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CURRENT STATE AND USES OF 3-D PRINTING IN DENTISTRY: A LITERATURE-BASED STUDY

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Objective: To study the existing status and usage of 3-d printing (AM) in dentistry combined with diverse technologies, benefits and future scope.

Procedure: Several AM technologies, as well as their advantages and disadvantages, are discussed in this study. Also covered are numerous advantages of 3D printing in dentistry and the methods involved in creating 3D printed dental models. As a result, the following ten significant applications of AM in dentistry have been outlined, along with primary references and goals.

Conclusion: The use of computer-aided design (CAD) data in the creation of dental implants and other dental instruments is an innovative technology that is advancing toward bespoke manufacturing. Orthodontic braces, crowns, bridges, and other dental appliances may all be made using this technique in less time, and it's less expensive, than traditional methods. Dental implants may now be manufactured precisely according to patient data acquired by a dental 3D scanner thanks to this game-changing breakthrough. Surgical templates for implants and removal prosthesis, as well as production models for treatment planning and preoperative jaw alignment, may all be made using this technique.

1 Introduction

The 3D printing revolution has been touted as the third revolution since it has ushered in a paradigm change in the production process. There are multiple processes involved in the traditional process of transforming raw materials into completed and assembled useful items, however these procedures are unnecessary when the raw material is used directly to generate functional products at a fraction of time previously required. As a result, AM has found use in a variety of fields, including automobile, aviation, printed electronics, and even healthcare. AM is still finding use in these fields. Because of its ability to produce patient-specific customised implants with the requisite accuracy and precision, additive manufacturing (AM) is rapidly being employed in the healthcare industry. An example of an implantable medical device that makes use of AM technology is the heart valve. Intricate implants have been 3D printed utilising a wide range of materials, including ceramics, metals, polymer, and composites. Dentures and other prosthetic devices are among the dental uses of AM. The simplicity with which anatomical models may be built with AM makes it useful for surgery training and planning as well. This article provides an introduction of additive manufacturing (AM) as well as an in-depth look at how it may be used in dentistry.

Customization has become a possibility thanks to additive manufacturing (AM) or 3D printing as it is more popularly called. Using 3D printing technology, it is now feasible to produce unique implants in a fraction of the time and expense that was previously required. [1]

Using computer-controlled additive manufacturing, a 3D solid item is created directly from 3D CAD data. Additive manufacturing is used in enterprises, defence, aerospace, art, medical, and design for customization and quick production. It is being used in dentistry to create customised dental models. Dental implant drill guides are effectively produced. [2,3]

Starting with a 3D scan or CAD software generated virtual picture, AM builds a product using several AM methods. AM technologies solving complicated problems in medicine and dentistry. These technologies can now help patients.

Stereolithography (SLA) is often utilised for aligner manufacturing, whereas direct metal laser sintering (DMLS) can produce high-quality metal dental crowns and appliance frames. [4,5]

3D printing has immensely improved dentistry. The capacity of the technique to make prosthetic teeth and implants quickly, often inside a dentist's office, has made it easier to construct them. [6,7]

The oral cavity contains the upper and lower jaws, 32 teeth (16 in each jaw), muscle, nerve, and blood vessels. These tissues are easily infected or damaged. A critical function for 3D printing in manufacturing life-like implants to repair damaged tissues. [8,9] Hands-on implant surgery. Using the scanned picture, dentists drill the patient's mouth. Imagination is used in this process, thus it's not.[10,11]

A clever approach for drilling placement, additive manufacturing. A complete set of dentures that fit comfortably in the patient's mouth helps to increase surgical precision. The AM technology is currently available. Dentists benefit from greater health care and diagnostic knowledge. Other medical uses include improving patient outcomes after complicated surgery. [12,13]

2. Process of 3D Printing

3D printing involves building an item layer by layer from basic materials. A virtual representation of the item is split into layers that are bound together or sintered. [14,15] The first step in 3D printing any implants is to get a picture of the organ. The implant is constructed layer by layer from a picture of the organ. [16,17] The process of constructing a model organ or implant starts with a scan to get a picture of the organ or implant to be created. A number of two-dimensional pictures are produced in this way. This is then assembled to form a model, which is then confirmed before being manufactured on a 3D printer using additive manufacturing technology.

