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The role of 4D printing materials, process and potentials for dentistry

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***Abstract*---**With the advancement of existing technology, every sector requires assistance in fast changing its working style. New technologies are improving manufacturing speed, lowering industrial process costs, and so on. To improve efficiency, technical professionals do ongoing research and development. The ability of 4D printing to change shape over time is a big improvement over 3D printing since external elements such as air, pressure, water, heat, and so on utilizes controlled impact. Instead of three "Ds," 4D Printing has one, and the fourth is time. As a result, 4D printing's ability to change shape over time is a substantial improvement over 3D printing methods. Manufacturers would undoubtedly benefit much from four dimensional printing in terms of features and advancements in dentistry. Surgical guide manufacturing, medical modelling, prosthodontics, orthodontics, dentistry, dentistry equipment and implantology are among its uses. This paper provides an overview of four dimensional printing and how it might be used to manufacture smart materials. The diagrammatic presentation of the Bio-Oriented 4D printed smart materials and process workflow for dentistry. The report also explores and recognizes the great potential of 4D printing in dentistry.4D printing is a cutting-edge technique that employs smart material inputs to convert a 3D printed object into a new structure when exposed to external energy sources such as light, temperature. The goal is to combine technology and design to build programmable material and self-assembly technologies which will improve design, manufacturing, and performance.

***Keywords*---**4D printing, dentistry, design, materials.

Introduction

4D printing is a new technical advancement that has the potential to revolutionise restorative dentistry.4D printed items are expected to replace 3D printed products in the near future. The notion of 4D printing was launched in 2012, and it

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sparked attention in procedures and materials. A 4D printing method permits the printed product/model to alter function and shape in response to environmental factors such as water, heat, electricity and light over time. This technology adds the capacity to incorporate product change from one shape to another.

Four dimensional printing is the digital method that creates three dimensional smart materials while also including time. This allows the printed item to be reconfigured after printing 4,5. Dentistry models are created and printed in this manner that as the temperature changes, one shape of the model is transformed into another. It improved the chances forgenerating the new dental product. Smart material approaches are set to revolutionized restorative dentistry. This technique appears to be capable of printing a three dimensional model using smart material that has the capacity to react to any situation. A smart material 4D printed dental implant may be capable to modify the aforementioned to recompense for missing tooth structure and repair broken portions. The fundamental issue in dentistry is missing teeth, which can produce and alter to the similar form as the new teeth. Though, such technology is not yet commercially accessible.

Dentists' jobs have grown easier because to 3D dental scanners, which are utilized to examination the four dimensional printing technologies and teeth of patient, which employ smart dental materials and smart machining technologies to create the scanned data. Dentists are also embracing digital technology for investigation purposes, creating a prototype and testing it for various qualities [1]. It simplifies and shortens the manufacturing process. After temperature changes, investigation in four dimensional printing in dentistry will increase in order to make smart bridges, aligner, sophisticated dental crowns, orthodontic braces and surgical templates customised as per the needs of the particular patient. It ushers in a new era of dentistry innovation. It will increase the quality of life for patients while also effectively resolving the dental condition. The dentist may turn a need or a concept into a reality, allowing for the production of smart dental instruments and gadgets tailored to the needs of the patient.

Four dimensional printed can generate dental implants with characteristics as good as unusual teeth. Denture patient could be reshaped to regulate with novel shapes as per the take care of temperature and humidity in the mouth, and eating habits. Four dimensional printed dental implants have properties of dimensional variations which could assistance to escape marginal leakage. Smart orthodontics implants improve the function of wires and ligature which assistance teeth to transfers in the chosen direction [2].

Form alterations in three dimensional printed objects can be produced through the diversity of outside stimuli, resulting in shrinkage, expansion, or folding as 4D. Shape remembrance alloys and shapes remembrance polymers are two types of 4D printing materials. SMPs may be favoured over SMAs because of their extensive variety of glass transition temperatures, Tg, ranging from 70 to 100°C, which allows them to tune their elastic characteristics. SMAs have a number of drawbacks, including complicated manufacture, greater prices, toxicity, and limited recovery. SMPs, for example, may restore their form up to four times the plastic strain, but SMAs only recover about 7–8%.In multi-material 4D printing, the issue is to use materials that are robust and pliable in the occurrence of stimuli. When material is tempted through diverse stimuli, it should ideally behave differently.

