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Fabrication of PDMS Membranes with Hierarchical Tapered Pores for Advanced Organ-on-a-Chip Applications

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Elastic porous membranes are essential components of mechanically active organ-on-a-chip (OOC) and microphysiological system platforms, where they serve as critical tissue-tissue or tissue-environment interfaces allowing nutrient exchange, stretching, and optical clarity. Despite their importance, conventional fabrication methods often suffer from low reproducibility due to the formation of residual polymer films, which can compromise pore connectivity and device integrity. To address these challenges, this work explores fabrication strategies suitable for polydimethylsiloxane (PDMS) membranes featuring hierarchical tapered pores.

The methodology utilizes multilayer SU-8 epoxy photoresist masters consisting of hierarchical cylindrical micropillars. By gradually stacking arrays of cylinders of decreasing diameters, a 3D template is created for the casting of negative replicas, i.e., PDMS membranes with well-defined, tapered through-holes. The subsequent formation of PDMS membranes can be performed in several ways, and this work aims to identify the optimal procedure to achieve high yields and membrane quality, as well as true spatial dimensions and pore passability.

The resulting hierarchical geometry is intended to offer unique advantages for biomimetic applications. The tapered pores, combined with surface hydrophobization, are expected to exploit Laplace pressure to prevent liquid flow between air and liquid compartments, maintaining a stable air-liquid interface in lung-on-a-chip models. Furthermore, the functional performance of these membranes will be validated through size-selective filtration experiments using polystyrene beads of two distinct sizes – below and above the pore diameter – to demonstrate the potential for precise particle capture and cell separation. This research aims to provide a versatile platform for developing high-fidelity microphysiological systems with highly customizable transport properties.