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Three Dimensional Printing: A Novel Technique in Dentistry.

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ABSTRACT

Three dimensional printing (3DP), also known as additive manufacturing or rapid prototyping (RA) or solid free form fabrication or layered manufacturing, is a futuristic method and is very popular idea nowadays, so numerous potential applications and its promising advances in the medical and dental fields make it promoted in recent days. Depending on the material of choice various printing methods are available; such as, stereolithography, DMLS etc. Although it requires investment and skills, the advantage of 3D printing lies in its reproducibility, accuracy and ability to create complex parts with ease.

Keywords: Three dimensional printing technology, Dental application.

INTRODUCTION

Three dimensional printing (3DP), also known as additive manufacturing or rapid prototyping (RA) or solid free form fabrication or layered manufacturing, turns out as one of the most important revolutionary technologies of 21st century.[1] This futuristic method creates a three dimensional object by distinct techniques. The term "3D printing" was coined by Ely Sachs in 1995 at Massachusetts Institute of Technology.[2] It is a very popular idea nowadays, for numerous potential applications and promising advances in the medical and dental fields and hence gets promoted. This paper reviews the 3D printing technology, its application in medical and dental fields in coming days.

History

Though the term "3D Printing" is relatively new but the technology is not. It was first developed by Charles W. Hall, an American engineer in 1984 who described it as a "system for generating three dimensional objects by creating cross sectional patterns of the object to be formed". Later in 1986, 3-D System was founded as the first commercial 3-D Printing machine named Stereo lithography Apparatus (SLA).[3] In 1999, Dawood A et al first used this method to treat a patient with cleft palate.[1]

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What is 3-D printing

Three-dimensional (3D) printing is a manufacturing method in which objects are made by progressively depositing materials in layers—like plastic, metal, ceramics, powders, liquids, or even living cells to produce a three dimensional object.[4-6] This process is also referred to as additive manufacturing (AM), rapid prototyping (RP), or solid free-form technology (SFF).[7]

How it works

These technologies can build a 3D object in almost any shape as defined in a computer-aided design (CAD) file.[6] It follows instructions in the CAD file and the foundation of the object is made by moving the printhead along the x-y plane. The printhead into moves along the z-axis to build the object vertically layer by layer. Two-dimensional (2D) radiographic images, such as x-rays, magnetic resonance imaging (MRI), or computerized tomography (CT) scans, can be converted to digital 3D print files, and allow the creation of various complex, customized anatomical and medical structures.[8]

Types of 3-D printers

3-D printers are broadly classified into twotypes- additive printer and reductive printer. Each type of printer has their own advantages and disadvantages but most commercially available printers for medical applications are additive printers.

Additive printers

Additive machines build 3-D structures by progressively depositing layer upon layer of material. Exp.- Stereolithography (SLA) style printer, Polyjet printers , Fused deposition modelling (FDM) printers, Selective laser sintering (SLS), Selective laser melting (SLM), and Electron beam melting (EBM) printers.

Reductive printers

This type of printer begins with a block of material and progressively cuts away to produce the final shape. Exp.- Laminated object manufacturing (LOM) machines.[9]

Ideal requirements for rapid prototyping

Since this technology is very helpful in medical and dental fields, its requirements should fall under the parameter for its use, such as:

- Cost effective
- Easy to install
- Colour capability
- Time required to print
- Biocompatibility
- Acceptance of large number of materials
- Should provide intended service
- Less technique sensitive
- Accept sterilization.[10]

Different rapid prototyping technologies used in dentistry

Various 3-D printing technologies evolve in recent days that are frequently used in dentistry among which three techniques are most common- selective laser sintering (SLS), thermal inkjet (TIJ) printing, and fused deposition modelling (FDM).

