Internal Ramp Flow Conditioning in Side-Port Embryo Transfer Catheters: A Computational Design Optimization Study on Fluid Recirculation and Shear Stress Reduction

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Abstract

Safe embryo transfer depends on hydrodynamic conditions within the catheter tip. While side-port catheters reduce endometrial trauma, abrupt 90° flow redirection can create stagnation zones and elevated shear stress, potentially affecting embryo viability. This study addresses the trade-off between mechanical safety and fluid expulsion by introducing an internal flow-conditioning concept. A 'Flow-Guiding Internal Ramp Architecture' (FGIRA) with an area-equivalent oval opening was evaluated using three-dimensional CFD simulations (SolidWorks Flow Simulation) under laminar Newtonian conditions at 310.15 K. Four configurations end-opening, circular side-port, oval side-port, and Oval-FGIRA were analyzed, with mesh independence verified through grid refinement. The circular side-port exhibited flow recirculation and a peak wall shear stress (WSS) of 3.92 Pa. While the oval side-port reduced stagnation, WSS remained at 2.13 Pa. In contrast, the Oval-FGIRA suppressed vortex formation and reduced maximum WSS to 1.65 Pa (Re = 72.7), remaining below the 2 Pa threshold. These findings indicate that internal ramp-based flow conditioning simultaneously improves expulsion efficiency and mechanical safety, offering a robust computational design framework for next-generation embryo transfer catheters.

Keywords: *catheter, computational fluid dynamics, embryo transfer, hydrodynamics, in vitro fertilization, wall shear stress*