4D Printing

In three-dimensional printing, four dimensional printing refers to the addition and management of the 4D. It is the new kind of preservative developed in that the 4D is controlled while constructing any part, component, machine, or other object. The fourth dimension can include time, heat, light, humidity, wind, water, magnetic field, electric energy, or any other type of energy.4D functions as a provocation, affecting the form, colour, and functionality of the 3D printed material to change.

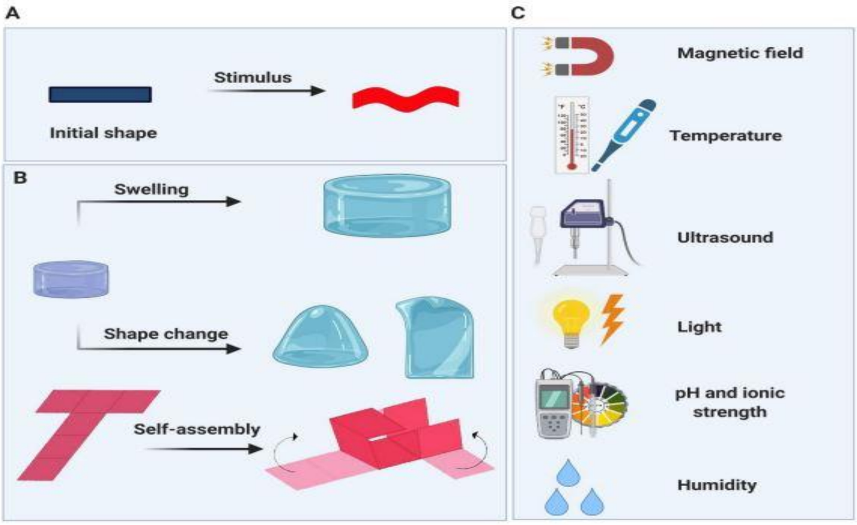

Figure:1. (A) Schematic of the deformation of a 4D-printed object in response to a stimulus. (B) Types of responses that may occur in 4D-printed dynamic materials. (C) Internal or external stimulus which may be used for triggering a four dimensional response.

Fused-Deposition Modelling (FDM)

Fused-deposition modelling, called as fused filament fabrication or melt material extrusion, is the additive manufacturing (AM) technology that uses thermoplastic filaments extrusion [3]. Before being extruded via a heated nozzle, a reel of polymer filament is melted to produce a semi-liquid. When the partly melted filaments are put on the build platform, they solidify, and the three dimensional structure is built up by piling the extruded filaments sequentially.

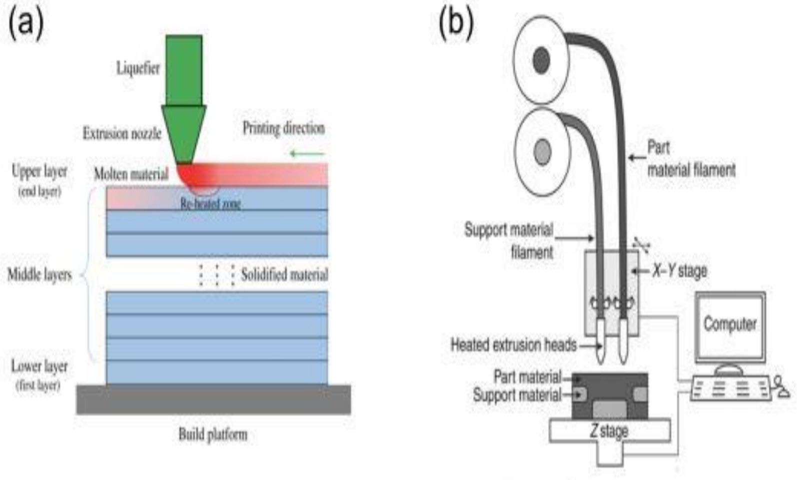

Figure 2. Fused-deposition modelling (FDM) extrusion-based AM technique. (a) Cross-section of printed material taken from [4]; (b) schematic of general apparatus taken from [5]

