Nanotools for Shaping 3D Microenvironments for Tissue Engineering

Oscar Castaño[1,2,3], Adrià Noguera-Monteagudo[1], Renato Eduardo Yanac-Huertas[1], Anna Vilche-Mariscal[1], Margherita del Caro[1], Joan Marti-Muñoz[2], Paula Ferrando-Huertas[1], Romen Rodriguez[1], Sandra van Vlierberghe[4], Elisabeth Engel[5,2,3]

[1]Electronics and Biomedical Engineering, University of Barcelona, C/ Marti I Franques 1, 08028, Barcelona, Spain
[2]Institute for Bioengineering of Catalonia (IBEC), he Barcelona Institute of Science and Technology (BIST) C/ Baldiri I Reixac, 15, 08028, Barcelona, Spain
[3]CIBER en Bioingeniería, Biomateriales y Nanomedicina, CIBER-BBN, Av. Monforte de Lemos, 3-5. Pabellón 11. Planta 0 28029 Madrid, Spain
[4] University of Ghent, S4 Krijgslaan 281, 9000, Gent, Belgium
[5]. Polytechnical University of Catalonia (UPC), Av. d'Eduard Maristany, 16, 08019 Barcelona, Spain

oscar.castano@ub.edu

Tissue engineering increasingly relies on moving beyond traditional 2D environments to 3D microenvironments that more closely replicate the intricate complexity of natural tissue. Since the beginning of the century, several authors have highlighted the essential role of biomimetic scaffolds that control physical and chemical signaling, in the form of mechanical, topographical, and biochemical stimulation to guide cell behavior[1,2]. Initially, methods like nanoparticles (Calcium Phosphates CAP) and electrospinning (Polylactic acid -PLA-, polycaprolactone – PCL-, etc) provided foundational control over these cellular cues [3,4,5]. Building on these early advancements, 3D printing techniques such as extrusion[6] and Digital Light Processing (DLP) brought greater structural and biochemical accuracy, creating more physiologically relevant environments for cell growth. Most recently, multiphoton polymerization has taken this a step further by enabling 3D scaffolds with nanoscale precision, allowing fine-tuned control of cellular microenvironments within biomaterials designed for tissue-specific repair. This expanding set of nanotools is enhancing our ability to regulate cellular behavior within 3D (bio)printed constructs, opening new doors for creating biomimicked tissues and beyond. Altogether, this comprehensive integration of nanotools marks a pivotal step toward developing complex, tailored, and clinically applicable therapies and tissue models, laying the groundwork for next-generation therapeutics.

References

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Figures

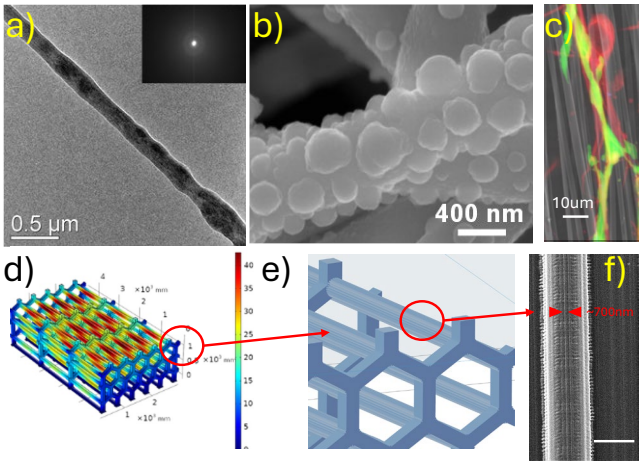

Figure 1. a) CaP nanoparticles embedded in an electrospun PLA fiber; b) CaP nanoparticles covalently attached to the surface of a PLA electrospun fiber; c) composite SEM-Confocal image of PLA electrospun fibers of ~600-700nm thickness guiding the migration of glial and neuron cells; d) Finite element analysis mechanical of a polymeric scaffold to reproduce electrospun fibers in 3D; e) Magnification of the 3D STL file detailing the nanometric bioactive ridges on the surface of the beams; f) Field-emission SEM image of a 2PP 3D printed scaffold reproducing the 700nm ridges ready for the cell culture.