

Magnetic Resonance Imaging

What are the uses of MRI?

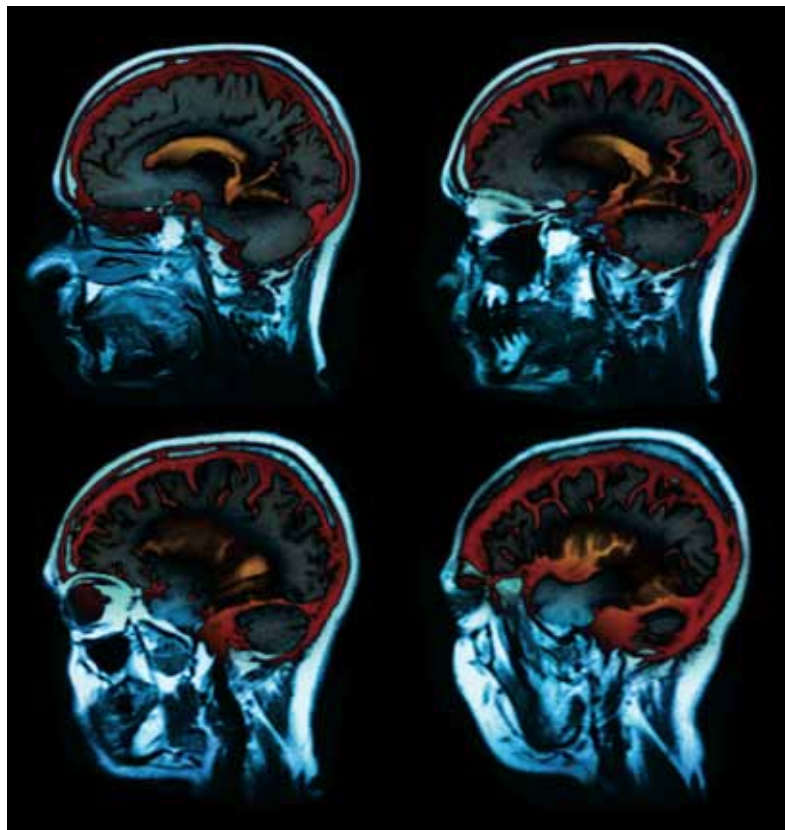
To begin, not only are there a variety of scanning methodologies available, but there are also a variety of MRI methodologies available which provide us in vivo 'pictures' (Latin for in the living), of the human body. Some scanning methods include computed tomography (CT), positron emission tomography (PET), and single-photon emission computed tomography (SPECT), to name a few. In regards to MRI, examples include T1 weighted MRI, T2 weighted MRI, fluid attenuated inversion recovery (FLAIR-MRI), diffusion weighted (DW-MRI), diffusion tensor (DT-MRI), and functional magnetic resonance imaging (fMRI). With such an array of tools, what makes MRI the tool of choice for assessing individuals with acquired brain injury?

One variable to take into account when choosing a scanning method is time of injury. Because of the properties of MRI (specifically the magnetic properties), the use may be contraindicated due to metals contained in the equipment required during the trauma phase of injury (Bigler, 2005). For this reason, CT is the preferred scan used in the acute stage of injury. According to Bigler (2005), "The most important aspect of acute CT imaging is the initial management, monitoring and surgical intervention for any treatable lesion(s)."

In the post acute stages (or chronic stages) of injury, MRI is the preferred scanning method. It is an excellent tool to detect brain anatomy at a level more specific than gross anatomy which is the limit of CT scans. It also can do so in any plane in the body. MRI can detect many pathologies associated with the chronic stages of brain injury including hematoma, edema, atrophy, changes in ventricle volumes, contusion, shear (diffuse axonal injury) and white matter abnormalities (Bigler, 2005). In summary, CT is most useful in the acute stage of brain injury, while MRI is most useful in the post acute or chronic stage of brain injury.

What is Magnetic Resonance Imaging?

Magnetic Resonance Imaging (MRI) is a scanning technology which provides in vivo high resolution images of anatomical structures within the body. The technology originally started out as tomography, which is a two-dimensional image of a slice or section through a three-dimensional object. A Computed Tomography (CT) scan is another form of tomography. CT scans send an x-ray beam through the body to measure tissue densities



and record the different densities along various angles. This data is then applied to a computer program algorithm which makes an image of the slice of the body measured. MRI, on the other hand, utilizes different technology to get not only two dimensional tomograms but three dimensional volumetric images as well.

How Does MRI Work?

The technology behind MRI is deeply rooted in numerous disciplines including: Physics (specifically quantum mechanics), biology, chemistry, computer science, mathematics, statistics and medicine. Methodologies and advancements from each of these fields have come together to provide the tools needed to allow for a non-invasive, relatively risk free method of looking at anatomic structure, pathology and function. The focus of this article is on the basic methodology of obtaining an MRI scan. MRI is an extraordinarily complex procedure that must be broken down into its component parts to better understand it. To do this, we must first start with the most basic elements of all matter – the atom.

