An Introduction to MRI

A Magnetic Resonance Imaging (MRI) System is designed to "see" inside a given object or tissue sample (living or dead), and produce an image that represents, as closely as practical, how the object or sample really looks on the inside. This image can be used then to diagnose physical and chemical abnormalities in the sample – or indeed declare the sample to be free of abnormalities (i.e. normal). MRI techniques are now commonly used for medical diagnoses, materials research, and newer industrial applications (test food quality, test timber quality, rock permeability, etc.). In order to do this, an MRI machine uses a combination of one large stationary magnet, three directional and precisely controlled electro-magnetic coils (gradient coils), an RF pulse generator, RF detector, and the properties of elemental nuclear magnetism.

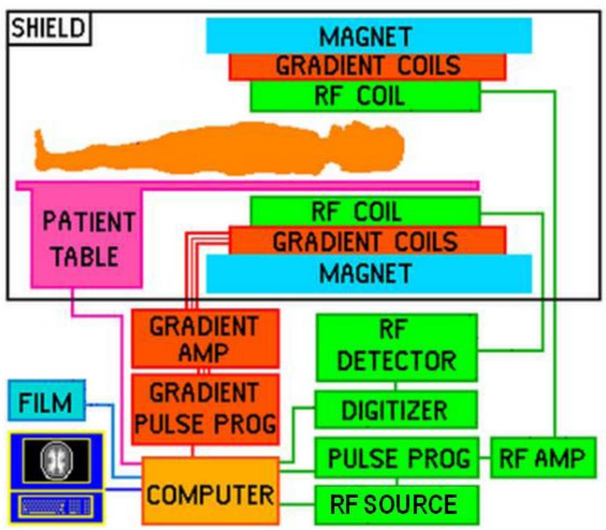
Nuclear Magnetism and Induced Magnetic Resonance

Inside the nucleus of every atom, individual protons and neutrons spin about an axis. This property, called spin angular momentum, is the basis of nuclear magnetism. Since atomic nuclei have charge, this spinning motion produces a magnetic moment along the spin axis. In most nuclei, the particles are paired so that the net magnetic properties cancel within each atom. However, if the number of protons or neutrons is odd, complete cancellation is not possible. Nuclei with an unpaired proton or neutron such as hydrogen-1, carbon-13, and sodium-23, among others, exhibit a net magnetic effect. The relative strength of this magnetic moment is a unique property for each element, and therefore determines its suitability for magnetic resonance (MR) energy absorption and detection. **The hydrogen (^{1}H) nucleus, which is highly abundant in biological systems, has the strongest magnetic moment.** In MRI for human tissue then, the system takes advantage of the specific nuclear magnetic properties of our hydrogen atoms, and how those nuclear magnetic properties interact with large, external, controlled magnetic fields.

Basically, the hydrogen nuclei inside our various body tissues are spinning (in their magnetic moment) all of the time. When inserted into a large external magnetic field (as in the MRI system's main magnetic field), the spin axis of the various atoms line-up in a usable way. As they are spinning in this lined-up manner, a pulse of RF energy from a source pointed perpendicular to the main MRI magnetic field axis, and at a specific frequency (F0), called the Larmor frequency, is targeted at a small area of the body to be imaged. The spinning H atoms, with their magnetic moment, absorb RF energy during the pulse and alter the axis of their magnetic spin (i.e. the atoms resonate or "flip") to the same perpendicular axis as the RF pulse. This could be referred to as a "temporary state of induced magnetic resonance". When the RF pulse is removed, the same atoms that absorbed the RF energy and altered their spin axis, now begin to revert back to their previous state – and in this process, they release a measurable amount of RF energy at the same frequency, F0. It is this small amount of RF energy, and the timing associated with its release, that needs to be detected and analyzed with precision after each and every applied RF pulse.

RF Energy (Transmit/Receive) and Precisely Controlled Magnetic Fields

If you look at this basic MRI system block diagram, you can get an idea of how the various blocks work together to produce a usable image. The huge static magnet, usually providing a magnetic field measuring either 1.5T (Tesla) or 3.0T (Tesla), is shown in blue. It is usually enclosed in liquid helium and the enclosed unit often weighs between 9 and 12 tons. This large superconducting electromagnet provides the strong, stable magnetic field that lines-up the nuclear magnetic spins of the H-atoms inside the body.



An Introduction to MRI (cont.)

The real MRI magic is in the RF sections (lime green) and the magnetic field Gradient sections (red) which work together respectively to: 1. Set-up the magnetic resonance conditions within the “slice” of the sample under test at a given moment; and, 2. Encode those specific resonating atoms with three-dimensional “markers” to pinpoint the location of the tissue being analyzed (in real time). The transmit/receive sequence (roughly stated here) starts with a particular individual RF coil transmitting a measured pulse of RF energy at the specific 1H Larmor frequency (F0). For a 1.5T machine, F0 is 63.864 MHz; For a 3.0T machine, F0 equals 127.728 MHz. At the end of the Transmit Pulse, the 1H atoms are resonating in their new axis. Next the Gradient coils are pulsed to encode the X-Y-Z coordinates into the resonance, so that shortly thereafter, a receive RF Coil can detect the tiny RF signal (frequency and encoding) being released as that particular group of atoms head back toward their previous state. In this way, detailed information is gathered (in an iterative fashion) about the precise chemical make-up of each small area of the tissue being resonated, sample section by sample section.

The entire system is controlled by a sophisticated computer running specialized software (including different programs for each type of scan - full-body, knee, ankle, brain, heart, etc.). The software controls the precise sequencing for each dynamically controlled sub-system (all RF sections, and the X, Y, and Z gradient coils), and collects/analyzes the large amount of received data to product an image. The computer even tunes the RF coils, in real time at the very beginning of each MRI session, by impedance-matching the coils to the sample under test (tuning the RF Coils for maximum Signal-to-Noise Ratio).