Biosensor-Integrated Organs-on-a-Chip: Bridging Nanotechnology and Personalized Medicine for Advanced Nanotherapeutics and Nanodiagnostics

Abstract

The convergence of nanotechnology, biosensors, and tissue engineering represents a transformative paradigm in biomedical research, offering unprecedented opportunities for developing next-generation diagnostic and therapeutic platforms. At the Institute of Bioengineering of Catalonia (IBEC), our research focuses on creating innovative multi-organ-on-a-chip (OOC) systems that seamlessly integrate advanced biosensing technologies with engineered human tissues, providing powerful tools for drug screening, disease modeling, and personalized medicine applications.

Our platforms incorporate multiple sensing modalities including electrochemical sensors, optical detection systems, and impedance spectroscopy for real-time monitoring of cellular responses, metabolite concentrations, and tissue functionality. We have pioneered the use of plasmonic biosensors based on gold nanogratings for direct, label-free monitoring of protein secretion in disease models, representing a significant advancement in nanodiagnostic capabilities. Through our ERC-funded research, we have developed revolutionary multi-organ-on-a-chip systems that faithfully mimic the physiological characteristics of in vivo tissues, with particular focus on diabetes and muscular dystrophy research. These platforms uniquely enable the study of organ-organ interactions and systemic drug responses, bridging the gap between traditional cell culture and animal models.

Our biosensor-integrated OOC platforms demonstrate significant potential across multiple biomedical applications. We have successfully created muscle-on-a-chip systems with integrated multiplexed biosensing for in situ monitoring of inflammatory markers (IL-6, TNF-α), providing unprecedented insights into drug efficacy and toxicity profiles. These platforms offer more predictive and ethical alternatives to traditional animal models and conventional 2D cell cultures. In disease modeling applications, our tissue-engineered models have been successfully applied to study rare neuromuscular diseases including myasthenia gravis and Duchenne muscular dystrophy. Through strategic collaborations with clinical groups at Hospital de Sant Pau, Newcastle University and INCLIVA, we have developed human microtissues that accurately recapitulate disease pathophysiology, enabling more relevant therapeutic screening.

The integration of patient-derived cells with our OOC platforms enables autologous drug screening and personalized therapeutic approaches, representing a significant advancement toward precision medicine applications. Looking toward the future of

nanotherapeutics and nanodiagnostics, we are actively developing valorization projects to bring plasmonic biosensors for clinical diagnosis to market, demonstrating the translational potential of our nanotechnology-based approaches.

The integration of nanotechnology with tissue engineering and biosensing represents a paradigm shift in biomedical research and clinical applications. Our biosensor-integrated organs-on-a-chip platforms demonstrate how nanotherapeutics and nanodiagnostics can be effectively combined to create powerful tools for drug development, disease modeling, and personalized medicine. The trilateral collaboration between Albania, Italy, and Spain provides an exceptional opportunity to advance these technologies through shared expertise and complementary resources, ultimately benefiting patients worldwide through improved therapeutic outcomes and enhanced diagnostic capabilities.

The future of nanomedicine lies in the seamless integration of multiple nanotechnology disciplines, and our work exemplifies how this integration can lead to revolutionary advances in healthcare technology. Through continued international collaboration and knowledge exchange, we can accelerate the translation of these innovative platforms from laboratory discoveries to clinical reality, fostering the development of more effective and personalized therapeutic interventions.

Keywords: Organs-on-a-chip, biosensors, nanotechnology, tissue engineering, drug screening, personalized medicine, nanotherapeutics, nanodiagnostics