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Bone Tissue Engineering with 3D-Model Based Bioactive Composite Scaffolds

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Abstract

Bone is the second most commonly transplanted tissue worldwide, with over four million operations using bone grafts or bone substitute materials annually to treat bone defects. However, significant limitations affect current treatment options and clinical demand for bone grafts continues to rise due to conditions such as trauma, cancer, infection and arthritis. Developing bioactive three-dimensional (3D) scaffolds to support bone regeneration has therefore become a key area of focus within bone tissue engineering (BTE). A variety of materials and manufacturing methods including 3D printing have been used to create novel alternatives to traditional bone grafts. However, individual groups of materials including polymers, ceramics and hydrogels have been unable to fully replicate the properties of bone when used alone. Favourable material properties can be combined and bioactivity improved when groups of materials are used together in composite 3D scaffolds. The ideal properties of bioactive composite 3D scaffolds and examine recent use of polymers, hydrogels, metals, ceramics and bio-glasses in BTE. Scaffold fabrication methodology, mechanical performance, biocompatibility, bioactivity, and potential clinical translations will be discussed.

Keywords: Bioactive composites; 3D scaffold; Tissue engineering

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Introduction

Scaffolds are three-dimensional (3D) porous, fibrous, or permeable biomaterials that allow bodily liquids and gases to pass through, enhance cell contact, viability, and extracellular matrix (ECM) deposition, and biodegrade at a controlled rate. Tissue engineering trio refers to the fundamental components of designed tissues: cells, scaffolds, and growth-stimulating signals. Scaffolds, which are primarily constructed of polymeric biomaterials, provide structural support for cell adhesion and tissue formation [1]. The most often used polymers in bone tissue engineering are aliphatic polyesters like poly-lactic acid, poly-glycolic-acid, and poly, as well as their copolymers. Significant research in the field of bone tissue engineering (BTE) has been dedicated toward finding unique alternatives to standard bone grafts in order to overcome the limits of current therapeutic choices. To aid and direct bone regeneration, porous 3D scaffolds built using a number of technologies and using a variety of biomaterials have been used. However, the ideal scaffold material has yet to be discovered, and as a result, clinical translation of 3D scaffolds has been limited. Bone is a heterogeneous composite substance having hydroxyapatite mineral, a mixed organic component, and water as components [2]. It would therefore seem natural to use a variety of materials in the scaffold manufacturing process to produce a composite scaffold, potentially allowing for higher scaffold bioactivity and structural biomimicry. Incorporating elements that can interact with or bind to biological tissues can also boost scaffold bioactivity [3]. Improved bone cell ingrowth (osteoconduction), stable scaffold attachment to host bone tissue (osseointegration), stimulation of immature host cells to develop into osteogenic cells (osteoinduction), and greater vascularisation are all possible outcomes of higher scaffold bioactivity. Bioactivity refers to the ability of scaffold materials to interact with and bind to host tissue.

Properties that are osteoconductive and osteoinductive Incorporation of biological cues with growth agents to promote cell adhesion, differentiation, and ingrowth. Scaffolding Design: Diffusion and cell migration are facilitated by interconnected pores. To provide a vast surface area for cell-scaffold interactions, microporosity is used. Macroporosity is a property that allows cells to migrate and invade the vasculature. Pore size is matched to the tissue and cells of interest [4]. Enough porosity to allow for cell ingrowth without compromising the integrity of the material. Mechanical Properties: Comparable compressive,

elastic, and fatigue strength to host tissue, allowing for cell mechanoregulation while maintaining structural integrity in vivo. Scaffold material that can be easily modified in the clinic to repair specific patient bone abnormalities. The desirable mechanical and cell-friendly features of single tissue-engineered structures have been integrated as scaffold fabrication has increasingly looked to include composite materials with greater bioactivity. As a result, a number of effective bone and cartilage structures with therapeutic application have been produced, with ceramic and polymer composites having the most success [5]. In the future, it will be important to achieve even closer replication of natural mechanical and biochemical stimuli that cells are exposed to, as well as increased construct vascularisation, to maximise osteogenesis and chondrogenesis. This may be possible thanks to advancements in biomaterials, scaffold fabrication techniques, and computer modelling, among other things. In addition, more efficient methods for cell isolation, culture, and seeding into constructs are necessary.

Conclusion

3D biofabrication and bioprinting technologies allow for more exact control of the microarchitecture and spatial content of constructs. When paired with the growing number of bioactive materials, growth factors, functionalization processes, and biomimetic scaffold designs available, the future potential for constructing sophisticated BTE scaffolds suited to patient-specific applications is enormous. This gives hope to people suffering from osteonecorosis, osteoporosis, and significant bone abnormalities. As scalability and manufacturing technologies improve, it is believed that treatment personalised to the particular patient will become more cost effective, efficient, and repeatable.

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