Enhanced mass transfer hollow fiber Membranes by immersion precipitation 3D-printing for Organ Support

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Extracorporeal membrane oxygenators (ECMOs) serve as critical life-support systems for patients suffering from severe respiratory or cardiocirculatory failure. Despite their widespread application, commercial ECMO devices are currently limited by the physical properties of their hollow fiber membranes, these fibers generally feature large outer diameters (300 µm) and relatively thick walls (80 µm). These geometric constraints cap the specific surface area at approximately 70 cm^2/cm^3 and create significant resistance to gas diffusion, resulting in suboptimal oxygen (O_2) and carbon dioxide (CO_2) mass transfer rates.

To address these limitations, this work investigates the development of thermoplastic polyurethane (TPU 1170A) hollow-fiber structures utilizing a novel manufacturing technique: immersion precipitation 3D printing (ip3DP). This process combines the geometric flexibility of syringe-based 3D printing with the chemical mechanism of phase inversion, enabling the fabrication of complex membrane geometries designed to improve fluid dynamics and increase the effective mass-transfer surface area.

A comprehensive experimental study was conducted to determine the structure morphology and operating window across a wide range of process parameters. he results demonstrated that ip3DP allows for the production of filaments with tunable internal morphologies, ranging from solid to hollow, by manipulating solution viscosity and solvent extraction rates. The optimal conditions for ECMO fiber fabrication were identified as a 10 wt% TPU/DMF solution containing 2.5 wt% UiO-66, extruded through a 0.306 mm needle at 50°C into a 55°C demineralized-water bath, with a printing speed of 100 mm/min.

Under these conditions, we achieved hollow fibers with significantly smaller outer diameters (200 µm) and drastically thinner walls (5-20 µm) compared to commercial devices, yielding specific surface areas exceeding 75 cm^2/cm^3. The incorporation of MOFs was found to be essential for preventing lumen collapse and maintaining mechanical stability. Although SEM analysis revealed external microporosity requiring a PDMS coating, the resulting membranes demonstrated excellent dimensional uniformity. While the smaller diameters led to higher flow resistance (0.15 bar), the reduced membrane thickness provided superior and transfer performance, validating ip3DP as a promising route for high-efficiency ECMO fabrication.

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