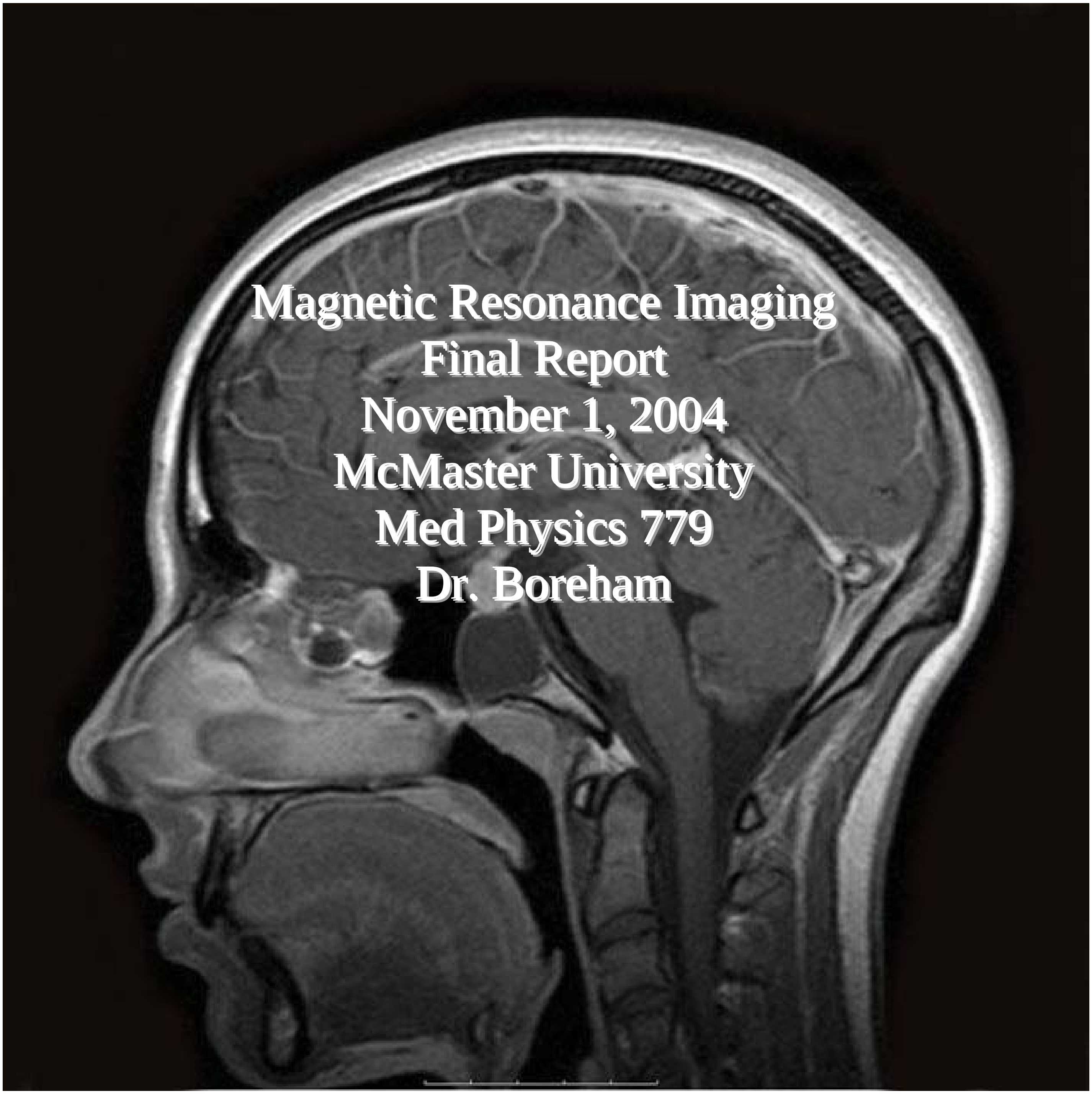

# Magnetic Resonance Imaging
# Final Report

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## Introduction

Magnetic Resonance Imaging (MRI) is a non-invasive diagnostic technique capable of providing detailed images of the human body with exceptional soft tissue contrast. For the purpose of introducing the reader to the science of MRI, this report will review the history, physics, hardware and software, the medical procedure, and several of the applications. Biological hazards associated with this modality and its advantages and disadvantages will also be discussed. The report will conclude with a brief discussion of the future of MRI.

