Using a placental blood flow model to interpret diagnostic images

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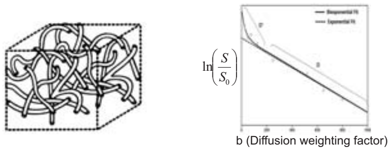
Intravoxel incoherent motion (IVIM) imaging

- MRI technique to quantify blood circulation in a capillary network from molecular diffusion in organs such as brain & liver [1]
- Assumes flow is a quasi-diffusion process due to randomly oriented capillaries

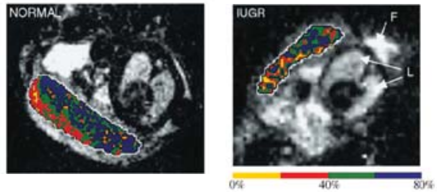


$$\frac{S}{S_0} = (1-f)e^{-bD} + fe^{-bD^*}$$

Signal attenuation; Volume fraction with blood circulation; Diffusion coefficient of water in tissue; Apparent diffusion coefficient of water in capillary

Placental IVIM imaging

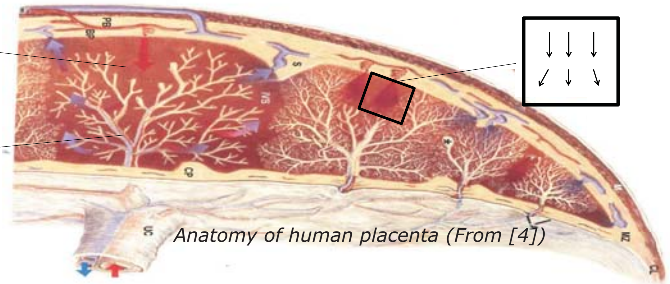
- Safe and non-invasive
- Sensitive to MRI due to large blood volume in placenta
- Differences in perfusion distribution between normal and compromised pregnancies [2]
- However, association between IVIM measurements (f & D*) and physical properties of placental structures is unclear



Placental perfusion maps (From [2])

Open questions in placental IVIM imaging

- Unique compared to other organs as the placenta has **two interacting blood flows**:



Anatomy of human placenta (From [4])

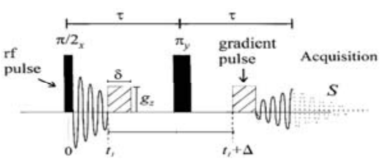
- How do flow profiles expected in the placenta influence MRI signal?
- Is IVIM adequate for quantifying blood flow in placenta?
- What is the physical significance of f, D and D* obtained from IVIM?

Methods

To answer these open questions in placental IVIM imaging, a IVIM model has been developed:

1) Calculate magnetisation:

- Pulsed Gradient Spin Echo **(PGSE)** used in IVIM imaging:



- Change in magnetisation of spins (ψ) during PGSE is given as [3]:

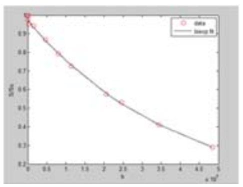
$$\frac{\partial\psi}{\partial t} = -i\gamma(g\cdot z)\psi + D\nabla^2\psi - \nabla\cdot v\psi$$

- ψ is solved using velocity fields from flow models
- Equation is solved using Lagrange-Galerkin method

2) Signal generation:

- Equally spaced sample points are seeded in the voxel
- Sample points are assigned ψ depending on whether they fall within or outside the capillaries
- ψ are summed over entire voxel to obtain signal

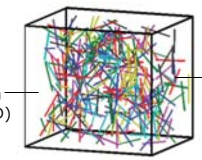
3) Predict flow properties:



- Signal attenuation fitted to find f, D & D*

Model verification

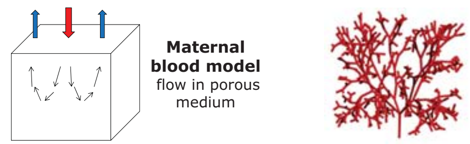
- A flow model with randomly oriented capillaries is set up:



- Able to correctly predict f, D and D* values for flow model
- D* proportional to v^2

Next steps

- Implement placental flow models in IVIM model



- Investigate how signal is affected by perfusion in placenta

Model applications

- Provide physical interpretations for f, D and D* obtained from MRI scan results
- Assist in diagnosis of placenta-related pregnancy complications
- Useful tool to study normal and pathological placental development

References

[1] - Le Bihan, Denis, et al. "Separation of diffusion and perfusion in intravoxel incoherent motion MR imaging." *Radiology* 168.2 (1988): 497-505.

[2] - Moore, R. J., et al. "In utero perfusing fraction maps in normal and growth restricted pregnancy measured using IVIM echo-planar MRI." *Placenta* 21.7 (2000): 726-732.

[3] - Kaufmann P, Scheffen I: Placental development. In, Neonatal and fetal medicine physiology and pathophysiology, Vol. 1. R Polin and W Fox, eds, pp 47-55. Saunders, Orlando 1992.

[4] - Stejskal, E. O., and J. E. Tanner. "Spin diffusion measurements: spin echoes in the presence of a time-dependent field gradient." *The journal of chemical physics* 42.1 (1965): 288-292.