Simulation of Placental Jets and Mega-jets

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Background

- Blood flows to the placenta through maternal arteries called spiral arteries which feed placental tree-like structures called villous trees.
- Over gestation villous trees become more dense which decreases the free space (porosity) and makes it harder for maternal blood to penetrate into the placental tissue (**Fig1**).
- Jets and mega-jets (penetration>50% of placental thickness) are observed in Doppler ultra-sonography[1]. **HOW?**
- Length of jets increase with gestational development[1]. **HOW?**

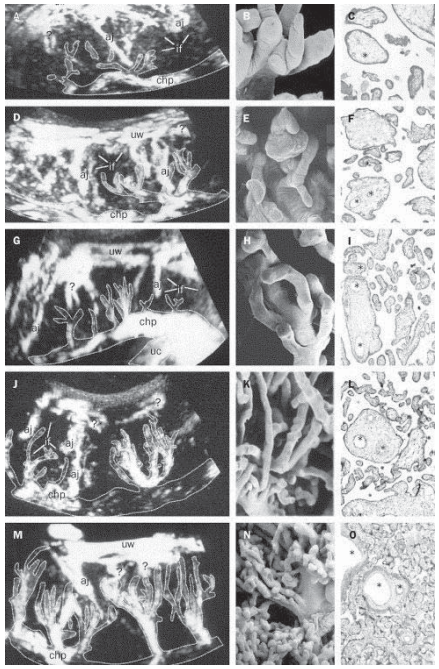


Fig1: Picture obtained from Konje, J., et al., *3-dimensional colour power angiography for staging human placental development.* Lancet, 2003. **362**: p. 1199-1201.

Methods

Placentone: A placental circulatory unit with just one spiral artery as blood source (**Fig2**).

- We used literature data for porosity, radius of the funnel shaped opening, the placental thickness and the mean velocity at the opening[1,2,3] and used computational fluid dynamics to predict blood flow velocity within placental tissue.

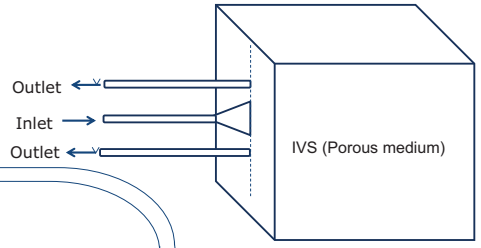
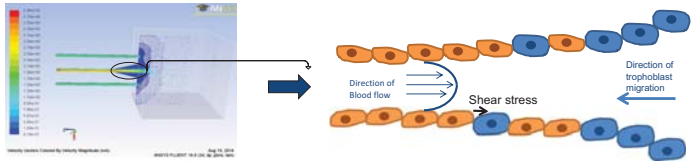
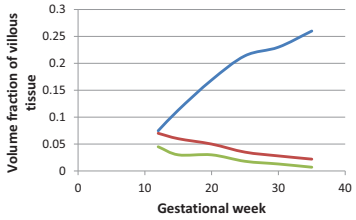


Fig2: Placentone

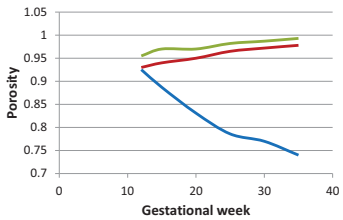
Results

1) Shear stress in the context of spiral artery remodelling is the force that endothelial and trophoblast cells in the walls of the spiral arteries feel as a result of blood flowing through the arteries. Our model predicts this shear stress.

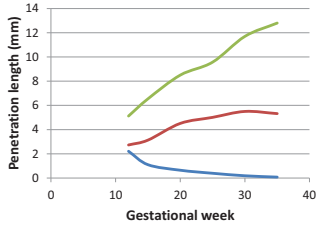




- Average volume fraction
- volume fractione needed to have penetration as measured by ultrasound
- volume fraction needed to penetrate >50% of placental thickness



- Average porosity
- Porosity needed to have penetration as measured by ultrasound
- porosity needed to penetrate >50% of placental thickness



- Penetration length for average porosity
- penetrationlength measured by ultrasonography
- penetration length >50% of placental thickness

2) We predict ultrasound observed 'jets' at the opening of a spiral artery only when porosity is greater than average placental porosity.
3) Some hollow spaces (with low volume fraction) are needed to get penetration more than 50% of the placental thickness (Mega-jets - **Fig4**).

✘ **Instead of:**

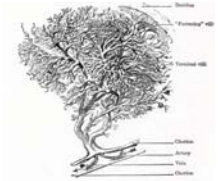


Fig3: Picture obtained from V. Chaddha et. al., Developmental biology of the placenta and the origins of placental insufficiency Seminars in Fetal and Neonatal Medicine, October 2004, Vol.9(5), pp.357-369

✓ **Villous trees at mega-jet entrance are more like:**

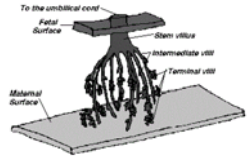
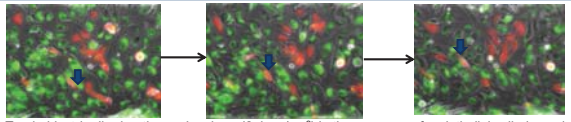


Fig4: Picture obtained from http://showcase.netins.net/web/placenta/triage.php

Future direction

Time-lapse imaging of human trophoblast under flows[4] suggests that shear stress increases migration in the direction of flow. We aim to model trophoblast migration in response to blood flow (or shear) and chemotaxis using agent based modeling techniques.



Trophoblast (red) migration under shear (2 dyne/cm^2) in the presence of endothelial cells (green)

References

[1] S. Collins et al. Placenta (2012):33 782-787
[2] K. Benirschke et al. *Pathology of the human placenta*. Springer Berlin Heidelberg, 2012. 41-53.
[3] I.O. Chernyavsky, et al. A mathematical model of intervillous blood flow in the human placentone. Placenta, 2010. **31**: p. 44-52.
[4] James et al. Cardiovascular Research 93 (2012) 152-161

Acknowledgements

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