## History

Felix Bloch and Edward Purcell discovered the magnetic resonance phenomenon in 1946. The true pioneers of MRI however, were Ronald Damadian, Paul Lauterbur and Peter Mansfield. In the early 1970's, Damadian developed the technique to characterize/ extract physiological information from human tissue (i.e., to differentiate healthy tissue from malignant tissue). In 1973, Lauterbur developed a back projection method to produce an image of two test tubes of water. This was the first time that MR recorded position information. The technique allowed MRI to enter the three-dimensional world, using tri-plane gradients to excite selected areas of the body. Independently from Lauterbur, Mansfield also developed images using tri-plane gradients to excite selected areas of the body. Mansfield also went on to develop an echo planar imaging (EPI) technique that was capable of producing tomographic images at video rates. In 1987, Mansfield used his EPI technique to perform real-time imaging of a single cardiac cycle. For their work in developing a process to determine the location of malignant tissue in a sample, Lauterbur and Mansfield received the Nobel Prize in Medicine in 2003.

## Physics

When a magnetized bar is subjected to an external magnetic field, the bar will move in order to have its north pole align with the south magnetic field and vice versa. A compass needle operates the same way by aligning itself with the earth's magnetic field. If the compass however, were to be subjected to another, stronger energy source (such as an electromagnetic field), then the poles of the needle would align with the stronger source. MRI works on the same principle. That is, molecules in the human body will change their orientation (align with the stronger energy source) if an external magnetic field and radiofrequency pulse are applied at sufficient strength and frequency.

A hydrogen nucleus, having only a single proton, behaves much like a tiny bar magnet. Although no charges are actually spinning in the nucleus, the magnetism of the nucleus is called spin[1]. The significance of this magnetism is that it allows the protons to align its spins (i.e. poles) with the applied magnetic field, the same way the needle of a compass aligns itself with the North Pole (ref figure 1). As alluded to above, it is possible to energize hydrogen protons by subjecting them to a radiofrequency pulse and thereby alter their spin. The radiofrequency pulse is a photon of energy. If the energy contained within the photon exactly matches the energy required to alter the spin, the proton will absorb the photon and change its orientation. When the pulse is removed, the energized hydrogen proton will revert back to the initial spin and release an amount of energy equivalent to that applied by the radiofrequency pulse. The MRI machine detects the released energy from the hydrogen proton via a transmission coil and translates the signal into an image on the monitor.

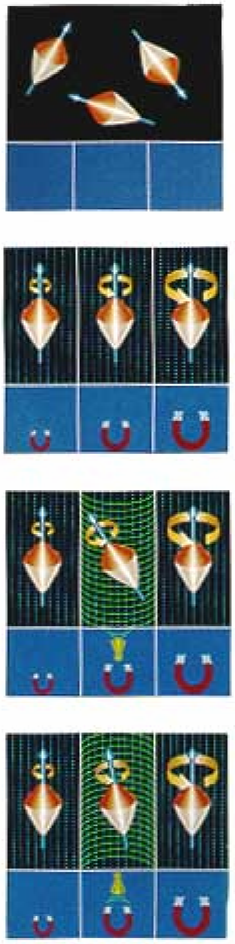
**Selection of Detection Element:** In theory, many elements could be imaged by MR. Any nucleus with an odd number of either protons or neutrons could produce an MR signal[1]. However, MR is primarily applied to the imaging of hydrogen, for two reasons: 1) the machine is highly efficient at detecting the hydrogen MR signal; and 2) there is a high natural abundance of hydrogen in the human body. To understand why hydrogen produces such an efficient MR signal one must first understand the relationship between the transition in nuclear spin states and the applied magnetic field. Specifically,

$$\Delta E = h\gamma B$$

where:

$\Delta E$ = energy required to transition between nuclear spin states
h = Planck's constant (relates energy to frequency)
$\gamma$ = gyromagnetic ratio (ratio of magnetic moment to total angular momentum)
B = applied magnetic field in Tesla (T)

Through experimentation, Hydrogen ($^1$H) has been determined to have the highest gyromagnetic ratio ($\gamma$) of any element, and therefore will produce the largest $\Delta E$ for a given magnetic field (B)[2]. Note that, a larger observed $\Delta E$ will result in more efficient detection of the element. There are other elements, which have gyromagnetic ratios similar to that of hydrogen, which mean that they too could be detected with the same efficiency. However, the relative abundance of these other elements, particularly in the human body, has limited their effectiveness in producing quality MR images.



1. Hydrogen protons, positively charged particles in the hydrogen molecule's nucleus, normally spin in random directions

2. Protons wobble in alignment with magnetic fields of varying intensity; frequency of wobble is proportionate to strength of individual magnetic field

3. A brief radio signal, whose soundwave frequency equals the frequency of wobble of certain protons, knocks those protons out of alignment

4. When radio signal ceases, protons snap back into alignment with magnetic field, emitting a radio signal of their own, that announces the presence of a specific tissue

Figure 1: Hydrogen atom alignment when subjected to an external magnetic field
*(Source: http://www.ee.duke.edu/~jshorey/MRIHomepage/work.html)*

**The Radiofrequency Pulse:** To understand how a signal is detected, one must now look at the role that the radiofrequency (RF) pulse plays. When the magnetic field is applied around the subject, there will be a net excess of nuclei aligned in a specific state or spin[2]. This net excess has been termed net magnetization (M) and by convention has been assigned a vector on the z-axis (or longitudinal axis; $M_z$). The plane perpendicular to the longitudinal axis is the x-y or transverse plane. Elements can only be detected when their magnetization is in the transverse plane as this magnetization is time dependent and, according to Faraday's law of induction; can induce a voltage on a receiver coil[1]. As discussed previously, the RF pulse consists of packets of energy (i.e. photons) and if the photon energy precisely matches $\Delta E$, then, and only then, will the proton absorb the photon and alter its spin[3]. Figure 2 represents the path taken by the magnetic field as the photon is absorbed. The net effect of absorbing the photon is that $M_z$ transitions to $M_{x-y}$. The energy associated with a photon is a direct reflection of its frequency and is known as the Larmor or resonance frequency.

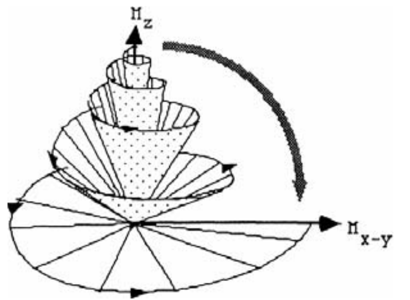


Figure 2: Magnetic field path[2]