The Atom

The hydrogen atom is the key to MRI because of its abundance

MRI *continued*

in the human body and because of its specific atomic properties (NAS). The human body contains approximately 63% hydrogen atoms, due in large part to the fact that hydrogen is a main building block in both water and fat (Hornak). Take for example water, which is made up of 1 oxygen molecule and 2 hydrogen molecules (Figure 1). The hydrogen molecule is comprised of an electron (negative charge) that is bound with a proton (positive charge). The proton is the nucleus of the hydrogen atom (Figure 2).

Spin & Magnetic Moments

All protons have a fundamental property termed ‘Spin.’ Spin can be quantified, and can be thought of as a planet spinning about its axis (Hornak), as in Figure 3. This spinning generates a small magnetic field and creates what is called a ‘Magnetic Moment.’ The magnetic moment can be weak or strong, and has direction much like a magnet has North and South poles (NAS; Figure 4).

When the proton is placed in a strong external magnetic field, as happens when one is placed in an MRI machine, the proton either aligns with or against the magnetic field (Figures 5 and 6).

Because the hydrogen atom has a strong magnetic moment, it has a strong tendency to flip direction when placed in an external magnetic field, causing it to align with or against the magnetic field. Once the hydrogen atoms align themselves, many of them cancel each other out. In other words, one proton aligned with the external magnetic field will cancel out one proton aligned against the magnetic field. Some of these protons are extra in that they do not cancel each other out (Figure 7). These “extra” protons are of high importance to MRI, because of another property of atoms related to spin.

Wobble & Resonance Frequency

When the proton spins about its axis, it also wobbles much like a spinning top. This wobble occurs at a particular frequency, which is specific to the type of atom (NAS). Again, this spin property of the hydrogen atom is taken advantage of for use in MRI. While in the external magnetic field, a radio frequency is pulsed through the magnetic field via a coil at an appropriate frequency (in this case the frequency specific to the hydrogen atom). The ‘extra’ protons that did not cancel each other out are then induced to flip direction or spin in a different direction. When the frequency of the pulsed radio beam matches the frequency of the hydrogen atom, which induces the protons to

Figure 1 – Water Molecule

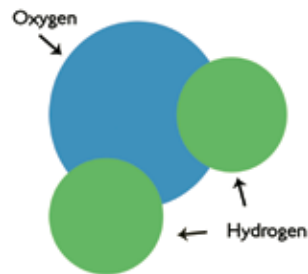


Figure 2 – Hydrogen Atom

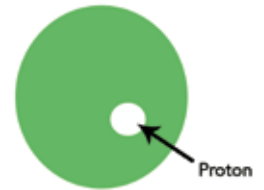


Figure 3 – Proton Spin

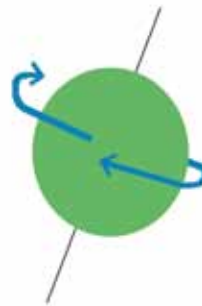


Figure 4 – Proton

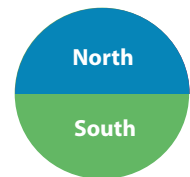


Figure 5



Figure 6

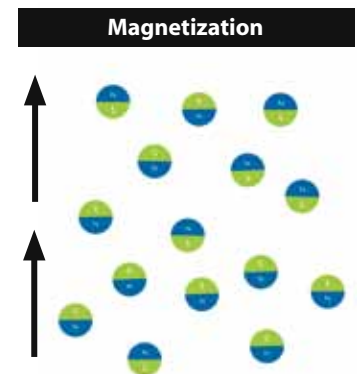
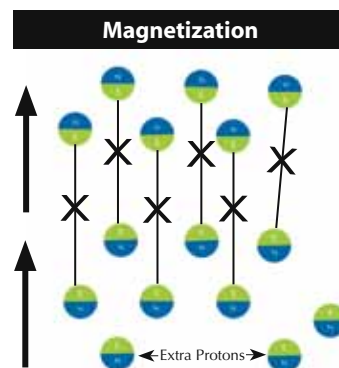


Figure 7



MRI *continued*

flip, this is called the ‘Resonance Frequency’ (Gould). The reason that the proton flips is due to the absorption of energy from the beam and is the next important element in MRI.

