4D Printing in Dentistry: An Innovative Approach

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Abstract

4D printing is the process through which a 3D printed physical object transforms itself into another structure over the influence of external energy input as temperature light or other environmental stimuli without human control by adding smart materials layer-by-layer through computer operated computer-aided design data. Skylar Tibbits in 2012 TED conference has developed the model and predicted that 4D printing is going to replace 3D printing very soon. In this paper, progress in 4D printing field is reviewed with a focus on its practical applications in dentistry.

Keywords: 3D printing, 4D Printing, Advancements in dentistry, Digital dentistry

Introduction

Dentistry has evolved from various old treatments such as crude restorations made of wires and wood to the new world of digital dentistry. Digital technology being one among them has resulted in precise fabrication of prostheses with less chance of error. In the patient's mouth and required adjustments are done. Recent progress in 3D-printable smart materials has brought into fruition a newer generation of "dimensional printing" that is coined 4D printing. 4D printing is the combination of 3D printing with time as the fourth dimension.[1] 4D printed products will replace 3D printed products. 4D printing concept was introduced in 2012 and created an attracted interest in processes and materials. A 4D printing technology allows the printed model/product to change its shape and function concerning time effected external condition such as heat, water, light, and electricity. This technology provides added capability of embedded transformation in product from one shape to another. 4D printing is a digital process that prints 3D smart materials and adds time dimension. Such a printing platform produces pre-programmable bio-objects that change their shape in response to the surrounding media.[2] Raviv *et al*. had designed self-folding structures that reshape overtime under certain environmental conditions. They converted the stable 3D-printing materials into actively moving objects by the novel 4D-pritning approach. The printed models transform into a predetermined shape and function after fabrication. Self-folding materials are the name given for the outcome of the recently introduced 4D printing technology. 4D printing is based on adding a fourth dimension to the standard 3D printing, that is, motion over time.[3,4] The aim of 4D printing is to produce functional objects rather than static ones. 4D scanning could allow modeling complex anatomical structures improving the pre-operative planning.[5] 4D printing relies on 3D printing of multi-materials followed by selective photocuring to give the 4D-printed objects motility nature. In this review, the future applications of 4D printing in dentistry are discussed as recent boon in modern dentistry.

Application

3D printing has enabled clinicians to improve their diagnostic and surgical procedures as it allowed for better visualization, realistic training, and surgical planning. In dentistry, this technology has revolutionized the practice as it could provide maximum accuracy with little clinical setup and short operative time.[6] The use of 3D printing in dentistry has been essential in the modern restorative and prosthetic fields, orthodontics, and implant dentistry as well as maxillofacial surgery. In particular, 3D-constructed models have played a principal role in facial reconstruction surgeries (e.g., zygomatic fractures) and temporomandibular disorders that require surgical intervention.

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In the medical field, the term "4D" has been linked to a scanning approach that is used for monitoring the dynamic characteristics of different organs and it has shown great advantages for the accurate positioning of dynamic tissues during radiotherapy; it also allowed orthopedic clinicians to develop printed models of carpal and metacarpal bones to monitor thumb movement to help in arthroplasty procedures. Based on the concept of motion over time, 4D scanning could allow modeling complex anatomical structures improving the preoperative planning. 4D printing is the process of self-folding overtime under thermal and humidity changes. This concept relies on understanding how the microstructures of 3D-printed models can undergo spontaneous shape transformation under thermal and moisture changes. 4D printing relies on 3D printing of multi-materials followed by selective photocuring to give the 4D-printed objects motility nature. The transformation mechanism can be assessed by evaluating the strain properties of each component within the printed model and putting them under a controllable pattern.[7] 4D printing has two essential steps: Processing and programming.

Responsive Materials for 4D Printing

4D printing adds the time dimension to 3D printing by producing pieces made of smart materials. 4D printing indeed combines 3D printing with the use of responsive materials that change their properties or shape in response to mechanical, chemical, thermal, or electrical stimuli. Smart materials may be divided into shape-memory materials and shape-changing material.[1] Shape memory materials may be derived from alloys, polymers, or ceramics. Each material has advantages and disadvantages depending on the applications of the material. Shape memory polymers have applications in dentistry including orthodontics, endodontics, prosthodontics, oral surgery, and implantology.[8,9] Through molecular view, shape memory polymers are elastic matrixes enjoying some reversible functional covalent cross-linking. This kind of polymers consists of functional groups that undergo some changes toward a temporary shape under a stimulus. They can subsequently reverse that change to the previous permanent shape once the stimulus is cancelled; or they undergo cleaving the covalent bond induced by the stimuli between the functional groups throughout the matrix.[10]

4D Printing in Restoration

4D printing can be used for the production of dental restorative materials. The common factor of failure of restorative materials is dimensional changes and microleakage. To outcome of 4D printing can be restorative materials with continuous self-folding adjustment, that is, materials are capable of moving toward the peripheries avoiding microleakage or overhangs at the margins. 4D-printed filling materials can be programmed to move downward toward the fitting surface of the cavity to ensure maximum adaptation. In addition, 4D-printed fillings can be used for inaccessible areas in the oral cavity where manipulation and longevity of current restorative materials are difficult.

