Flow Rate Dependence on Stenosis Order in a Serial Stenosis Model: Effects of Viscosity and Turbulence

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Arterial stenosis, the narrowing of arteries by plaque buildup, is the primary cause of cardiovascular diseases. Diseased arteries often contain multiple or non-uniform stenoses, so clinical practices often assess severity using the narrowest constriction or additive resistance models. Studies have observed weak order dependence in laminar flow, suggesting interference in adjacent stenoses, yet it remains unclear how stenosis order affects flow, especially in non-laminar flow. I used a model system with two pairs of stenoses (ID 0.17" & 0.25") in four sequences: 0.17–0.17–0.25–0.25 (A), 0.17–0.25–0.17–0.25 (B), 0.17–0.25–0.25–0.17 (C), and 0.25–0.17–0.17–0.25 (D) to study how flow rate varies with stenosis order, focusing on how this dependence scales with viscosity (0-40% sucrose w/w solutions) and hydrostatic pressure (0.6-1.5 m head). Flow rate strongly depended on stenosis order: A & D (clustered narrow stenoses) exhibited similar flow rates; B & C (separated narrow stenoses) exhibited similar flow rates but consistently lower than A/D. As overall flow rate decreased, the mean-flow-rate ratio between B/C and A/D decreased from 82% to 55%, corresponding to an approximately 24-fold increase in flow resistance difference between B/C and A/D. This dependence did not scale monotonically with Reynolds number or viscosity. This suggests that flow recirculation at diameter transitions may induce major flow resistance, producing the observed order dependence. The observed order dependence scaling with flow rate is consistent with turbulence reducing recirculation zones. This study highlights the importance of accounting for the flow resistance at stenotic transitions when evaluating multi-stenotic systems, especially in severely diseased arteries.

Awards Won:
Third Award of $1,200