Relaxation Times and Signal

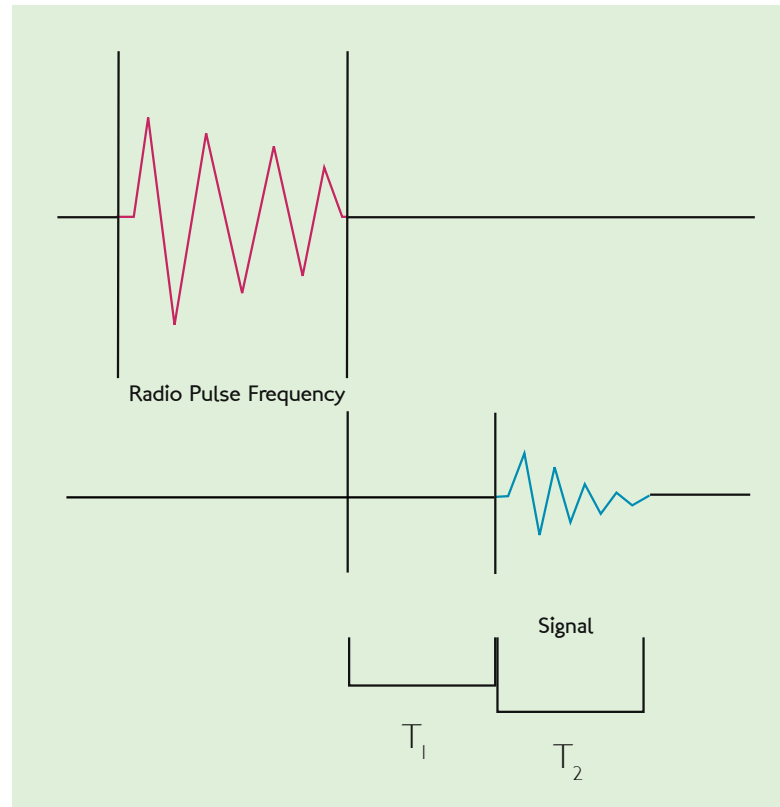
When the pulse of the radio frequency is stopped, the concept of ‘Relaxation Time’ becomes important. The cessation of the pulse allows the proton to return to its previous “un-flipped” state. When it does so, it releases the energy it had absorbed, and this release of energy is a signal that can be recorded. The time it takes for the pulse to stop to the proton returning to its former state (and thus emitting the signal) is the relaxation time. Precisely when or how the signal is recorded is of great importance. One measure of relaxation time is T_1 . This measure records the time from the cessation of the pulsed radio beam to the signal being emitted. This is called the ‘spin lattice relaxation time.’ Another measure of relaxation time is T_2 . This measures the length of the signal once the proton has un-flipped and released the signal. This is called the ‘spin-spin relaxation time.’ Figure 8 illustrates these times.

Lets take a moment and recap what we know so far.

1. Within our bodies, we have numerous hydrogen atoms. We know that they have a proton that spins and wobbles.
2. This spin and wobble creates a small magnetic field.
3. These hydrogen protons have a specific magnetic moment with direction and magnitude.
4. When the protons are placed in a strong external magnetic field, their magnetic moment property induces them to align with or against the magnetic field.
5. Most of these protons then cancel each other out, but some do not, leaving extra protons.
6. When a specific pulsed radio frequency is introduced through the external magnetic field which matches the ‘wobble’ frequency of the hydrogen proton (called the resonance frequency), the extra protons flip direction.
7. When the pulsed frequency is stopped and the protons return to their original state, they emit a signal which can then be measured via various methods.

The preceding is a basic rendering of how signals from living tissue can be captured. In reality, the processes and technologies that are used to capture that signal are far more complex. For example, varying pulses (by using short pulses versus continuous pulses) allowed for better information from the signal (NSA).

Figure 8 – T1 and T2 Relaxation Times



Gradient Magnets & Signal Collection

Now we are at a point where we are able to measure signals. But how does that translate to an image of the body? To understand this, we must begin to understand the components of the MRI machine itself. Within an MRI machine, there is the Main Magnet, which creates a large, stable magnetic field. In addition, there are 3 other magnets called Gradient Magnets. These magnets allow for scanning a slice at any angle, without requiring the person being scanned to move. But how do they work?

The gradient magnets work in conjunction with the coils that send out the pulsed radio frequencies, allowing for precise measurement of any area within the field of view inside the scanner. The coils send out the radio frequency pulses while the gradient magnets turn on and off to change the magnetization of the hydrogen atoms at precise locations within the subject being scanned. There is one gradient magnet to vary the magnet field from top to bottom, one gradient magnet to vary the field from side to side, and a third to vary the magnetic field up and down.

MRI *continued*

Figure 9 illustrates a basic MRI schematic. To make MRI practical to use, the speed of collecting signals needs to be quite short, since it requires that the patient remain very still throughout the process. One way to speed up the process of collecting the signals is to send out multiple signals simultaneously (without affecting other signals) and recording the multiple signals that are emitted. The resulting signals are measured as are the combination of the 3 spatial coordinates of the signal from the gradient magnets. This allows for a “map” of the signals to be created.