When the Larmor frequency is applied to the subject, the magnetization of the proton rotates (processes) to be in line with the transverse plane. This alignment is not instantaneous and in the human body it can take between 0.1 to 10 seconds of RF application to obtain proton alignment. In fact, most MR techniques tip the magnetization repeatedly by using successive RF excitation pulses. Repeated tipping is usually necessary to accumulate all of the desired data for an MR image[1]. This alignment time is known as T1 and also describes the time required for the spins to regain equilibrium after the RF has excited them. When the excitation phase is complete, there is no longer any longitudinal magnetization (i.e. no $M_z$); it has all been tipped into the transverse plane. With the Larmor frequency no longer applied to the subject, the signal will start to dephase as protons start to re-orient themselves back to their initial state or spin[2]. The re-orientation will not occur at the same rate for all protons, as there are interactions with neighbouring protons or nuclei that may increase or decrease the relative speed at which they recover. This time is commonly referred to as T2 and is always smaller than T1. The relaxation (T1) and dephasing (T2) times are different for various tissues within the human body. This fact helps when trying to decipher the tissue signal (i.e. contrast) of an MRI. Depending on the nature of the image taken, the tissues will show up with varying grades of contrast (i.e. white to black). By altering between the modes of imaging a much clearer picture of the tissue can be achieved.

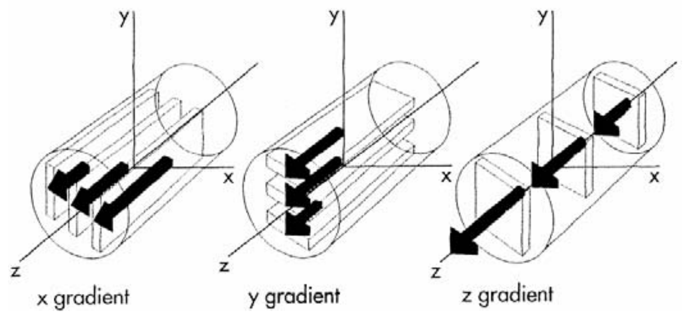


Figure 3: MR Magnetic field gradients[1]

**Imaging Gradients:** An MR image is obtained by taking multiple “slices” of the patient. These “slices” are generated by gradient magnetic fields that are activated along a particular direction (i.e. x, y or z axis as detailed in Figure 3). It is possible to generate oblique slices by energizing two gradients during an RF pulse. Slice selection combines the magnetic field gradient with a specially shaped RF pulse to restrict MR signals to a slice instead of the entire region under the influence by the transmitter coil[1]. Slices are located where the frequency of the RF pulse matches the Larmor frequency. The thickness of the slice is a direct result of the shape and duration of the RF pulse. The most widely sited RF pulse shape is the sinc function[1] (refer to Figure 4 (A)). The sinc-shaped pulse excites an approximate rectangular distribution of nuclei, which is the ideal shape for MR slices. In order to decrease the thickness of each slice, the pulse can be altered by changing the length (Figure 4 (B)) or the number of lobes (Figure 4(C)). Thinner slices can be produced by either increasing the length of the pulse (with the number of lobes kept constant) or by having a pulse of lesser lobes (with the length being the same). Both options have their respective drawbacks and selection of the proper technique will depend on the imaging type being used (i.e. T1 or T2 weighting).

To convert the information received by the transmission coil from the frequency domain to the time domain, an inverse Fourier Transform is used. The Fourier transformation evaluates the match between a curve and sinusoidal waves of a particular frequency[1]. It uses the wave pattern to generate a sequence of spikes, which is in turn encoded into a picture of the tissue being scanned.

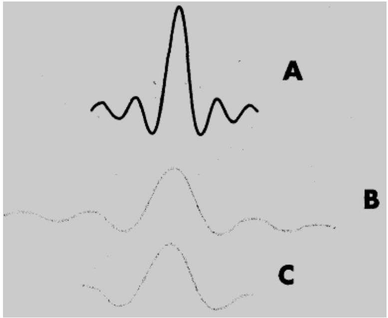


Figure 4: Sinc-shaped RF pulses[1]

## Software and Hardware

The modern MRI machine contains a substantial number of hardware and software components, which make it one of the most expensive imaging technologies available today. The MRI scanner is typically the size of a minivan and weighs over four tons. The major hardware components are the large magnets, the gradient coils, and the radiofrequency coils. The software is responsible for controlling all of the hardware as well as processing the received signals to produce the desired images. In the sections that follow, each major component shall be described in detail. Refer to Figure 5 for a general block diagram of the major systems.

