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Editorial

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3D printing technology for periodontal complex neogenesis in regenerative medicine

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Since 3-dimensional (3D) printing technology was commercialized in the 1980s by Charles W. Hull, who invented and patented stereolithography, various types of additive manufacturing systems have been developed, such as fused deposition modeling using thermoplastics, selective laser sintering or selective laser melting (SLM) with a high-energy laser source and powder materials, and digital light processing by light curing technology, as well as different materials (e.g., polymers, metals or metallic alloys, and ceramics) in order to create rapid-prototyping models. Although the SLM process was introduced to manufacture dental products in the early 2000s, conventional methods based on dental impression techniques, including computer numerical control milling systems, have continued to be utilized for dental prostheses because newer methods have limitations for the clinical acceptability of fabricated dental prostheses. Moreover, 3D printing techniques have recently received attention due to improvements in the quality of high-resolution medical images from intra-oral scanners or cone-beam computed tomography, which have enabled rapid, highly accurate, and reproducible manufacturing of digitized models with micron-scale architectures. Consequently, temporary crowns, splints, implant surgical guides, or different dental prostheses can now be fabricated as tissue replacements or disposable devices.

As regenerative medicine has emerged since the foundational publication by Langer and Vacanti [1], various tissue engineering strategies in dentistry have also been developed for tissue regeneration and replacement, such as dental prosthetics after tooth extraction involving damaged tooth-supportive structures and periodontal tissues. Numerous approaches have been investigated to promote target tissue regeneration in damaged or diseased regions, such as biologic delivery systems, stem cell regulation, biomaterial fabrication, or biological microenvironment optimization [2]. However, their main purpose has been alveolar bone formation for tooth-extraction socket healing, osseointegration with dental implant surfaces, or support of dental prosthetic loads, instead of the neogenesis of periodontal tissue, such as the alveolar bone, periodontal ligament (PDL), and cementum, which could facilitate the preservation and management of natural teeth throughout the patient's lifetime.

Most recently, geometric designs of microenvironments (or bioactive scaffolds) have been a significant development for the control of tissue infiltration and regeneration into target defects, spatial compartmentalization of multiple micron-scale tissues, or the creation of functioning restorations by integrating multiple tissues in the periodontal complex.

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However, it has still been challenging to reconstruct hierarchical tissue architectures with the structural complications of tooth-supportive tissues or periodontia. At this point, 3D printing technology can be a key player in designing architectures for guiding the required tissue infiltration into target regions, manufacturing individual interfaces for tissue compartmentalization, or promoting the formation of functioning PDL bundles and their integration into mineralized tissue surfaces. The 3D printing techniques make it possible to manufacture guidable pore architectures in bone scaffolds to facilitate mineralized tissue infiltrations and control the desired orientation of fibrous connective bundles to the tooth-root surface, with a structural similarity to natural PDLs. In particular, optimized microgroove patterns on 3D-printed PDL-guiding scaffolds were recently investigated as critical topographies to regulate the spatiotemporal orientation of PDL cells and tissues with high predictability, even though micron-scaled patterns are well known to be subject to the stair-stepping error effect, which can be created during layer-by-layer manufacturing and is generally removed, if possible, for smooth surfaces [3].

The 3D printing systems have been further advanced to produce accurate and precise dental prostheses with various printing resolutions, which is an essential factor for determining consistent manufacturing qualities. However, in addition to progressive technological improvements, recent developments of 3D-printable biomaterials with biodegradability and biocompatibility and medical imaging technologies can lead to a revolutionary paradigm shift to create pre-clinically/clinically implantable scaffolds and regenerate tooth-supportive complexes with anatomical mimicry for the natural tooth preservation. Based on tissue-guidable platforms created using 3D printing systems, the structural integration of regenerated tissues such as alveolar bone, PDLs, and cementum onto tooth surfaces could be the next ground-breaking research program with biologic applications in dental, oral, and craniofacial tissue engineering and regenerative medicine.

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