Imaging Technique:

There are a variety of imaging techniques available for creating a 3D representation of the organ. Whilst magnetic resonance imaging (MRI) is the primary technique of scanning for soft tissues, other modes of scanning are available [17,18]. And for hard tissues CT scan is preferred. [18]The picture is created by layering cross-sectional sections together. [16-18]

Because the quality of the picture has a significant impact on the final output, it is recommended that the optimal thickness of each layer produced be a minimum of 1 mm. Thick layers, on the other hand, will result in a stepped structure as a consequence. The use of algorithms that eliminate the phases and smooth them out to generate curves might help to mitigate some of the shortcomings of imaging. [19,20]

Additionally, photographs of the organ may be gathered by the use of photoprogrammetry tools such as 123D Catch, which allow a 3D image of the organ to be made by capturing photos of the item in multiple angles and combining them to build a virtual object to be created. The use of photoprogrammetry programmes is easy, but since the item is not scanned throughout the cross-section, it only enables for surface reconstruction to be performed. [21]

2 Types of 3D Printing

There are several AM technologies utilised to create product layer by layer; utilises distinct ways of manufacturing of the physical model as discussed below:

Additive Manufacturing	Process	Materials Used	Advantages	Disadvantages	Example
Stereo lithography	Form of 3D printing technology that uses a computer controlled moving laser beam, pre- programmed using CAD/CAM for creating models prototypes, pattern and production parts in layer by layer fashion using photochemical processes.	1 Standard resin. 2 Clear resin. 3 Cast-able resin. 4 Tough resin. 5 Dental resin.	1 Functional part can be built in a relatively short period of time. 2 Cost –effective for low-production. 3 Provides quick lead times.	1 Fragility. 2 Expensive machines. 3 Unit production.	1 Scaffold fabrication for tissue engineering heart valves. 2 Bio-printing 3 3D printing in investment casting. 4 Chemical engineering from macro to micro.

Fused deposition modeling	Type of 3d printing used to create a 3D structure by extruding melted thermoplastic filament layer by layer along with apre joined support materialthat islater dissolved away.	1 ABBS-M30. 2 ABS-ES07. 3 AB-Si. 4 ABS-M30i. 5 ASA.	1 Compact construction 2 Possibility to sterilize. 3 Better geometric accuracy.	1 Slow building speed. 2 Low surface quality.	1 Automotive. 2 Aerospace. 3 Material. 4 Medical.
Selective laser sintering	It is a form of 3D printing which uses a laser bean to create solid objects by heating powder particles and then fusing them together.	1 Pol-carbonate. 2 Nylon. 3 Glass composite. 4 Wax. 5 Ceramics.	1 Ability to use different thermoplastic powders 2 Easy post-processing 3 No support required.	1 High cost 2 Abrasive surface of sintering models.	1 Drug development and industrial pharmacy 2 Health care and dental setting 3 Design verification 4 Fashion industry
3D printing	It is a process which uses inkjet printing head to spray the binder material in selective areas toblend the powder together.	1 PLA. 2 ABS. 3 HIPS. 4 PVA.	1 Good fabrication 2 Low material cost.	1 Surface finish 2 moderate strength 3 Material is not easily available.	1 Prosthetic limbs and body parts 2 Homes and buildings 3 Manufacturing 4 Fireman and military.
Laminated object manufacturing	It is a type of 3D printing based on the principle of lamination which is generally used to fabricate parts using paper, ceramic, polymer or metals. Next step is followed by subtractive step followed by gluing of new layer and the entire process is repeated until the whole part is fabricated	1 PVC. 2 Paper. 3 Composites. 4 Non-ferrous metals.	1 Fast and accurate 2 Variety of material can be used 3 Good handling strength 4 Relatively high speed.	1 Not idle for making complex geometries 2 Material used is paper which is not very stable.	1 Dental mold 2 Pattern making 3 Decorative objects.
Poly jet printing	It is a type of 3D printing which uses Ink-jet printing process, suitable for plastic, here each layer is cured by UV light, it uses two different photo-polymer material.	1 Poly-propylene. 2 Dental materials.	1 Ability to produce highly detailed parts. 2 Pats can be printed with little to no post-processing finishing 3 Fast and scalable.	1 Poor mechanical properties 2 Very expensive.	1 Consumer goods industry 2 Medical industry 3 Commercial products industry
Electron beam melting	It is a type of 3D printing in which metal powder or wire is placed under a vacuum and fusedtogether by an electron beam.	1 Titanium alloy. 2 cobalt steel chrome. 3 Steel powder. 4 Nickel alloy.	1 Electrical conductor material can be machined. 2 Different size holes can be machined. 3 Process can be easily automated 4 Brittle and fragile materials can be used.	1 Very low accuracy 2 Exclusively used in metals 3 Limited build volume.	1 Aerospace and aviation components. 2 Orthopedic implants. 3 Electron beam melting of metal wire.
Laser engineered net shaping	It a type of 3D printing which uses 3D laser cladding and is a laser powder forming used for fabrication of metals. It uses a high power laser to melt metalpowder and a deposition head is used to supply the powdermaterial coaxially, powderis supplied and distributed using pressurized carrier gas or gravity.	1 Stainless steel. 2 Copper. 3 Aluminum. 4 FGM. 5 Composites.	1 High productivity 2 No residual internal stress 3 Less support required 4 Good mechanical properties.	1 Its little tricky to work with fine powders. 2 Maintenance contract is expensive.	1 Build models and die inserts. 2 Produce FGM.