**Magnet:** To align the Hydrogen protons in the body along the longitudinal axis, a high-strength homogeneous magnetic field is required. There are three main magnet options available to the MRI manufacturer, they are: permanent magnets, resistive magnets and superconducting magnets.

A **permanent magnet** can be installed which requires no energy to operate. One disadvantage of a permanent magnet is that it must be very large to generate the fields required for accurate imaging. It is important to note that as the homogeneous field strength decreases, so too does the "crispness" of the resulting image[4]. Another disadvantage is that it is also not possible to change the field strength of the permanent magnet or ever "turn it off". This is a drawback since varying the homogeneous field allows for differing contrasts. In short, due to the very large size required for a permanent magnet to be of the right strength and due to the inability to modulate field strength, permanent magnets are not commonly employed.

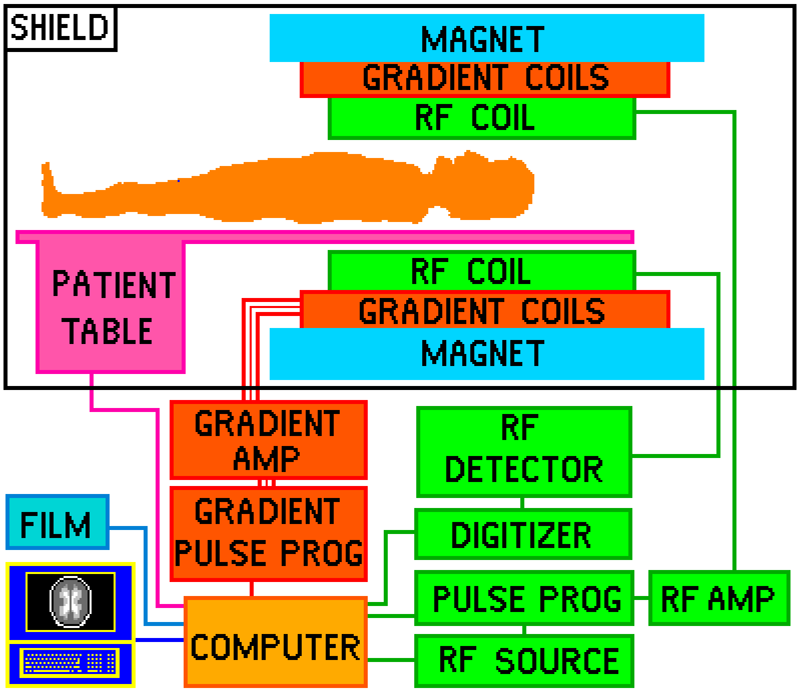


Figure 5: Block Diagram of the major components

*(Source: http://www.cis.rit.edu/htbooks/mri/)*

A **resistive magnet** is essentially a large coil wrapped around a cylinder through which a current is applied. The current in the coil generates a magnetic field proportional to the current supplied to the coil and the resistance of the coil. Although the initial cost of resistive magnets are low, the negative factor is high operating costs. Due to the high power requirements needed to generate the desired field strength and the associated costs for that power, resistive magnets are not a cost efficient solution and not commonly employed.

**Superconducting magnets** are the most popular MRI magnets. The basic hardware is similar to resistive magnets as the conductor is again a metal coil wrapped around a cylinder. In this instance however, the coils are completely immersed in liquid helium or nitrogen to almost absolute zero (~3 Kelvin). At such extremely low temperatures, the resistance of the coils is negligible. This translates into the ability to generate very high fields with little power. Although the hardware cost is high, the operating electrical costs are low. Superconducting magnets can also be designed to provide field strengths as high as 3 Tesla[3]. By comparison, the Earth's magnetic field strength is 0.06 milli-Tesla.