Selective laser sintering (SLS)

It uses powdered material as the substrate for printing new objects. Scanning laser beam hits the powder particles and draws the shape of the object in the powder, fusing it together. Then a new layer of powder is laid down and the process repeats, to form the object. Oxygen must be strictly excluded from this SLS process to create a protected atmosphere in order to avoid formation of oxide layer inside a 3-D object.

Uses:- Laser sintering can be used to create metal, plastic, and ceramic objects.

Advantage:- Detailed and delicate structures can be achieved with this type of printer.

Disadvantage:- The degree of detail is limited only by the precision of the laser and the fineness of the powder.[11]

Thermal Inkjet printer (TIJ)

Also known as "noncontact" technique which uses thermal, electromagnetic, or piezoelectric technology to deposit tiny droplets of "ink" onto a substrate according to digital instructions. In this technique heat or mechanical compression of the printhead is used to eject ink drops. The volumes of the air bubbles are as small as 10 to 150 picoliters which can be varied by adjusting the applied temperature gradient, pulse frequency, and ink viscosity. TIJ printers are particularly used in tissue engineering and regenerative medicine. This technology is already being applied to print simple 2D and 3D tissues and organs and known as bioprinting.[12,13]

Fused Deposition Modelling (FDM)

FDM printers are much more common and inexpensive than the SLS type. This technology was developed by Schott Crump. It is mostly used for modelling and prototyping applications.[14] It works on the principle where a thermoplastic filament material is extruded through a nozzle controlled by temperature which uses a printhead similar to an inkjet printer. Instead of ink, beads of heated plastic are released from the printhead while moving, building the object in thin layers. The deposition occurs in a layered fashion, to build objects from the bottom to top by instantly combining all the layers of melted material and the material hardens immediately (within 0.1 sec) after extrusion. Materials like acrylonitrile butyro styrene ABS, polycarbonates, polysulfones, acrylics or waxes are used in this technology.[11,14,15] Besides these above said techniques there are other varities of 3-D printers available.

Stereolithography (SLA)

Stereolithography is an additive manufacturing process invented by Charles Hull in 1980s and it was the first commercially available printer for rapid prototyping. In this process UV light is focussed onto the surface of a vat, filled with liquid photopolymer and as beam draws the object onto the surface of liquid each time a layer of resin is polymerised.[16] The curing time and the thickness of the layer polymerized is affected by the dynamics involved in the entire procedure. The kinetics can be controlled by the power of the light source, the scanning speed and the chemistry and amount of the monomer and photo initiators. UV absorbers can be added on to the resin to control the depth of polymerization.[14]

Uses

It is used in making implant surgical guides because of high mechanical strength, obturators, surgical stents, and duplication of prosthesis and burn stents.

Advantages

1. High accuracy,
2. Good surface finish,

3. High mechanical strength ,
4. Smooth surface finish.

Disadvantages:

1. Scarcity of biocompatible resins with proper SLA processing properties.
2. Cost of the equipment,
3. Requirement for post-cure,
4. Use of photo initiators and radicals which may be cytotoxic with long processing times,
5. Entrapment of unreacted monomer and residual photo initiator, and inability to create compositional gradients along horizontal planes.[14,16]

Photopolymer jetting (PPJ)

This technology uses either a stationary platform and dynamic print head or a stationary print head and dynamic platform. Light sensitive polymer is jetted onto a build platform from an inkjet type print head, and cured layer by layer on an incrementally descending platform. A support structure is laid down in a friable support material. A wide range of resins and waxes for casting, as well as some silicone-like rubber materials can be printed.They can be utilised for printing dental or anatomical study models. The 3D systems and printers use a UV lamp or a light source to harden the resin or wax after each layer is jetted.[1,16]

Advantages

1) This technology is fast and cost effective
2) Resolution is high
3) High-quality finish is possible.

