Plasma Surface Bio-Engineering of Porous Materials

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The global rise in implantable medical devices is paralleled by persistent complications, particularly infection and poor tissue integration, that hinder long-term outcomes. These challenges are further amplified in porous biomaterials, where complex geometries and high surface area-to-volume (SA:V) ratios demand spatially controlled biofunctionalisation. Plasma bio-engineering offers a dry, reagent-free platform to uniformly modify internal and external surfaces of porous constructs with bio-instructive functionalities.

This work presents the development and application of advanced plasma technologies, including packed bed plasma immersion ion implantation ($PBPI^3$), to functionalise 3D-printed scaffolds and tubular constructs. $PBPI^3$ enables plasma ignition within micrometre-scale pores, overcoming the long-standing barrier of uniform internal activation. COMSOL Multiphysics simulations and spatial surface characterisation confirm the homogeneity of activation throughout the porous architecture. Radical-rich surfaces generated by this approach support covalent attachment of biomolecules such as fibroblast growth factor 2 (FGF2), enabling cost-effective stem cell expansion while preserving mesenchymal stem cell (MSC) phenotype and multipotency.

Beyond stem cell biomanufacturing, we demonstrate covalent hydrogel immobilisation, peptide orientation control, and nanoparticle coating across diverse materials including titanium, stainless steel, bioceramics, and polymers. These plasma-enabled porous interfaces have been translated to applications in bone and soft tissue implants, vascular devices, wound dressings, and immunomodulatory platforms.

By enabling spatially resolved surface engineering across complex topologies, plasma bio-engineering transforms porous biomaterials into functional, tissue-instructive systems, driving the next generation of regenerative and therapeutic devices.