What Life Scientists Should Know About Molecular Imaging

MR Fundamentals for Life Scientists

Contemporary MR: Pushing the Limits

Joel R. Garbow
Biomedical MR Laboratory, Mallinckrodt Institute of Radiology, Washington University in St. Louis, Missouri, USA

Learning Objectives:

- Understand the importance of contrast in MR imaging
- Describe T1, T2, and T2* relaxation phenomena and how they are measured
- Understand relaxation as a source of image contrast
- Understand the role of magnetization exchange in relaxation and as a source of contrast (MT)
- Describe more technically advanced, endogenous-contrast experiments (diffusion, per fusion, flow, BOLD, CEST)
- Describe the role of exogenous contrast agents
- Describe more technically advanced, exogenous-contrast experiments (DCE, DSC, ParaCEST)

The vast majority of clinical magnetic resonance (MR) imaging experiments involve 1H imaging of the water, which is ubiquitous in biological tissue. Water has a wide variety of biophysical magnetic signatures that are characteristic of specific tissues and organs. The exquisite sensitivity of water's MR properties to its local environment can be used to enhance image contrast and provide detailed structural information. MR image contrast distinguishes organs and soft tissues and helps to identify normal vs. abnormal, healthy vs. damaged, and viable vs. pathologic tissue. The key to tissue MR contrast is effective encoding of the physical properties of tissue into the MR image.

The question of which physical property to encode often reduces to questions of "What are we trying to measure?" and "What MR property generates the best contrast?" Herein, we will discuss different MR contrast mechanisms, including longitudinal relaxation (T1), transverse relaxation (T2 and T2*), diffusion, velocity (perfusion and flow), and blood oxygen level dependence (BOLO) MRI, the mechanism that serves as the underpinning for functional MRI. We will explore the role of exogenous agents in generating contrast and describe their use in dynamic MR experiments that can provide measures of perfusion and vascular permeability.

We begin with a phenomenological discussion of T1 and T2 relaxation and a description of how the corresponding relaxation rate constants, R1 (=1/T1) and R2 (=1/T2), are measured. The manner in which tissue differences in R1 or R2 can provide a source of image contrast will be illustrated. Exchange processes are central to MR and MR relaxation. Contrast arising from magnetization transfer (MT), in which 1H magnetization is exchanged between macromolecules not visible by MR and mobile water molecules, will be discussed. We will then describe the basic role of MR contrast agents. Built around paramagnetic centers, MR contrast agents are fundamentally different than optical tracers or PET probes, in that the agents themselves are never directly observed. Instead, MR contrast agents function by changing the 1H relaxation properties in nearby water molecules. The consequences of such indirect observation of these agents in terms of contrast and quantitative detection and modeling will be explored. Examples of both T1 agents (e.g., Gd-based), which brighten images, and T2/T2* agents (e. g.,

iron oxides), which darken images, will be provided. The use of contrast agents in a static mode – inject an agent and wait for it to be distributed within the body – provides a powerful and versatile source of contrast. However, these same agents can also be used in a dynamic mode to provide information about vascular structure and function. Two such experiments, dynamic contrast enhanced (DCE) and dynamic susceptibility contrast (DSC) MRI, will be described. Both DCE and DSC experiments begin with injection of a bolus of contrast agent- the DSC experiment focuses on measuring tissue perfusion, while DCE highlights both perfusion and vascular permeability (vessel “leakiness”). The use of iron-oxide contrast agents to label and track cells will also be reviewed.