SLA: The introduction of an ultraviolet laser to a vat of resin results in the construction of products. Because this technique makes use of light-sensitive polymers, there is a limited supply of materials that can be used with it. It provides a superior surface polish while also resulting in reduced waste of basic materials. [22, 23]

SLS: Sintering is accomplished by the use of a laser beam in this additive manufacturing technology. The substance in question is now in the powder form, and it is sinterized using a laser. [24, 25]

FDM: Identical to the extrusion technique, the product is created by layering hot thermoplastic material over a model to create a three-dimensional model. It is possible to extrude multiple types of material at same time using this procedure since the print head is multi-nozzled in nature. [26, 27]

DMLS: This technique is utilised to manufacture metal components that are very accurate and have increased mechanical strength and durability. Metal material is applied layer by layer with this process, and a laser beam is utilised to melt powder at a specific spot. [28, 29]

PJP: Making use of UV-curable acrylic plastic to create a component is something we're doing. It makes use of a number of different sorts of printing materials. In the medical and dental fields, a model produced with this technology allows for a better grasp of the anatomy of the patient. [30, 31]

PJ: The fluids used in this technique, such as polymer solution given in liquid form being coated layer at a time to construct a product, are distinct from one another. It prints a wide range of materials in less time and at a lower cost. [32, 33]

LOM: 3D models are created by layering different types of materials onto a predetermined sheet of material. Sheet material is cut using a laser to create the cross-section that is needed for the project. Adhesives are utilised to join the layers together, and they are created by repeating the process. [34, 35]

CJP: Using powder as the core material and binder as the resin, this method builds the component by spreading the core material in layers over the build plate using a roller. The part is then assembled on the build platform. The printing head jets/sprays binders (sticky) on the powder bed at defined spots as determined by the CAD software, resulting in the construction (printing) of a colourful product with widespread use in the medical area. [36, 37]

EBM: With the use of a powerful electron beam, a metal powder is utilised to construct an object layer by layer under the control of a CAD model with precise geometry. An electron beam stores and fuses the raw material in a vacuum, which is created by the vacuum. [38, 39]

MJP: It is possible to build a thin solid coating of metal or ceramic powder with this technique by spraying a binding liquid over metal or ceramic powder using nozzles. After the model has been created, it is sintered in a furnace in order to strengthen its structural strength. [40,41]

Dental and surgical professionals benefit from a 3D physical model produced by AM because it gives them a correct view of the patient's anatomy. Implants customised to a single patient are made with geometric flexibility and are used to address common dental issues.

3 Advantages of 3D-Printing in dentistry

In dentistry, individuals have a variety of needs, such as crowns, implants, and bridges, among others. Various additive manufacturing methods are valuable in the field of dentistry. Dental prostheses are manufactured using binding jet technology, which is a kind of laser. Various criteria are taken into consideration, including the drying powder level, the quantity of binder used, the drying period, and the pace at which the powder spreads. The outcome demonstrates that it gives a precise implant at a reasonable cost while also providing greater strength. [42]

Additive manufacturing is being utilised to build patient-specific eruption guiding appliances, which is boosting patient comfort while also lowering the total cost of the model. [43] Metallic powder is utilised in conjunction with 3D printing technology to create a partial denture utilising Binding Jet technology. Micro-computed tomography (MCT) is used to scan the established system in order to create a 3D printed model of the structure. The outcome demonstrates that it is beneficial.