Filaments for fused-deposition modelling have been made out of a change of thermoplastics, as well as acrylonitrile butadiene styrene copolymer, polylacticaci, polyurethane, polycarbonate, all of that have different elasticity, toughness and stiffness [6]. Fused-deposition modelling printers are inexpensive, reliable and simple [7] with potential to manufacturenumerous medical devices for example modified discharge dosage forms for drug delivery systems, as demonstrated through Goyanes et al. Bodaghi et al. have also used fused-deposition modelling to generate a structure with triple-SME utilizing the mixture of cold and hot programming over the SMP.

Fused-deposition modelling can individually be utilized with heat hardy materials because of the high printing temperatures required. Because of higher printing temperatures necessary, fused-deposition modeling can only be utilized with heat-resistant materials [9]. FDM is an intriguing tissue engineering manufacturing approach since it allows for the creation of porous polymer scaffolds [10]. At room temperature, low Tg polymer filaments lose their rigidity, creating extrusion by printing nozzle close lying credible [11]. This can be avoided through using materials with working or larger glass transition temperatures at temperatures much lower than Tg [12]. Let's say, the observe through Kashyap et al. examined the progression of unitingFused-deposition modelling with salt leaching to generate a radiopaque [13]. To prevent obstruction, the researchers advised using a bigger diameter printing nozzle, however this affected the exactness and correctness of the produced structure [14]. The researchers hypothesized that utilizing stiffer filaments at ambient temperatures, and later polymers with greater Tg, would enhance minimize obstructionand aggressive force [15]. Finding acceptable materials for constructing biomedical devices with included shape-memory behaviour is the subject of much study.Improvements in the previousperiod have massivelydecreased the price of fused-deposition modelling printers. Fused-deposition modelling (FDM) extrusion-based AM technique. (a) Cross-section of printed material taken from [16]; (b) schematic of general apparatus taken from [17]. Filaments appropriate for utilize in fused-deposition modelling have been created from numerous thermoplastics, for example polylactic acid, acrylo nitrile butadiene styrene copolymer, polyurethane, the polycarbonate, that all demonstration adjustable toughness, stiffness and elasticity [18]. FDM printers are inexpensive, reliable,and simple [19] with the potential to producenumerous medical devices such as modified release dosage forms for drug delivery systems, as evidenced by Goyanes et al. [20]. Bodaghi et al. have also usedfused-deposition modelling to generate a structure with triple-SME utilizing a combination of cold and hot programming of the SMP . FDM can only be utilized with heat-resistant materials because of the high printing temperatures required. It is consequently not appropriate for hydrogels or printing cell-laden bioinks that become denatured when placed under higher temperatures . FDM is an interesting fabrication technique in the field of tissue engineering due to the potential for creating porous polymer scaffolds. At room temperature, low Tg polymer filaments lose their rigidity, making extrusion through the printing nozzle nearly impossible . This can be avoided by using materials with greater glass transition temperatures or operating at temperatures much lower than Tg . To prevent obstruction, the researchers advised using a bigger diameter printing nozzle, however this affected the correctnessand exactness of the produced structure.

Responsive materials for 4D printing

By manufacturing items consisting of smart materials, four-dimensional printing adds a temporal dimension to 3D printing. 3D printing is combined with the usage of responsive materials, which change their characteristics or form in response to chemical, mechanical, electrical or thermalstimuli . Ceramics, alloys or polymers give shape memory material. Each material has disadvantages and advantages dependent on the material's applications. In dentistry, shape memory polymers are utilized in endodontics, orthodontics, oral surgery, implantologyand prost hodontics. Once the stimulus is cancelled, they can either revert the change to the prior permanent form, or they can cleave the covalent link established. Embedding magnetic nanocompoundsare constructed the magnetically-sensitive materials (e.g., Co, Fe, $Fe2O3$, Ni, $CuFe2O4$, $Fe3O4$, $NiFe2O4$, $ZnFe2O4$) into the raw material. This might also be done using conductive carbon-based nanostructures and metal nanoparticles. Light-responsive materials are made from photosensitive metal nanostructures and light-conducting materials such as zobenzene, stilbene, spiropyran, fulgide, or diarylethene. (e.g., $TiO2$, Pt and Au). Ultrasonic-sensitive materials are made up of polymers whose bonds are cleaved when exposed to high ultrasound intensity.

