Geometric Determinants of Oxygen and Heat Exchange in Placental Mammals

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Abstract

The mammalian placenta is one of the most complex and unique exchange organs. Despite its transient nature, this crucial life-support system not only nourishes growing fetuses but also determines their lifelong health. The human placenta features an intricate disordered micro-porous structure that packs a large surface area (~ 10 m^2) into a relatively thin disc connected to the fetus via a helically coiled umbilical cord. The placenta also exhibits unusually high evolutionary diversity across placental mammals, while the impact of its architecture, and in particular of cord coiling, on human pregnancy pathologies, such as fetal growth restriction, remains poorly understood [1].

The talk summarises recent progress in hyper-multiscale 3D imaging (spanning μm to cm) [2] and associated image-based modelling of placental exchange. Our combined analytical and numerical approaches reduce complexity and offer direct insights into the dominant geometrical determinants of maternal–fetal solute and heat transfer in humans and other species. The models demonstrate a certain universality of upscaled approximations for a wide class of transported solutes [3] and explore the surprising role of the helical vascular configurations of the umbilical cord in modulating solute and heat exchange [4]. These results clarify the role of placental and cord morphology in the context of evolution and fetal resilience.

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