4D Printing in Prosthodontic

4D printing can be used in removable prosthetic dentistry. The technology can produce materials with similar properties of the natural hard and soft tissues. 4D-printed prosthetic materials can have reliable fitting and retention characteristics and optimal dynamic properties according to their self-folding nature. The denture base can be fabricated of certain structures that encompass elasticity and thermal criteria similar to the periodontal ligaments or overlying mucosa.

4D Printing in Implant

In implant dentistry, 4D-printed structures can be used as fused to the currently available dental implants by modifying their apical portion to act as soft base under implants. A 4D printed dental implant with a smart material can be able to adjust itself to compensate the lost tooth structure and fix failed parts. In dentistry, missing tooth is the primary challenge which can grow and change to the same shape as of the original teeth. This can help to avoid injury of vital structures around implant site such as maxillary sinus or inferior alveolar nerve. Thus, the technique can overcome sophisticated surgeries such as sinus augmentation when done for implant cases.

4D-printed objects can be used in TMJ and maxillofacial surgeries. 4D-printed materials can replace cartilage while undergoing continuous movements compensating for the articulation and occlusion.

4D Printing in Orthodontics

The use of 4D printing in dentistry can also extend to orthodontics. At present, the modern use of both removable appliances as well as fixed braces relies on data imported from 3D orthodontic software.

Discussion

4D printing is an interesting research topic and can have a positive and practical impact on medical and dental applications. A comprehensive understanding of the folding pattern is essential to produce functional appliances without harmful effects. In the system, 4D printing technology can give active and responsive functions to their counterpart 3D printed objects. It can be triggered by a response to different stimuli, for example, light, to change their structure. Fortunately, through using simulations and analytical calculations to theoretically model, the structural changes are well predictable. In other words, we know what will happen for the material which at the mercy of any external stimulus. In dentistry, it is of the most interest to have such materials.[11]

One of the most common materials used in orthodontics is nickel-titanium archwires, with many advantages and disadvantages. Some of the drawbacks of these shape memory archwires may be prevented with the application of shape memory polymers.[8] Superior esthetics improved elastic modulus and enhanced mechanical and chemical stability and ability of the archwire to self-adjust during the treatment make the application of this material more suitable for the patient and the practitioner. Endodontics is another field that may benefit from 4D printing. One of the most common complications during root canal therapy is instrument separation. The ability of shape memory metals to adapt to root canal curvatures is an important asset that makes them competitive as a replacement of traditional nickel titanium rotary instruments in the future.[2,12]

In prosthodontics, permanent seating of bridge pontics while the surrounding hard and soft tissues are undergoing changes may result in suboptimal fitting of the pontics. Application of shape memory polymers in these cases may be beneficial because of the self-adjustment capability of the material, which helps to minimize future complications. Full or partial removable dentures are often problematic for the patient because of bone resorption that accompanies tooth removal, as well as forces applied over the bony ridge by the denture. As a result, denture relining is a common procedure. The use of shape memory polymers for 4D printing of dentures may improve the ability of these dentures to adapt to the altering hard- and soft-tissue profiles. In implantology, titanium alloys are the most common materials used for fabricating oral implants. Although there are many benefits associated with titanium alloys, hypersensitivity and surface degradation have been reported. Replacement of titanium alloys with shape memory polymers may result in improved biocompatibility and better osseointegration.[13] Shape-memory polymers are advantageous by well filling the root canals, leading to prevent reinfections, biofilm formation, and periradicular diseases. They exhibit the natural tooth like expansion and contraction to fill the gap at the interface, decreasing the microleakage as well. Shape-memory polymers also produce biocompatible degradation products — they are biocompatible — as well as not produce metal ions which triggering chronic diseases, in comparison with metals. By the features far outweighing other types of materials, the shape-memory polymers show great stability and much more effectiveness, at least here in dentistry.[14]

4D printing relies on important the sequence and path of movements, which determine the self-folding pattern.[4] The designing step should take into account the movement of the circumferential structures around the 4D-printed prosthetic appliance. For example, designing a cardiac valve should consider the contractile movements of the heart muscles together with the motion of cardiac and pulmonary vasculatures in addition to potential aspects of high/low blood pressure. In other words, designing 4D-printed appliances should be done on kinematic and dynamic bases.[15-17]

Another important aspect is the shaping time under thermal/physical conditions. In this regard, patients who have newly introduced 4D-printed appliances should be closely monitored as the time of folding can range from minutes to days, and the success rate of the treatment procedures would rely on the time of transforming the material into its final shape and in final position while still being functional.[4]

The other major properties of ideal 4D-printing structures are biocompatibility, modulus of elasticity, and coefficient of thermal expansion which should mimic those of body structures to hinder undesired body reactions such as swelling, inflammation, or ischemic reactions. In addition, 4D-printing materials should have good strength properties to prevent their fracture overtime, which could necessitate revision surgery.[5] 4D-printed structures should possess smart structures and high resolution so that they can be thermomechanically programmed to change into functional configurations.

Conclusion

4D printing has progressed in the past few years and hold promise to impact many field of dentistry it also bring down material wastage with recycling in dentistry. Every model is customize and vary from patient to patient, which source from an individual patient can be printed easily in less time. It provides extensive support in dental as well as medical field with better accuracy in manufacturing of implants, appliances, tools, and other devices.

Conflict of Interest

None.

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