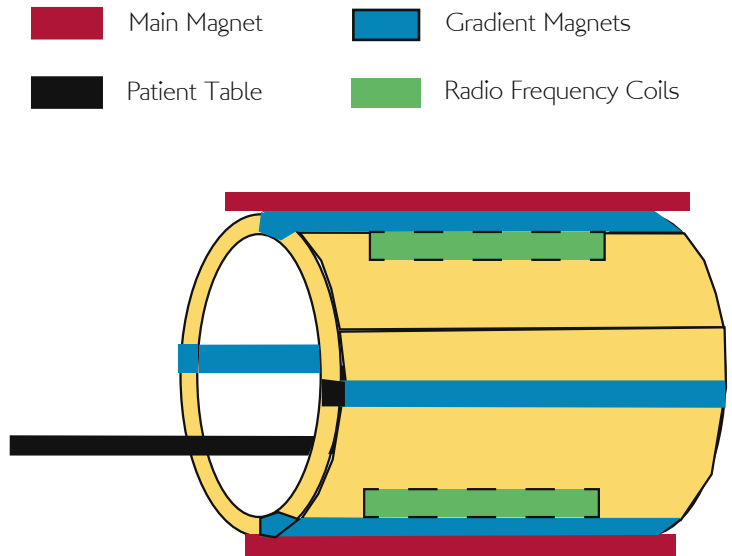
Image Output

The process of going from signals to an image involves the use of what is called the Fourier Transformation. This takes the raw signal data and transforms it creating the map of the signals. Early on, the use of the Fourier Transformation was only limited by the ability of computers to process the information quickly. When computer technology was able to process Fourier Transformations rapidly, the utility of MRI was realized. Given that the first MRI scan of a human body in 1977 took nearly 5 hours, it is evident that speed of capture would determine its practical utility (Tesla Society).

Once the transformation is made, we are left with an image in the form of a slice that tells the reader what types of tissue were scanned. We know this, by and large, due to the known properties of hydrogen. For example the signal from healthy white matter (WM) will differ from unhealthy WM, because we know the difference in hydrogen properties from these tissues. Gray Matter (GM) will differ from WM, and will differ from cerebral spinal fluid (CSF), and so on. Determining what type of scan sequence to utilize will depend on what outcome is desired. For example a T_1 weighted sequence will show anatomy best, whereas a T_2 weighted sequence will show pathology best.

The key to differentiating one tissue type from another is contrast. While the image from an MRI is not a photograph, the analogy of a black and white picture will help to explain contrast in MRI. When you see a black and white photo that has lots of gray tones but very little black and white tones, it tends to be dull and lifeless. When you see a black and white photo with good tonal range from dark blacks to white whites, it stands out due to the contrast between the tones. For an MRI image, it is the range of tones that help distinguish the different tissue types. For normal tissue, a T_1 weighted scan will result in GM that is gray, WM that is white, and dense bone and water that is dark (Johnson). For a T_2 weighted scan, fat and water will appear bright, dense bone and

Figure 9 – Basic MRI Schematic



How is an MRI scanner rated?

MRI scanners “main magnets” are rated in Tesla. A rating of 1 Tesla equals 10,000 Gauss or 20,000 times the earth’s magnetic field. The stronger the main magnet the more stable the magnetic field, the better the MRI image. The following table shows current Tesla ratings.

| | |
|-------------------------|----------------------|
| Low Field | .2T and under |
| Mid Field | .2T to .6T |
| High Field | 1T to 2T |
| Ultra High Field | 3T and higher |

For clinical use, the current approved MRI rating is 3 Tesla. There are however, MRI’s ranging from 4T to 35T+ used for imaging research.

MRI *continued*

air will appear dark (Johnson). For abnormal tissue, a T_1 weighted scan will reveal blood as bright and a tumor as dark (Johnson). A T_2 weighted scan will show an infarct, blood, tumor or MS plaque as very bright (Johnson). To differentiate WM and GM from CSF, a T_1 weighted scan would be called for, and to determine if there is abnormal tissue, a T_2 weighted scan would be appropriate.

The range of advanced techniques for MRI scans is absolutely dizzying. There are new techniques being created that find yet another use for this technology. While this article served to highlight the most basic components of MRI, it does not delve into the true complexity of the technology involved. For an excellent, thorough and technical review by J.P. Hornak, go to: www.cis.rit.edu/htbooks/mri/index.

The true potential of MRI at this point may not be fully realized, but its current utility is evident. MRI can detect abnormalities in the form of lesions, infarcts, dead tissues, changes in white matter, gray matter or cerebral spinal fluid volume changes. The use of MRI to further understand acquired brain injury is clearly evident, and one can expect continued use of MRI to help us understand how the brain responds to injury. Look to this space for continued illumination of this technology and others that can so greatly impact our knowledge of ABI and its long-term consequences. ❖

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