'4 D Printing' in Dentistry, A Paradigm Shift! - A Narrative Review

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Introduction:

4D printing promises evolutionary changes in the field of dentistry in the near future. The medical field has achieved extraordinary results with 4D printed devices. In 2015, a medical team in Michigan was able to save 3 babies with customized patient-specific respiratory implants [1] The extension was extended to produce new stimuli-responsive, adaptive cardiovascular stents and targeted drug delivery systems. 4D Bioprinting for Grafts, Scaffolds, Organs and Implants[2]In vitro studies of cardiovascular implants have shown promise[3] A successful smart material has demonstrated its potential for use as a vascular graft. University of Missouri Research Group[4]. It is well known in the field of dentistry that the use of 4D printing is not far away, as each dental specialty has its own potential and endless applications. The use of nanomaterials in 4D printing can develop dental materials with improved mechanical properties [5] Just like the dynamic oral environment, restorative materials could also become dynamic, allowing them to change shape according to oral stimuli, resulting in a reduction of microleakage and protruding fillings [6]Certainly due to the self-folding of smart materials, prostheses can be made using them to contact bone during resorption without recharging. Shape memory metals have taken over the current technology of rotor instruments for root canal instrumentation procedures. The possible use of 4D printing in implants could prove effective because the stress is distributed equally at the implant site. [6] Traditional implants are made of hard materials that cause fatigue damage, while PEEK (polyether ether ketone) / CHAP (calcium hydroxyapatite) polymer implants have a higher modulus of elasticity that distributes stress evenly across the implants. the force is concentrated at the tip. In addition, biomaterials can also be added to implants as support structures to promote cell proliferation. [7,8]

The main difference between 3D and 4D printing is dimensions and the ability to change over time. 3D printing, also known as additive manufacturing, involves creating three-dimensional objects layer by layer from digital models. [9,10]They can explore how 4D printing enables the creation of more complex and customizable structures compared to traditional 3D printing methods.[11] This may include evaluating factors such as print speed, material usage, post-processing requirements and overall production costs.[12]]This may involve testing prototypes for specific applications, such as biomedical implants, robotics components, or aerospace parts, to assess how well they meet performance criteria under real-world conditions.[13] Research could explore how 4D printing improves customization and adaptability in areas such as healthcare, architecture, automotive or consumer goods. [14]

1). It usually uses materials such as plastic, metal, ceramic or composites.[15]

2). Object produced by 3D printing are static and do not change their shape or properties after printing.[16]

3).3D printing is widely used in various industries for prototyping, product manufacturing, custom part manufacturing and more.[9]

4).4D printing is based on 3D printing by adding a fourth dimension, time, to the production process.

5). It creates objects that can change their shape, properties or functions over time in response to external stimuli such as temperature, humidity, light or magnetic fields.

The materials used in 4D printing often contain smart materials or programmable materials that can change under certain conditions. Objects produced by 4D printing can be independently assembled, repaired, or adapted to the environment. Applications of 4D printing include self-folding structures, shape-shifting materials, adaptive architecture, and adaptive medical devices. It explores various examples of 4D printed dental implants, orthodontic and drug delivery systems and highlights their potential benefits for patients and clinicians. Although 4D printing in prosthetics is still in its infancy. 4D printing can be used to create dental implants that adapt over time to the patient's oral environment. For example, an implant made of a smart material can change its shape or surface properties in response to temperature changes, promoting better bone integration and long-term stability.

4D printing technology can benefit orthodontic treatments such as braces or aligners. The 4D-printed aligners could gradually adjust their shape to guide teeth more comfortably and efficiently into the desired position, reducing treatment and patient discomfort. Smart prostheses Dental prostheses made with 4D printing technology can adjust their fit and function according to changes in the oral cavity. For example, dentures can change shape slightly to accommodate changes in gum tissue or bone resorption over time, improving wearer comfort and functionality. 4D printing can also be used to create drug delivery systems tailored to the specific needs of individual patients. For example, a 4D-printed dental device could release drugs at a controlled rate over time and more effectively target oral diseases such as periodontitis or tooth decay. 4D printing can produce temporary prostheses that adapt to changes in the oral environment during the healing process. For example, a temporary crown or bridge made with 4D printing technology can gradually dissolve or change shape while the surrounding tissues heal, reducing the need for multiple replacements [6,17]

4D printing technology has many potential applications in oral and **maxillofacial surgery**, providing innovative solutions for patient care, surgical planning and postoperative outcomes. Here are some possible examples:

1. Patient-specific surgical guides: 4D printing can produce patient-specific surgical guides that adapt to each individual's unique anatomy. These guides can help surgeons accurately align implants, grafts or osteotomies during procedures such as orthognathic surgery, dental implant placement or reconstructive surgery.

