A Versatile, Biomimetic, 3D Electrochemical Device for Monitoring Cell Growth and Epithelial Barrier Integrity

R. Acharya; D.v. Niekerk; M. Lopez Cavestany and R.M. Owens

University of Cambridge, Cambridge (United Kingdom)
ra646@cam.ac.uk

Three-dimensional (3D) cell culture and in-vitro bioelectronic systems have advanced significantly in recent years, offering new capabilities for monitoring and predicting biological activity in a variety of applications. While bioelectronic devices such as impedance sensors and electrochemical transistors have traditionally been based on two-dimensional (2D) organic semiconductor films, tissue engineering has developed 3D culture platforms—such as porous scaffolds, hydrogels, and fibre meshes—that better replicate native tissue architecture and physiology.

In this work, we present a novel bioelectronic device that integrates these two domains. The device is built around a 3D microporous scaffold based on the conducting polymer PEDOT:PSS, serving both as a biologically relevant substrate and as an active electronic interface. The scaffold functions as a transmembrane structure that hosts multiple cell types, enabling the formation of stratified tissue models, while simultaneously transducing biological (ionic) signals into readable electrical outputs.

We demonstrate the design, fabrication, and electrical characterization of this transmembrane bioelectronic platform, which combines dual sensing modalities: electrochemical impedance spectroscopy (EIS) for monitoring epithelial barrier formation and integrity, and organic electrochemical transistor (OECT) operation for real-time tracking of cell growth and extracellular matrix (ECM) deposition in 3D.

Using fibroblast cultures as a model, we monitored tissue development over a 10-day period. Changes in drain current provided a quantitative readout of cell proliferation and ECM accumulation. We evaluated the influence of initial seeding densities (125k, 250k, and 500k cells), observing distinct patterns of cell migration, proliferation, and matrix remodeling, which were corroborated with biological assays including immunofluorescence imaging and DNA quantification.

Additionally, we used EIS to monitor epithelial layer formation and barrier integrity over time and correlated this with the underlying fibroblast dynamics, demonstrating the device's ability to support and assess multi-layered tissue constructs.