**Gradient Coils:** The purpose of gradient coils are to facilitate the localization of image slices as well as, frequency and phase encoding for 3D volume localization[3,4]. These secondary sets of magnets have low field strengths in the range of 10-30 milli-Tesla. To produce "gradients" (e.g. alterations) of the homogeneous field, three sets of gradient coils are used to produce gradients in the x, y and z directions.

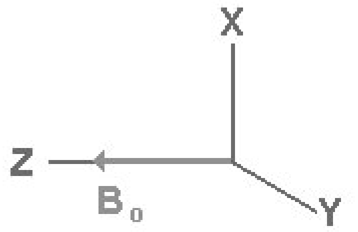


Figure 6: $B_o$ direction along longitudinal axis[3]

The gradient coils for the z-direction can either boost or decrease the homogeneous field strength in the $B_o$ direction (see Figure 6). Correspondingly, the x and y gradient coils alter the field in the x and y-axis.

**Radiofrequency Coils:** The Radiofrequency (RF) coils are typically used to transmit pulses to excite protons from the z axis to the x-y plane but can also invert protons 180 degrees. The greater the RF strength applied to protons, the greater the rotation from the longitudinal (z) axis. When the RF signals are no longer being transmitted, the spinning protons will relax back to their original orientation before the RF pulse. The RF coils are also used to capture the energy released during the recovery to equilbrium[3].

RF coils used in MRI machines can be used to send and receive, send only or receive only. Many different combinations are used in MRI machines for accurately imaging different portions of the body. Imaging coils can be added around the head or torso of a person to improve detection and can even be inserted into a blood vessel using a catheter.

**Computer - Hardware and Software:** An MRI operator uses software applications to: control the RF and gradient coils, acquire data and generate images. When the scan parameters are defined on the computer, signals are sent to amplifiers that control the RF coils and to gradient amplifiers that control the gradient coils to excite and localize the desired slice or volume.

Following each RF transmission phase, a reception phase acquires the signals and converts the analog signals into a digitized map, sampled in the frequency domain. The map is called a k-space. In the k-space, each point contains data from all portions of an image[4]. To obtain an image in physical space, a Fourier Transform is performed by the computer (or an external signal processor), which renders a 2D map of amplitudes and phases for each frequency. When a high intensity (white) point appears on an image, it is because the RF coils detected a longer relaxation (T1) period. The important point to remember is that longer relaxation times result in greater signal intensity, and the signal intensities are the frequency and phase amplitudes obtained from the Fourier Transforms.

**Two-dimensional Multi-section Acquisitions:** To obtain multiple slices along the same plane, the process described above is repeated at set time intervals. The repetition time (TR) is the time required for performing the sequence of: issuing RF pulses, issuing gradient field signals, acquiring data, and processing the results[5]. Certain imaging techniques require short TRs while some require long TR periods, typically a longer TR will result in improved contrast when imaging tissue with long relaxation times. In practice – and to save time – as soon as one planar (2D) section is excited, another section is excited, hence the name 2D Multi-section Acquisitions. The space between adjacent slices must be large enough to avoid gathering relaxation data from the previous and currently excited sections. This is also referred to as crosstalk. The solution is to interleave slice images, which is the scanning of the odd slices (1,3,5…) followed by the even slices (2,4,6…)[4].

**Three-dimensional Multi-section Acquisitions:** It is also possible to generate three-dimensional images by exciting an entire volume instead of single slices[6]. In 3D, the k-space matrix is defined from Phase versus Frequency versus partitions (the thickness of the image sections) data[4].

**Software Packages:** MRI vendors such as Siemens, GE Medical and Philips Medical are the primary developers of MRI software packages. The software performs the functions describe in the previous sections such as RF and gradient coil excitation, data acquisition and data processing/imaging.