Disadvantages

1) Tenacious support material can be difficult to remove completely,
2) Support material may cause skin irritation
3) Cannot be heat sterilised
4) Materials cost is high.[16,17]

Power binder printers

It uses a modified inkjet head for printing. Liquid droplets are made to infiltrate a uniform and single layer of powder one after the other. Powder bed drops incrementally and a final model is ready which is built of many layers and a new fine layer of powder is swept over the surface. In order to boost the strength and surface hardness, a cyanoacrylate or epoxy resin is infiltrated during post processing procedures.

Advantages

1) Machines and materials are lower cost, but still less expensive.
2) Lower cost materials and technology, can print in colour, Un-set material provides support, process is relatively fast and materials are safe to use.

Disadvantages

1) Low resolution, messy powder, low strength
2) Difficult to heat sterilize.[1,17,18]

Applications

In Dentistry

3D printers can provide a precise virtual model of the prepared tooth, the implant position, and the dental arch. The scan data and CAD design can be used to print crown or bridge copings and partial denture frameworks, models for restorative dentistry, implant abutments, and bridge structures. 3D technology can lead to faster, less invasive, and more predictable surgery. Also in digital orthodontics by using orthodontic CAD software indirect bracket bonding splints, printed in rigid and flexible materials for precise bracket placement.3D printing may be used to print the implanted structure directly in maxillofacial prosthesis.[15,19]

In the field of oral and maxillofacial surgery

Anatomical models can be fabricated by using 3D printing technology as a new outlook for surgical treatment planning. In the early 1990s Anderl et al used CT guided stereolithography technique andmanufactured an acrylic model that allowed pre-operative treatment planning and intraoperative management in surgical correction of a wide midline craniofacial cleft in a 8 month old patient. 3D printing can also be used to fabricate customised reconstruction plates and morphological reconstruction of bony defect area in fracture cases and reconstruction surgery.[20,21]

In the field of implantology

In recent days CAD/CAM and 3D printing technology has obtained popularity in implant dentistry. Customized dental implants are printed using Selective laser melting (SLM) method. SLM is an efficient means for printing fully dense customized implants with increased strength and sufficient dimensional accuracy. In cases where conventional implants cannot be used 3DP customised subperiosteal implants can be used. It also avoids the requirement of an extra oral donor tissue or bone and the use of allografts.[22,23]

In the field of digital orthodontics

In the field of digital orthodontics 3DP is considered as a beneficial tool where the technique is used to realign patient's teeth digitally and a series of 3D printed models are made resulting in reposition of teeth over a period of time. The advantages are time saving, patient data set can be digitally saved, printed when needed and minimises the physical storage requirement. With the help of CAD/CAM technology two separate processes of bracket production and bracket positioning are combined into single unit which is helpful for the patient as well as for the dentist.[1,22]

In forensic odontology

3-D printing is an important aid for forensic anthropologists. Digital scanners are used to indenture the bite marks by eliminating the external pressure and tendency to undergo distortion. After scanning, the entire bite mark can be reconstitutewith an appropriate material using 3d printing technology and used to match with the evidence. The post mortem CT scans of the victims can be used to remake the skull and other bones. Other important recent advancements of 3-D printing in Forensic sciences include facial reconstruction, identification of pattern of fracture, identification and reconstruction of weapons used etc.[24-26] other than the above said applications there are various other fields in dentistry like- in prosthodontics, endodontics etc. where this productive technology has significant uses.

In other fields

3-D printing is presented with increased attention in fields such as architecture as its increased potential in the direct construction of parts. Due to the ease of making various small parts used in spacecraft construction it is used in aeronautics. Telecommunications is another field where 3-D printing is used now a days.[15]

CONCLUSION

3-D printing is a potentially transformative tool that becomes imminent on all aspects. With the evolution of 3-D printing, replication of complex geometrical form without an expensive tool can be achieved which were not feasible with conventional techniques. As the technology evolves, it is important in the forthcoming days that dentist should be alongside with the advances that cause benefit for both the dentist and the patient. 3-D printing is coming up as a promising technology in the field of dentistry that creates its own significance with an elevated success rate.

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