Lumped-Parameter Modeling of Retrograde Flow in Fetal Aortic Coarctation

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Background Retrograde flow within the aortic arch is a prominent hemodynamic feature observed in severe cases of fetal aortic coarctation and is routinely identified during prenatal Doppler assessment. Although this phenomenon has been associated with abnormal aortic arch development and impaired cerebral perfusion, the cardiovascular mechanisms governing flow reversal in the fetal circulation remain incompletely understood due to the complexity of fetal–placental physiology.

Methods In this work, lumped-parameter modeling approaches are employed to investigate the physiological factors influencing aortic flow direction in fetal aortic coarctation. A zero-dimensional (0D) lumped-parameter model of the fetal–placental circulation is developed to represent global fetal hemodynamics, including the ventricles, ductus arteriosus, foramen ovale, placental circulation, and systemic vascular beds. To provide additional hemodynamic resolution, the framework is extended to a one-dimensional (1D) formulation that captures spatial pressure variations and wave propagation effects along the aortic arch and major vessels. Paired magnetic resonance imaging and ultrasound data, including 2D flow MRI measurements, are incorporated to support model calibration and physiological consistency

Conclusion This combined 0D–1D lumped-parameter modeling framework provides a mechanistic platform for exploring fetal hemodynamics under pathological conditions. By enabling systematic investigation of flow redistribution, ventricular output balance, and shunt interactions, the approach supports improved interpretation of prenatal flow measurements and advances physiological understanding relevant to risk stratification in fetuses with suspected aortic coarctation.