The software packages are also used as data historians, image analyzers and also as merging tools. Data historians are essentially databases where previous images are stored for future use. Image analyzers help the clinician view the acquired images and apply filters to highlight certain tissues. Merging tools allow the clinician to overlay images from various sources such as CT (Computer Aided Tomography) or PET (Positron Emission Tomography) scans with the corresponding MRI image[6]. Figure 7 displays an image overlay of a CT scan (grey-scale) and an MRI scan (tinted orange). On the right pane is the CT scan with a lesion that is not very noticeable. Lesions and tumours however have long relaxation times, which appear very clearly on an MRI[4]. The left pane of Figure 7 shows the image overlay clearly displaying the lesion. The resulting image can be used as input for radiological therapy.

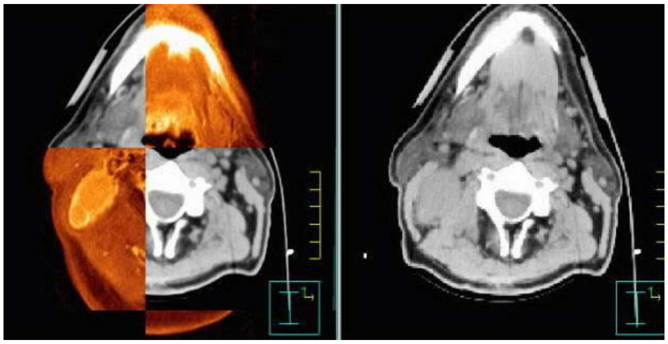


Figure 7: Image overlay of CT and MRI image

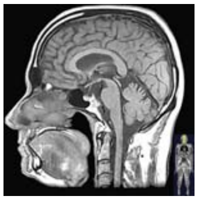
*(Source: http://www.rmg.md/Articles/Cancers of the head and neck.htm)*

## Clinical Procedure

The MRI procedure can be characterised as a five (5) stage process. First, the correct RF coil must be selected in order to produce the best possible image. The correct coil is one that both optimizes the signal-to-noise ratio and is proportional to size of body part being scanned. Second, the patient must be screened to ensure that they have: a) no loose metallic items on their person, or imbedded in their body; b) no medical implants or surgical clips; and c) that they are not pregnant. The patient is screened both for the safety of the patient and staff and for insurance reasons. Third, the patient is placed on the table and the table positioned into the magnet. Once inside the magnet, the MRI room must be isolated to minimize the potential for outside "noise"/ magnetic interference. Fourth, a pilot image must be then taken to ensure the patient is properly aligned and the correct area targeted. Finally, multiple scans or slices of the target area are performed. Each scanning sequence lasts approximately three (3) to six (6) minutes, but the patient will typically have to remain in the scanner for between fifteen (15) to thirty (30) minutes to ensure the examiners have sufficient data to make an accurate diagnosis.

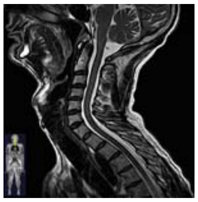
## Applications

The applications for this diagnostic modality are extensive. MRI is used to evaluate anatomy, pathology, and metabolism. MRI is used for diagnostic imaging of the brain, head and neck, spine, musculoskeletal system, cardiovascular system, chest, abdomen, and the reproductive organs. The section that follows will provide the reader with a sampling of a few of the many applications.



### Brain

MRI plays an important role in diagnosing brain tumours and infections, epileptic imaging, and in monitoring the efficacy of multiple sclerosis therapies[7].



### Head and Neck

MRI can be used to determine the extent and location of trauma (i.e., both hemorrhagic and non-hemorrhagic injury). MRI has proved valuable in detecting moderately acute contusions and chronic haematomas that are difficult to see using CT techniques[8]. MRI is also able to image the blood vessels of the head and neck via a technique known as MR angiography.

### Spine

MRI has revolutionized the imaging and diagnosis of spine disease. MRI is the preferred imaging technique for spinal cord and column tumours, for recurrent herniated discs, for determining congenital abnormalities and for assessing spinal cord compression[9].

