The Physics of Imaging Diffusion & Perfusion

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Synopsis

This lecture will cover the basic principles of diffusion and perfusion-weighted MRI. The basic diffusion sensitization module will be presented, together with the apparent diffusion coefficient (ADC) and diffusion tensor imaging (DTI) models. Different strategies to measure tissue perfusion will be introduced, relying either on the injection of an external contrast agent as in Dynamic Susceptibility Contrast-MRI (DSC-MRI) and Dynamic Contrast Enhanced-MRI (DCE-MRI) or by using water as an endogenous contrast agent as in Arterial Spin Labelling (ASL). Clinical examples will be briefly presented for both diffusion and perfusion imaging including brain ischemic stroke and tumour imaging.

Objectives

At the end of this lecture participants should be able to:

- Describe the phenomenon of diffusion molecular motion
- Understand how sensitivity to diffusion can be achieved in MRI
- Describe the basic principles of the three main perfusion acquisition methods: Dynamic Susceptibility Contrast-MRI (DSC-MRI), Dynamic Contrast Enhanced-MRI (DCE-MRI) and Arterial Spin Labelling (ASL)
- Identify the main advantages and pitfalls of the different perfusion methods
- Understand the relevance of diffusion and perfusion imaging in the clinical context, focusing on brain ischemic stroke and tumour imaging

Description

This lecture will cover the basic principles of diffusion and perfusion-weighted MRI. Firstly, the phenomenon of thermal molecular diffusion will be introduced. Identifying the spatial and temporal scales of this phenomenon will enable attendees to understand how the motion of water molecules can be used to probe tissue structures that are much smaller than typical MRI voxel sizes. The physics behind the standard bipolar diffusion-sensitization pulse sequence module will be presented, and the b-value introduced. The simple apparent diffusion coefficient and diffusion tensor imaging (DTI) models will be described, and their main limitations discussed to motivate the need for the development of more advanced diffusion models.
The main strategies used to measure tissue perfusion with MRI will then be covered. One option is to inject an external contrast agent such as gadolinium into the bloodstream. The injection of a paramagnetic molecule modifies the local magnetic field, producing a reduction in both the longitudinal (T1) and transverse (T2*) relaxation time constants. Following injection, a series of images are acquired to track the dynamic passage of the contrast agent from major arterial vessels to the capillaries that feed the tissues. Depending on the selected pulse sequence, the measured tissue signal will reflect mostly a T2* shortening, as in Dynamic Susceptibility Contrast-MRI (DSC-MRI), or faster T1 recovery as in Dynamic Contrast Enhanced-MRI (DCE-MRI). Although these approaches provide high signal-to-noise ratios, not all patients tolerate external contrast agents and the recent reports of long-term gadolinium deposition in brain tissues provide further motivation for the development of alternative techniques. Arterial Spin Labelling (ASL) uses water molecules as an endogenous contrast agent. It is based on the inversion of a tissue slab distal to the field of view of interest sometime prior to imaging. The slab should comprise a feeding artery, and inverted spins in the blood will travel towards the imaging slice, exchanging from the capillaries to the cerebral tissue, and providing sensitivity to perfusion.
In the final part of the lecture, a few clinical examples will be presented for both diffusion and perfusion imaging including brain ischemic stroke and tumour imaging.

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