Integrating bioelectric signaling into 4D hybrid scaffolds for enhanced bone regeneration

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Natural bone is a composite material composed of an organic phase, which provides the elasticity and sclerenchyma; and inorganic phase, which provides the mechanical support and the bioactivity, osteoconduction and osteoinduction. However, although bone is a thoroughly studied tissue there is still a challenge when attempting to replicate its characteristics outside of living organisms. The main reason is that bone regeneration is not only influenced by the biological and chemical characteristics of scaffolds, but also by other aspects such as physical cues. Nowadays, hydroxyapatite (HA), a bioabsorbable porous ceramic, has attracted great interest in bone regeneration due to its osteoregenerative properties. However, if these synthetic 3D structures present promising properties in terms of bioactivity, they do not integrate the possibility of mimicking the dynamic bioelectrical signals present in vivo in the bone. The emergence of organic conductive materials such as electronic conductive polymers, as poly(3,4-ethylenedioxythiophene) (PEDOT), offers the opportunity to transform bioceramic synthetic and passive structures into 4D composite dynamic architectures, which include electrical and mechanical cues.

This research faces a challenge of bone tissue engineering: the printing of dynamic 4D structures that mimic the biochemical and biophysical signals of bone. To achieve this, the combination of HA with electrical signals derived from conductive polymers, such as poly(3,4-ethylenedioxythiophene) (PEDOT), was explored. Furthermore, the integration of cellulose nanofibers (CNF) provides a flexible platform for the PEDOT mechanical response, high porosity as well as improved mechanical properties. This synergy results in a highly porous biocompatible material with high levels of bioactivity, thanks to the proliferation capacity of HA, and with bioelectric properties of the conductive polymer PEDOT.

This advance has the potential to contribute significantly to the development of regenerative therapies and advanced biomaterials for bone tissue regeneration, opening up new possibilities in the field of regenerative medicine and tissue engineering.