2.Dynamic tissue scaffolds: 4D printing enables the creation of dynamic tissue scaffolds that mimic the mechanical properties and structural changes of natural tissues. These scaffolds can be used to support tissue regeneration after injuries such as bone damage, cartilage or soft tissue damage due to trauma, disease or surgery.

3.Shape Memory Implants: Implants made of shape memory materials can be manufactured using 4D printing technology. These implants can change shape in response to external stimuli, such as changes in temperature or pH, allowing more precise adaptation to surrounding tissues and improved functionality.

4.Custom Prostheses: 4D printing can be used to create custom prostheses for patients with congenital deformities, traumatic or acquired deformities. These prostheses can adapt to changes in the patient's facial structure over time, providing a better fit and improved aesthetics compared to traditional fixed prosthetic devices.

5. Drug Delivery Systems: 4D printing technology can be applied to develop drug delivery systems tailored to the specific needs of oral and maxillofacial surgery patients. For example, 4D-printed implants or scaffolds can be loaded with therapeutic agents and programmed to release drugs in a controlled manner, promoting tissue healing and reducing the risk of infection or inflammation. [22,23]

6. Dynamic TMJ Implants: Temporomandibular (TMJ) implants made with 4D printing technology can mimic the dynamic function of the natural TMJ, allowing more natural jaw movement and improving patient comfort. These implants can be tailored to the patient's unique anatomical and functional requirements, reducing the risk of implant failure and improving long-term results. [24]

The applications of 4D printing in **endodontics** have been relatively little researched compared to other areas of dentistry, but there are still several possible areas where this technology could be applied: [6,17]

(1). Smart endodontic instruments: 4D printing can be used in endodontic applications to create instruments with shape memory properties. These instruments can adjust their shape to temperature changes in the root canal, allowing better cleaning and shaping of the canal system.

(2). Bioactive root canal sealants: 4D printing can be used to produce bioactive root canal sealants that release therapeutic agents over time. These sealants can help prevent reinfection and promote tissue regeneration in the root canal space.

(3). Custom Endodontic Posts: 4D printing technology can be used to make custom endodontic posts that adapt to the specific shape and size of the root canal. These posts can provide better stability and fixation for restorative crowns, bridges or other prostheses.

(4). Shape-changing endodontic obturators: 4D printing enables the fabrication of shape-changing endodontic obturators that conform to the complex anatomy of the root canal system. These obturators can improve the quality of root canal filling and reduce the risk of postoperative complications such as leakage or reinfection.

(5). Smart endodontic materials: 4D printing can be applied to the development of smart endodontic materials that respond to changes in the oral environment. For example, 4D-printed gutta-percha cones can expand or contract with temperature fluctuations, providing a more precise fit in the root canal space.

(6). Dynamic endodontic irrigation systems: 4D printing technology can be used to create dynamic endodontic irrigation systems that adapt their flow rate or pattern to the specific needs of each root canal. These systems can improve the efficiency of root canal irrigation and improve debris removal during the cleaning process.

4D printing technology offers several potential applications in **orthodontics** and is revolutionizing the field by providing more personalized and customizable solutions to patients' dental needs [17,25], includes:

1. Self-adjusting braces: 4D printing can be used to create braces or aligners that adapt and adjust their shape over time. These devices can gradually move teeth into the desired position more comfortably and efficiently, reducing the need for repeated adjustments and minimizing patient discomfort.

2. Shape-changing braces: 4D printing makes it possible to produce shape-changing braces that adapt to changes in a patient's teeth over time. These retainers can adjust their shape or applied pressure to maintain tooth alignment after orthodontic treatment, improving long-term stability and reducing the risk of relapse.

3. Custom mouthpiece expanders: 4D printed mouthpiece expanders can adapt their shape over time to the patient's palate, gradually widening the arch to correct problems such as crowding or crossbites. These custom dilators can provide more precise and controlled dilation, reducing the risk of patient discomfort or tissue irritation.

