considered the use of 3D printer for bridges and bigger restoration.

5.2. Education purpose

Schweiger et al.(23), explained that the Department for Dental Prosthetics of the University of Munich thanks to the 3D technologies they were able to produce models with the SherPrint D30 printer and material which has good capacity for producing cast for phantom and good characteristics for working on it with turbine.

Also, they can make multi-layered cast allowing for example layers of colour for preparation of crowns so the student can know when he reaches the 0,5mm and 1mm of preparation.

They could produce tooth for root canal treatment for student training and cast for surgery with specific resins and realistic cortical and trabecular bone while in the article of Boonsiriphant et al.(34), they used prepared tooth from typodont by a professional and then the arch is scanned with intraoral scanner and reproduced with 3D printer to student can have prepared tooth on their typodont to see how is it in the arch.

They explain that compared to 2D images of preparation, 3D printed preparation illustrates in a better way the form of a preparation and the different preparation types. One is going to serve only as an example and the other one is going to allow to learn preparation on coloured tooth and other applied learning techniques.

5.3. Cast (also removable gingival tissue cast)

Schweiger et al.(23), explained many uses of 3D printer in modern dentistry. About the impression of cast, they recommend the use of DLP printer technologies and the use of polymer resin. Also is allows personalisation of the cast as removable teeth or any other (we will see later cast for surgeries with removable gingiva). On the other side Yoo et al.(37), have compared three technologies used for the production of casts: DLP, MJP and SLA.

They have prepared premolars and molars with different preparation types, scanned it and then print it with the different printers but the same parameters and then scanned it again to compare with a software the differences. The best result was obtained with the MJP compared to the DLP and SLA but also, they concluded that all of them were in an acceptable range for a use in dentistry for prosthesis production.
They were in a range sufficient even compared to conventional technique with plaster but in the article of Schweiger et al. they preferred the use of DLP technology.

Bukhari et al.(40), have made using two types of resins. The model can be as classic model or a dies type model with removable tooth or removable adjacent tooth for implant case and there is the gingival part which is removable to a perfect adaptation of the crowns or bridges.
They used SLA technology and Formlabs standard resin and the Formlabs flexible resin for the gingival tissues. There is now a specific resin for the reproduction of gingiva: Next dent gingival mask from the brand Next dent. They have used the SLA technology and they added removable element while the other articles just worked on simple cast while Schweiger et al. preferred the DLP and Yoo et al. concluded the best was the MJP.

Agnini et al.(41), treated aesthetic cases using full digital workflow. They did not have in the clinic 3D printer, so they worked with DSD virtual lab in Madrid to produce cast by 3D printing.

5.4. Wax-up, mock-up and silicon keys

Rewilla-Leon et al.(42), reported a case for which they used only digital technologies. Usually, we would print in 3D the cast which include the digital design and then use putty soft on the cast for the mock-up using for example PMMA or the mock-up can be fully digital printer in 3D or made with subtractive technique such as milling. In this case it is another alternative by printing directly the silicon key. The printer RapidShape D30 were used with NextDent Model material. It is a different way compared to the article of Lo Giudice et al.(39) who directly printed the mock-up with 3D printer which clearly allow a gain of time and is simpler.

They have compared two methods for production of mock-up: on one hand, milled mock-up from material disc of Polymethyl methacrylate from the brand Synergy Disk Tempo Multi, Opal, Nobil-Metal SPA. On the other hand, they measured 3D printed mock-up with Formlab and SLA machine. They found that 3D printed mock-up had a better fit than the milled ones and less dimensional changes. Also, the 3D printer allows to print out multiple mock-ups at the same time without the loss of material produced by the milling technology.

5.5. Guides (for veneer preparation, for surgeries)

Gao et al.(32), have been using a full digital workflow and for the preparation of the veneer, they have used a specific guide designed in 3D with multiple holes in which a special burr can be inserted in a specific burr. Once all the holes are done on the surface of the tooth, can be equalise with a long burr and having only the minimal preparation depending on the design of the veneer.

On the other side, in the article of Agnini et al.(41), they have made a full digital workflow for preparation of anterior restoration. They did not used guide for the preparation of veneer, but they did used on for the gingivectomy. It is going to be designed in 3D with the digital smile and it is made with 3D printer, has

the shape of an aligner with fenestration where it is needed to remove gingiva. Allows a good control and perfect shape for gingivectomy.
Classic guide works same as silicon index but in this case, the guide is really going to guide what the dentist does and how deep he is going. The holes give the reference of the depth in each part of the tooth that is needed.

Both guides are good option, the first one is a little bit complex; it exists simpler model working same as silicon key and that seems to be good option also. This one could need some more test seeing the complexity of the system. The second guide for gingivectomy is already quite used and very simple and efficient.

5.6. 3D printer materials

Pagac et al.(26), have compared different materials compatible with the following technologies: SLA, DLP, CDLP and CLIP.

Classic resins, structural resins, ceramic resins, flexible resins, and biocompatible resins have been compared.
They compared them in a large range of application and not only dental. They gave information about all the actual types of resins that can be found and about their mechanical properties.

But on the other side, Andjela et al.(35), the different studies they reviewed shows good result for biocompatible and antimicrobial resins with a significant reduce in the development of bacteria.

About the accuracy for SLA and DLP resins, some resin brand shows better mechanical stability and precision. But Andjela et al. also concluded that all of them had better result than conventional techniques. Some studies explain that on large pieces, additive manufacturing can show limit because of dimensional properties problems but on small piece there was no problems. From the articles, the scanner has a secondary role but the use of a 3D printer allowing the use of different types of resins is useful to choose the most adapted one depending on the case. But in the Pagac et al. explained there is no evidence of problem related with bigger size of piece. Even tough, always, when the impression is larger, larger will be the range of dimensional problems.

The choice of material is important to produce dental piece. It is still in evolution and need furthermore evaluations and tests. But as we have seen it, we can find different types of resins like flexible one if we want to reproduce gingiva or for silicon index.

6. Conclusion

In conclusion, we have seen in this work many possible uses of 3D printer for fixed prosthesis in dentistry. Some are already very used as the cast impression for digital workflow, but some are very innovative like the impression of coloured cast for educational purpose.

We have seen different types of guides (guide for veneer preparation and guides for making holes for veneer preparation), silicon index (either fully made with 3D printer or using putty soft on 3D printed cast including the wax-up), different techniques for provisional production (can use either the 3D cast on which with conventional technique we can make the provisional or directly 3D printed provisional).

About the limitation, depending on the use the main limitation nowadays are the materials. There are limitations on the size of the 3D printed piece. It is still in discussion and depend on the 3D printer and its material, but larger piece might be more complicated. Also, on the use of 3D printer for definitive prosthesis we consider that it still needs more test and articles because the technology is not effective yet. But for the other uses as impression of unique or small bridge in 3D or the impression of a flexible silicon key for provisional it is a good solution allowing gain of time and efficiency in the workflow.

About the future of 3D printing, there is already, as we saw it, studies about the use of ceramics in liquid resin material to produce definitive restorations. We have seen an article about the addition of zirconia in resin liquid with specific characteristics and special post impression treatment. There is still doubt about these materials and need more evolution and test, but it is very probable that in a near future dentist could be able to use 3D printed zirconia crowns. In combination with the technologies apart that, we could be able to make layered coloured zirconia with good strength and so have aesthetic zirconia crowns without loss of matter and good mechanical properties. 3D uses in dentistry is still recent and need development.

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