Materials Safety

Ceramic materials utilized in dentistry have been reported to be reasonably safe and toxicity-free for tooth pulp and periodontal tissue. The most common issue is corrosion, which is followed by metal devices in the oral cavity. Hypersensitivity, cytotoxicity, and genotoxicity are only few of the possible side effects of metal application. Metal exposure produces inflammation, redness and discomfort in the oral mucosa, as well as cellular metabolic disruption at a deeper level.The capacity of a metal to cause cancer varies depending on how much corrosion it has. The symptoms might emerge even when the metal alloy is far away. Polymer materials have a variety of uses in dentistry, although light curable resins are the most common type used in 3D printers. The degree of conversion is quite high after photocuring, which indicates the number of unreacted monomers is reduced; nonetheless, leftover monomers may cause inflammation, mucosal irritation, edoema and ulceration. The effects of leftover monomers are not restricted to local tissue; they can alter systemic circulation when they enter the bloodstream. This condition may be well for three dimensional printers that do not use resin (e.g., FDM technique). There are no cytotoxic monomers in the filaments used in the FDM technique, however the kind of composite/polymerutilized for filament should be considered.Most vendors, however, supply a variety of resins for each 3D printer, ranging from biocompatible to non-biocompatible materials.As a result, the desired materials may be chosen based on the intended applications.

Applications

3D printing technology has been increasingly popular in dentistry teaching and patient care over the last decade.Drill guides for orthodontics, prosthodontics,oral maxillofacial surgery and endodontics are only a few examples. New technologies have been created for the creation of crowns, bridges, orthodontic brackets, and aligners, as well as dentures and implants.

Dentures

Tooth loss happens because of fracture, trauma, caries and periodontal disease. Partial or complete detachable prostheses, implant-supported crowns and tooth-supported bridges have all been utilized to replace lost teeth. Traditionally, a prosthetic device's fabrication began with an alginate or polyvinylsiloxane imprint. A model is then built to allow a competent dental technician to do intricate laboratory procedures. The introduction of computer-aided design (CAD/CAM) technology has dramatically transformed the way dental prostheses are made.In the first step, virtual imprints are taken utilizing extraoral and intraoral scanners, and the occlusion of patient is recorded. The prosthesis is designed utilizing computer software in the second step.These treatments can be done in a dental clinic or in a laboratory.This allows the practitioner to see the finished outcome more clearly.The prosthesis is built in the third step, which can be done utilizing subtractive or additive developed procedures.

Crowns and bridges

Appealing uses of 4D printing technology in the dentistry is dental crowns and bridges.Crowns are used to safeguard the underlying tooth structure, as well as to make dental implants functional and tooth-like. One of the most significant functions of crowns is to act as a tooth abutment in the replacement of a lost tooth. Crowns and bridges have recently been made using 3D printing technology.In addition, employing SLA printing technology, lower price 3D printers have been utilized to fabricate additional exact temporary bridge and crown restorations. SLA has a high level of efficiency and precision .SLA can generate objects with a resolution of 0.05 mm, making it a better approach in terms of precision, especially when compared to newer techniques like digital light projection (DLP) [205].

