What Life Scientists Should Know About Molecular Imaging

MR Fundamentals for Life Scientists

Introduction to MR Physics
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Learning Objectives:

- Understanding of the underlying physics of MRI
- Familiarity with the main components of an MRI scanner
- Introduction to the basics of image acquisition

The MRI technique depends on the phenomenon of Nuclear Magnetic Resonance (NMR) which, as the name suggests, is based on a fundamental magnetic property of certain atomic nuclei and their resonant interaction with externally applied electromagnetic photons. The use of the word "resonant" is critical in this context, and refers to the fact that the energy of the photons must be very exact for the interaction to occur. The specific energy required is governed by the properties of the nuclei in question (usually hydrogen) and the magnetic field in which the sample containing these nuclei are situated (usually several Tesla in magnitude). Thus we may "excite" a sample of, say, water (contains many 1H nuclei) by irradiating the sample with photons with energies in the radio frequency range; the trick is then to observe how the signal we measure decays over time, and also to observe how the sample relaxes back to its unexcited, equilibrium state. These decay and relaxation times are exquisitely dependent on the molecular environment within each tissue type, and hence we can design experiments wherein we use these inherent tissue properties to determine the magnitude of our signal and ultimately to produce images with a wide variety of contrasts (for example, to enhance white matter signal over grey matter, etc.).

Although the NMR phenomena has been known to physicists and chemists since the 1950's, it was not until the 1970's that the idea to adapt it to imaging was conceived. The core concept enabling us to spatially-localize the measured signal involves the application of additional magnetic fields whose magnitude varies with position &ndash the so-called "magnetic field gradients" – which add to the existing large static magnetic field, effectively rendering the resonant condition dependent on position in 3D space. This allows us to selectively measure a signal from every position within the sample, a process which requires the repetitive application of gradients of varying strength and direction, typically resulting in image acquisition times of many tens of seconds (although sub-second scans are also possible, albeit with lower image quality).

The inherent dependence of the measured signal on the molecular properties of the constituent tissues in the sample enable us to design experiments, so-called imaging pulse sequences, to acquire images with contrast influenced or weighted by factors such as tissue density, the ability of water molecules to diffuse through tissue, the flow of blood through large vessels or its perfusion through tissue, the blood oxygenation level, the local temperature and/or pH levels, and many more physical mechanisms.

This talk with provide an introduction to the world of MRI, explaining some of the underlying physics of the NMR phenomenon, giving a brief overview of the main components in a modern scanner, and describing the basics of image acquisition.