4.Dynamic bite problems: 4D printing can be used to create compression splints or night guards that adjust their shape or thickness to changes in the patient's bite or jaw position. These dynamic splints can help relieve the symptoms of temporomandibular joint disease (TMD) and bruxism by providing customized support and alignment to the jaw joints and muscles

5. Adaptive orthodontic implants: 4D-printed orthodontic implants can adapt their shapes or surface characteristics to changes in the surrounding tissues. For example, implants used to anchor or move teeth can optimize their interface with bone or soft tissue over time, improving stability and biomechanical efficiency during orthodontic treatment.6. Smart orthodontic aligners: 4D printing can be used to produce smart aligners that include sensors or actuators to monitor tooth movement and apply forces as needed. These smart aligners can improve treatment outcomes by providing real-time feedback and adjustments based on patient progress and treatment goals.

4D printing technology has significant potential in the field of **prosthetics**, offering new solutions for manufacturing dental prostheses and devices. Here are several roles that 4D printing can play in prosthetics:

1. Personalization and customization: 4D printing can be used to create highly customized prostheses tailored to each patient's unique anatomical features and functional needs. Prosthetics such as crowns, bridges, dentures and implants can be precisely designed and manufactured for fit and aesthetics, improving patient comfort and satisfaction.[17]

2. Adaptability and functionality: 4D printing makes it possible to produce dental prostheses that can adapt and change their shape or properties over time. This adaptability is particularly useful for removable prostheses, such as dentures or partial prostheses, which can adapt to changes in the oral cavity due to bone resorption, tissue changes or functional requirements.

3.Dynamic Prosthetic Materials: Intelligent materials used in 4D printing can be incorporated into a prosthesis to improve dynamic properties such as shape memory, self-healing or sensitivity to external stimuli. For example, dentures made from shape memory polymers can adjust their fit or occlusion in response to temperature changes in the oral cavity, providing the patient with a more stable and comfortable denture solution.

4. Better rehabilitation outcomes: 4D printing technology can improve rehabilitation outcomes for patients who require complex prostheses. 4D printing enables the fabrication of prostheses with optimal fit, function and aesthetics, and can improve patient satisfaction, oral function and quality of life after tooth loss or oral surgery.[17]

5. Simplified manufacturing process: 4D printing offers opportunities to streamline the prosthetic manufacturing process, reducing production time, material waste and labor costs. Computer-aided design (CAD) software and additive manufacturing techniques can be integrated to enable efficient design iteration, rapid prototyping and on-demand manufacturing of custom prostheses. [17]

6. Research and development: 4D printing technology provides a platform for research and development of prosthetics, enabling the research of new materials, manufacturing techniques and design methods. Researchers and clinicians can work together to develop new solutions for difficult clinical cases, develop treatment protocols, and optimize patient prosthetic care.[6]. The possibilities of shape memory polymers to improve the fit, comfort and longevity of dentures are discussed. This highlights their applications in removable and fixed prostheses. [26,27]

Discussion:

The concept of 4D printing was introduced by Ge Q et al and discussed the use of smart materials to create objects that can change shape over time.[18] [4] According to Gladman AS et al., 4D printing materials mimic biological systems to achieve complex deformations.[19] Zolfagharian A and colleagues reviewed the development of 4D printing technology, current advances, and possible future trends in various applications.[20] Lantada A D et al.,discussed the application of intelligent 4D printing in biomedicine, including tissue engineering, drug delivery system and personal medical devices.[21]Hamza H, Javaid M et al. and Sharma R explore emerging trends in prosthetics with a special focus on the application of 4D printing technology. It discusses the role of 4D printing in creating custom prosthetics, improving treatment outcomes, and advancing the field of prosthetics. [6,17,28]Lee M stated that the use of smart materials and 4D printing in dental applications including prosthetics. It discusses examples of smart dentures made using 4D printing technology and highlights their potential to improve functionality and patient satisfaction. [29]

Limitations of 4D printing technology 4D printing technology, which involves the production of objects that can change shape or behavior over time in response to external stimuli, is promising in many different fields, including dentistry. However, like any emerging technological innovation, it is not without limitations, especially in the field of dental applications. Several limitations associated with 4D printing can be observed in dentistry.[30]

Conclusion:

4D printing in dentistry is still in its infancy, although the benefits of 4D are better than those of 3D, a technology that has not yet reached all dentists to benefit patients.

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