Orthodontic appliances and orthotics

3D printing opens up new possibilities for creating tooth-fitting orthodontic products like Invisalign® aligners .Because aligners are clear and may be eliminated for drinking, brushing and eating, they are a preferred alternative to braces for minor malocclusion therapy.Using an intraoral scanner, the orthodontist creates thesimulated imprint of the patient's lower or upper arch for 3D manufacturing clear aligners. The model is then printed using stereo lithography or FDM for thermoforming to aligner.Three dimensional printing improves manufacturing time while maintaining alignment quality.The decrease in production stages is responsible for this acceleration (Fig. 15).Orthotics isutilized to cure malocclusion and relieve symptoms of the temporoman dibular joint. Three dimensional printers and intraoral scanners were employed for fabricating these appliances. Nanofillers like hydroxyl apatite and silica, which are employed to reinforce these appliances, do not attach to the resin during SLA [14]. The nanofillers have also been functionalized with quaternary ammonium salts, which exhibit antibacterial and antifungal properties. The orthotics that resulted have improved mechanical characteristics and antibacterial activity.

4D printing in dentistry and maxillofacial surgery: Challenges and future perspectives

In the word, four dimensional printing technology allows 3D printed things to have active and responsive functionalities.It can modify their structure as a result of a reaction to various stimuli, such as light. Fortunately, by employing analytical and simulations calculations to theoretically simulate the microstructural variations, the structural alterations may be predicted.To put it another way, we know what will happen to stuff that is subject to external stimuli.Nickel-titanium archwires are one of the most often used materials in orthodontics, having several benefits and drawbacks. Form memory polymers may be used to mitigate particular of shortcomings of such shape remembrance archwires. Excellent aesthetics the use of material is extra suited for the practitioner and patient because of its better elastic modulus, improved chemical and mechanical stability.Another discipline that might benefit from 4D printing is endodontics. Instrument separation is one of the most prevalent problems during root canal treatment.Shape remembrance metals' capacity for adjust thr root canal curves is a key feature whichkinds them a viable future alternative for standard nickel titanium rotary instruments.In prosthodontics, enduringplaces of bridge pontics as the surrounding soft and hard tissues alter might produce in pontics that are not well fitted. Because of the material's capacity to self-adjust, shape memory polymers may be useful in several situations.Because of the bone resorption that occurs when teeth are removed, as well as the stresses imposed by the denture on the bony ridge, partial or full eliminate able dentures are frequently troublesome for patients.Denture relining is a typical surgery as a consequence. Dentures printed using shape memory polymers may have a greater ability to adjust to changing soft and hard tissue features. Titanium alloys are furthermost prevalent materials utilized to make mouth implants in implantology. Although titanium alloys offer several advantages, hypersensitivity and surface deterioration have been noted.The utilize of biocompatible shape remembrance polymers instead of titanium alloys does not improve implant power, although it may increase other attributes.SMPs, for example, have more tunable qualities, exceptional cost,time and elastic deformation ability effectiveness, low density, simplicity of manufacture, additional programming flexibility, and improved biocompatibility and biodegradability. As a result, they may be more easily developed and produced in particular applications. Shape-memory polymers are beneficial because they effectively fill root canals.They demonstrate natural tooth-like contraction and expansionto fill the space at the contact while also reducing micro leakage , demonstrate exceptional stability and efficacy due to properties that much surpass those of other types of materials.

Conclusion

In the field of dentistry, 4D printing is a must-have tool. It's utilised in the dentistry industry to make 3D smart aligner devices.The expanding usage of 4D printers to construct dental implants such as prostheses, bridges, crowns, and other dental implants presents profitable development opportunities for the target sector.While 3D printing is used in a variety of industries, the increasing complexity of materials provides chances for technical advances.Intelligent materials are used in 4D printing to create products that can be created, flexible, or adapt to changing conditions.In the medical, aviation and automotive industries, the technology is still being developed. 4D technologies is thedifferent business model dependent on 3D printing technology that will reduce inventory, time-to-market and capital needs while increasing corporate efficiency.The use of 4D printing in dentistry allows for the personalization of dental parts, drugs, and equipment for the benefit of healthcare professionals and patientsCustomfour dimensional devices, implants, and workingapparatus reduce surgery and recovery times while improving implant and operational success.In the future, this technology will give excellent opportunity to meet a variety of dental difficulties.

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