Perfusion Analysis

Michael A. Chappell
Institute of Biomedical Engineering and FMRIB Centre, University of Oxford, UK.

While there are a number of different MRI methods for measuring perfusion in vivo, the fundamentals of analysis are common to each of them. In all cases tracer kinetics can be used to describe how the blood containing contrast behaves. From this it is possible to predict the signal we will measure and by 'inverting' the problem arrive at estimates of perfusion and parameters related to perfusion. However, the different contrast mechanisms tend to be suited to different ways of 'inverting' the kinetics. These are broadly classified into 'model-free' and 'model-based' methods. In model-based analysis the measured kinetic signal is described in terms of parameterized mathematical functions, whose parameters we seek to fit from the data. Whereas a model-free approach attempts to determine the functional form more directly from the data, thus making fewer assumptions. There is a tradeoff between these approaches based on how strict we allow our assumptions about the signal to be and how robustly we can make estimates from noisy data. Consequently different perfusion modalities have tended toward differing solutions.

Whilst relative measures of perfusion are sufficient in some cases, often fully quantitative values are required. The different perfusion modalities rely on various methods both to generate the contrast and measure its progress through the vasculature. These differences influence whether we can derive quantitative perfusion measures and, if we can, what other calibration information is required.

In this session we will cover:

- The basics of tracer kinetics: arterial input and residue functions.
- The key parameters of kinetic theory, how they may vary and which ones we might be interested in.
- The two broad classes of 'model-based' and 'model-free' kinetic analysis methods. The advantages and disadvantages of each and why they are just two extremes of more general analysis approach.
- The bias that may be introduced into measurements of perfusion due to tracer remaining in larger arteries and how we might account for this in the analysis.
- What the most common analysis approaches are for the different modalities and the reasons why.
- A discussion of calibration and quantification – what extra information we might need for the different modalities to get quantitative measurements.

Useful introductory material:

Introduction to Functional Magnetic Resonance Imaging, R.B. Buxton, CUP, 2002. Good introduction to perfusion (Ch 2) and tracer kinetics (Ch 13-15).

Quantitative MRI of the brain: measuring changes caused by disease, P. Tofts (ed.), Wiley, 2003. A useful introduction to quantitative measurements using different MRI perfusion modalities (Chs 10, 11 and 13).

Special section from the 2004 ISMRM perfusion workshop. Magnetic Resonance in Medicine, 22(6):691-753, 2005.

A (far from comprehensive) list of relevant publications on the fundamentals of perfusion analysis and examples of different approaches:

Absolute quantification of perfusion using dynamic susceptibility contrast MRI: pitfalls and possibilities, L. Knutsson, Magnetic Resonance Materials in Physics, Biology and Medicine 23(1): 1-21, 2010.

Bayesian estimation of cerebral perfusion using a physiological model of microvasculature, K. Mouridsen *et al.*, NeuroImage 33(2): 570-579, 2006.

Model-free arterial spin labeling quantification approach for perfusion MRI, E. T. Petersen *et al.*, Magnetic Resonance in Medicine 55(2): 219-232, 2006.

Principles of cerebral perfusion imaging by bolus tracking, L. Østergaard, Journal of Magnetic Resonance Imaging, 22(6):710-717, 2005.

A general kinetic model for quantitative perfusion imaging with arterial spin labeling, R. B. Buxton *et al.*, Magnetic Resonance in Medicine 40(3): 383-396, 1998.

High resolution measurement of cerebral blood flow using intravascular tracer bolus passages. Part I: Mathematical approach and statistical analysis, L. Østergaard *et al.*, Magnetic Resonance in Medicine 36(5): 715-725, 1996.

Measurement of the blood-brain barrier permeability and leakage space using dynamic MR imaging. 1. Fundamental concepts, P. S. Tofts, Magnetic Resonance in Medicine 17(2): 357-367, 1991.