

Preliminary study of a Ceramic-Loaded Scaffold for Passive Monitoring of Bone Regeneration

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ABSTRACT

Bone regeneration in critical-size defects—resulting from trauma, osteosarcoma, or congenital anomalies—often requires patient-specific scaffolds. Advances in additive manufacturing and biomaterials now enable the fabrication of customised bone grafts with high biocompatibility and osteointegration [1]. However, monitoring the healing process remains a challenge, as conventional techniques are typically invasive, costly, and reliant on ionizing radiation.

This work introduces SENScaffolds, as illustrated in Figure 1, a novel 3D-printed scaffold designed using high ceramic-loaded materials compatible with additive manufacturing. These materials allow the scaffold to function as a dielectric resonator, capable of responding when interrogated with electromagnetic waves [2]. The resulting resonance frequency depends not only on the scaffold's intrinsic properties—such as material, geometry, and dimensions—but also on the surrounding environment [3]. Thus, the scaffold itself becomes a sensor whose resonance frequency shifts according to the presence or absence of bone regeneration around it [4].

In this work, a proof of concept is presented that validates this sensing approach. Electromagnetic simulations were conducted to analyse the frequency shift of a porous dielectric resonator scaffold in response to simulated bone growth. Scaffolds were fabricated using FDM 3D printing, ensuring compatibility with common biomedical manufacturing processes. PLA filled with ZrO₂ was selected due to the high permittivity of the ceramic material, which is essential for effective dielectric resonator behaviour. Hydroxyapatite-PLA composites, selected for their dielectric similarity to bone, were used to emulate progressive regeneration. Experimental data confirm the scaffold's ability to detect changes in the dielectric environment corresponding to new tissue formation (the increase of the HA layer growth surrounding the ZrO₂ scaffold).

This new technology represents a promising, cost-effective, and safe platform for continuous bone healing assessment, eliminating the need for implanted electronics or repeated radiological evaluations.

REFERENCES

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