The ability to attain more than 99 percent density while maintaining control over shrinkage at a lower cost It is particularly suitable with the production of complex-shaped dental implants with precise dimensions and dimensions.Metallic powder is utilised in conjunction with 3D printing technology to create a partial denture utilising Binding Jet technology. Micro-computed tomography (MCT) is used to scan the established system in order to create a 3D printed model of the structure. The outcome demonstrates that it is beneficial. [44]

Additive manufacturing allows dentists to meet their clients' specific needs in less time and at a lower cost. [3,10,12]

Some advantages are:

1 Service that is more timely and accurate.

2 Cost effective.

3 Calculate teeth's dimensions (depth and breadth).

4 Customized implants may be easily made.

5 Cut down on the time it takes to make things.

6 Physical models' inventories are greatly reduced because to the system's digital storage.

7 Custom designs may be created quickly.

8 Implant size has to be precise.

In the field of prosthodontics, dentists may now utilise a range of materials, including ceramics and metal alloys, thanks to the usage of AM. A great degree of precision is achieved in the production of dental models.

4 Research so far of Additive Manufacturing in dentistry

Sl No.	AM Technology	Approximate Technology	Dental Material
1	Stereolithography	50-55µm	Acrylate Photopolymer Plastic Ceramic
2	Selective Laser Sintering	45-50µm	Thermoplastics Powder Plastic Metals Ceramic
3	Fused Deposition Modelling	35-40µm	Polycarbonate Acrylonitrile Butadiene Styrene Polypropylene Polyesters
4	Direct Metal Laser Sintering	20-35µm	Titanium Cobalt Aluminium Bronze Alloy Steel Stainless Steel Nickel Alloy
5	Polyjet 3D Printing	20-85µm	Photopolymers
6	Inkjet 3D Printing	35-40µm	Powder Liquid Binder
7	Laminated Object Manufacturing	60-70µm	Metal Plastic
8	Colour-Jet Printing	23-30 µm	Gypsum Powder Binder
9	Electron Beam Printing	40-50µm	Metal Powder Titanium
10	Multi-Jet Printing	25-35µm	Powder Plastics

An AM-based search for the most articles in this subject returns nine results for the Journal of Prosthetic Dentistry. Second place in the Dental Materials journal is occupied by a second publication. In addition to Biomed Research International and Rapid Prototyping, there are a number of additional publications that publish one. By using AM in dentistry, the engineering field is used at a maximum of 27%. Despite this, dentistry gives 23 percent, Materials Science 16 percent, Biochemistry, Genetics, and Molecular Biology 11 percent, Medicine 5 percent, Computer Science 3 percent, and other fields also contribute 14 percent to the overall number. It has been shown that the use of additive manufacturing in dentistry is on the rise, based on data from Scopus. Dental technology is becoming more financially feasible as a result of this trend.

5 Basic Steps for creating dental model using 3D Printing:

Sl. No.	Step Used	Description	References
1	Digital 3D model of the patient's mouth	• Digital models are created by 3D scanners in the form of cloud data with fastand accurate dimensions	Haleem and Javaid Kumar et al.; 2018
2	Modification in Design	• Used 3D scanner for precise scanning of patient mouth and teeth • After scanning, it is essential to ensure that the dental model will fit perfectlyby adjusting shape, size and position • Easy modification in design is done through the use of different software andthe associated AM technology	Azari and Nikzad 2009; Tahmaseb et al.; 2014
3	3D Printing	• Fabricate 3D solid object directly from the 3D digital file by the addition ofmaterials layer by layer • Dental implants are manufactured using different AM technologies accordingto the specification of printing material • Post-processing is used to increase the physical property and strength of theImplant • Reliable for reconstruction of precise teeth and	Kumar et al; 2016; Chang et al; 2015; Javaid and Haleem 2018

		other tools used in dentistry • It is cost effective as compared to the other manufacturing techniques and canwell be used for training	
4	Testing and Implementation	• Ensures that the physical model is as per required quality and strength • Under a specific condition of load, it must be feasible & reliable • Testing is essential before actual implementation • Dental model printed by this technology is used during surgery of the patient	Chen et al.; 204 Francisco et al.; 2016

6. Conclusion

Today, a dentist's primary issue will be to transition to a computerised workflow and integrate novel tools and technologies into their normal practice. These tools enable dentists to provide greater creativity, predictable, and cost-effective treatments. However, with the introduction of new technologies, come new responsibilities. New rules for operating the device will need to be established to guarantee that the patient's level of care, health, and confidentiality are not jeopardised.

7. Conflict of interest

The author declared no conflict of interest.

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