BIOLOGICAL TRENDS IN 3D BIOPRINTING OF TISSUES AND ORGANS

Mamatov M.S., Belinska A.P.
National Technical University
"Kharkiv Polytechnic Institute", Kharkiv

Modern 3D bioprinting technologies are opening new horizons in regenerative medicine and tissue engineering by combining principles of biology, materials science, and computer modeling. The most promising materials for bioprinting are hydrogels based on alginate, fibrin, or hyaluronic acid, which mimic the natural extracellular matrix and provide cells with necessary mechanical and biochemical signals. Studies demonstrate that combining iPSCs with organ-specific niches in three-dimensional constructs promotes cell differentiation into functional structures resembling native tissues. For example, in study [1], researchers successfully reproduced liver microarchitecture through layer-by-layer deposition of hepatocytes, endothelial cells, and stromal fibroblasts, followed by cultivation in a bioreactor with dynamic nutrient flow.

A significant advancement in the technology has been the introduction of multimaterial printing systems, which allow simultaneous use of multiple bioink types with different mechanical properties. This is particularly relevant for creating vascularized constructs, where the combination of rigid polymer scaffolds and soft cellular matrices mimics the natural interaction between parenchyma and vascular networks. In study [2], a combination of electrospun polycaprolactone nanofibers with crosslinked collagen gel enabled the reproduction of hierarchical capillary structures, ensuring the viability of cardiomyocytes in printed myocardial tissue for 28 days. A promising direction is the integration of bioprinting with synthetic biology methods, particularly the development of "smart" constructs capable of self-organization or response to external stimuli. Experimental evidence confirms that introducing genetic circuits into target cells allows programmable changes in their morphology or secretory activity in response to specific biochemical signals [1]. This approach enables the creation of dynamic tissue models that can adapt to physiological conditions, mimicking wound healing or regeneration processes.

Despite significant progress, a key challenge remains scaling these technologies for clinical applications, particularly ensuring long-term stability of printed organs in vivo. Further development of the field is linked to the refinement of next-generation biomaterials that combine biocompatibility with functional activity, as well as the automation of quality control processes using artificial intelligence. Implementing these solutions will facilitate the transition from experimental models to fully functional biotechnological products for transplantation, toxicological screening, and personalized medicine.

References:

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