Modeling blood flow and mass exchange in the human placenta

Internship project

Location:	Laboratoire de Physique de la Matière Condensée, École Polytechnique
Internship level:	M1/M2 in Theoretical physics, Hydrodynamics, Applied Mathematics, Bioinformatics, Biosciences or similar
Internship duration:	4-6 months
Requested skills:	Basic knowledge of diffusion and hydrodynamics, some simulation/programming skills (e.g., in Matlab), as well as strong motivation for biological applications.
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Project description

The human placenta is the single link between the growing fetus and the mother during nine months of pregnancy. Since mother's blood and fetus' blood do not mix, the structure of the placenta is optimized for efficient exchange of oxygen, carbon dioxide, water, nutrients and waste products between the fetal and the maternal blood [1]. Anatomical observations report the placental structure as a 16-generation branching tree of fetal vessels immersed in a basin of maternal blood. Understanding exchange in this sophisticated structure is crucial for understanding the function of the human placenta and can help diagnosing health risk for newborns.

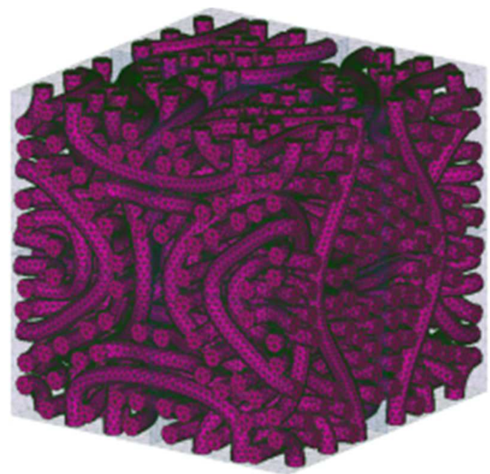

Figure 1. An example of a geometry imitating internal structure of the human placenta

The goal of this internship is to simulate maternal blood flow in a model structure of the human placenta and to compute oxygen uptake. The tree of fetal vessels can be modeled, e.g., as an array of curved cylinders arranged in a structured or random fashion (Fig. 1) mimicking the experimentally-observed structure (Fig. 2). The gas transfer model will be developed in this geometry, the blood flow part being modeled by the Navier-Stokes equations which can be solved numerically (COMSOL Multiphysics® and/or Matlab®). The influence of microvilli on the exchange across the villous membrane will be investigated, especially the respective roles of diffusion-based and advection-based transport. Results of the model will be compared to theoretical predictions [2,3] as well as medical observations. This project involves collaborations with medical doctors in Paris-5 and with physiologists in Southampton, UK.

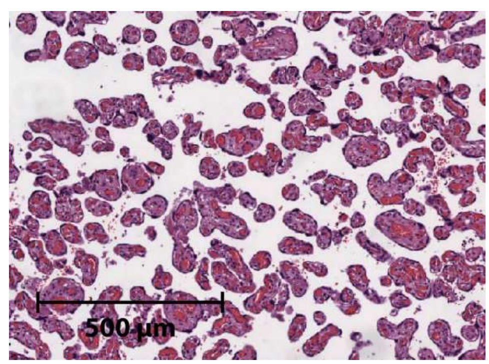

Figure 2. A typical histological placental section representing a 2D cut of the vessels tree of the human placenta (reproduced from Serov et al., 2014)

References

[1] A. S. Serov, C. Salafia, D. S. Grebenkov, and M. Filoche, *The Role of Morphology in Mathematical Models of Placental Gas Exchange*, J. Appl. Physiol. 120, 17-28 (2016).
[2] A. S. Serov, C. Salafia, M. Filoche, and D. S. Grebenkov, *Analytical theory of oxygen transfer in the human placenta*, J. Theor. Biol. 368, 133-144 (2015).
[3] A. Serov, C. Salafia, P. Brownbill, D. S. Grebenkov, and M. Filoche, *Optimal villous density for maximal oxygen uptake in the human placenta*, J. Theor. Biol. 364, 383-396 (2015).