Microphysiological systems and microenvironments models for cellular engineering

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The generation of tissue models that reproduce the three-dimensional characteristics of the cellular microenvironment remains one of the major challenges in biology and medicine. Recent developments in microtechnology, microfluidics and 3D bioprinting have led to the emergence of new in vitro models that allow selected parameters of the cellular microenvironment to be controlled. These models, commonly referred to as microphysiological systems (MPS), represent promising alternatives for studying tissue pathophysiology, performing pharmaceutical screening and developing personalized medicine approaches. The central challenge is therefore not to reproduce the full complexity of native tissues, but to identify which cues must be controlled to obtain robust, reproducible and physiologically relevant models.

In this seminar, I will illustrate this idea through three complementary examples. First, I will show how high-resolution 3D bioprinting can be used to define tissue topography, using GelMA/PEGDA scaffolds reproducing small-intestine crypt–villus architecture. I will then discuss how molding strategies can provide access to more physiological materials, in particular collagen-based hydrogels, while preserving controlled colon-like crypt geometry and matrix stiffness in microphysiological systems. Finally, I will present ongoing work on vascularized adipose tissue models, where the focus shifts from imposed architecture to matrix remodeling, perfusion and tissue function using photosensitive hydrogels.

Together, these examples highlight a central idea: controlling the microenvironment is essential, but effective tissue engineering does not necessarily require reproducing all tissue cues. A minimal and well-chosen set of physical, chemical and transport signals may be sufficient to promote tissue organization, maturation and function.