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SenScaffold: A 3D-Printed Porous Dielectric Resonator as a Self-Sensing Scaffold

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Abstract-

This study presents a proof of concept for the design, fabrication, and characterization of a 3D-printed porous dielectric resonator (DR) scaffold for real-time, non-invasive monitoring of bone regeneration. A scaffold is a biocompatible, porous structure that supports cell attachment, growth, and tissue formation to heal large bone defects. Full-wave simulations confirm that the porous DR exhibits electromagnetic (EM) field distributions similar to a conventional rectangular DR, with a frequency shift due to its porosity. The self-sensing scaffold is fabricated via Fused Deposition Modeling (FDM) 3D printing using polylactic acid (PLA) reinforced with zirconia (PLA_ ZrO2). It is then covered with one or more printed layers of PLA reinforced with hydroxyapatite (PLA_HA) to simulate varying stages of bone growth, as PLA_HA possesses a relative permittivity similar to that of natural bone. Theoretical and experimental results demonstrate that the resonant frequency shifts inversely with HA layer thickness, validating the scaffold's ability to function as a passive sensor for detecting and tracking tissue regeneration. A comparison of simulated and experimental field distributions confirms that the porous DR sustains a resonant mode suitable for interrogation via a coaxial probe coupled to the scaffold in the near-field region. Experimental evaluation reveals a high sensitivity of 500 MHz/mm during the initial stages of bone growth (up to 1 mm) and 380 MHz/mm for subsequent stages, confirming the system’s capability for early-stage clinical monitoring. This work represents an initial step toward a clinically relevant monitoring system, demonstrating that porous DR scaffolds can act as functional biosensors with integrated self-sensing capabilities. The ability to monitor bone regeneration via EM interrogation offers a scalable, wireless, non-invasive approach for real-time biomedical diagnostics. A key advantage of self-sensing scaffold is that it functions itself as a sensor, eliminating the need for additional components or devices within the body. The same structure that supports bone regeneration also enables real-time monitoring.

Index Terms- 3D-printing, Additive Manufacturing (AM), Bone regeneration, Dielectric Resonator (DR), Electromagnetic (EM) biosensor, Scaffold.

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