### Cardiovascular System

Since MRI is capable of functional imaging, the technique can be used to supplement other diagnostic imaging modalities for congenital abnormalities of the heart and great vessels. Functional imaging is a form of MRI that registers blood flow to functioning tissues.

### Musculoskeletal System

MRI is valuable in the evaluation of tendons and ligaments in sports-related injuries. Alterations in size, shape, continuity, and signal intensity of these structures can be well visualized with MRI[4]. Tendonitis, tendinosis (degeneration of tendon), partial tendon and ligament tears as well as complete tears are all readily detected by MRI[10]. The high degree of soft tissue contrast and the multiplanar capability of MRI, allows direct visualization as well as characterization of traumatic muscle lesions[11].

*(Image source: http://www.mialodestone.co.uk/mri.htm)*

## Biological Effects & Hazards

The following section is intended to provide a summary of the potential biological effects and hazards associated with the MRI process. Specifically, the biological effects and hazards associated with exposure to: static magnetic fields, gradient magnetic fields, and radiofrequency electromagnetic fields. It is worthwhile to emphasise that MRI utilizes non-ionizing, electromagnetic radiation to acquire patient information. At no time is the patient exposed to ionizing radiation such as with gamma-ray based technologies.

**Static Magnetic Fields:** The potential biological effects associated with static magnetic fields are categorised in terms of short term and long term exposures.

At the cellular level, the theoretical biological effects of short term exposure include: the potential to alter cell growth and morphology, cell reproduction, DNA structure and gene expression. At a system level, nerve activity, cognitive function or behaviour, cardiovascular dynamics, temperature regulation and immune responsiveness can be affected. To date however, no harmful biological effects have been conclusively identified [1,12].

Long term exposure to static magnetic fields can theoretically effect pathological change, but again no harmful biological effects have been conclusively identified [1,12].

**Gradient Magnetic Fields:** Gradient magnetic fields may stimulate nerves or muscles by inducing electric fields and currents in the tissue. The induced current is dependent on a variety of factors but is essentially proportional to the conductivity of the tissue and the rate of change of the magnetic flux density. The biological effect of the induced currents can range from peripheral nerve stimulation (i.e., a tingling sensation) to, in extreme cases, ventricular fibrillation (i.e., rapid, irregular twitching of the ventricles of the heart). However, since the gradient magnetic field associated with causing ventricular fibrillation is an order of magnitude greater than most MRI systems are capable of producing, the risk associated with gradient fields can be neglected [12].

**Radiofrequency Electromagnetic Fields:** Radiofrequency electromagnetic fields are capable of generating heat in tissue, but data suggests that excessive temperature elevations or loss of thermo-regulatory function is not a serious concern [12] at the fields necessary to obtain an accurate image.

**Hazards (Other):** Additional negative health effects can be associated with MRI. The electromagnetic fields produced can interfere with the operation of implants such as pacemakers or neurostimulators causing them to malfunction. The fields may cause aneurysm clips to move or tear the artery they were meant to repair. Patients with metal based pigment tattoos may experience exposure burns and patients with metallic fragments in their eye are at risk of eye damage or blindness.

## Advantages

There are many advantages to Magnetic Resonance Imaging:

1) The diagnostic technique is non-invasive.
2) MRI acquires patient information without the use of ionizing radiation.
3) No significant side effects have been observed at the magnetic field strengths necessary to obtain quality diagnostic images.
4) MRI produces excellent soft tissue contrasts when compared to the x-ray based techniques. The x-ray diagnostic techniques do not serve this function well because x-rays discriminate between tissues by electron density, which does not vary greatly between soft tissues.
5) MRI has the ability to acquire images in numerous planes (figure 8) without repositioning the patient. MRI can acquire images in the transverse (axial), sagittal, coronal, or orthogonal planes (not shown).
6) MRI is unobstructed by bone. This makes this modality especially useful in imaging the brain and spinal cord.

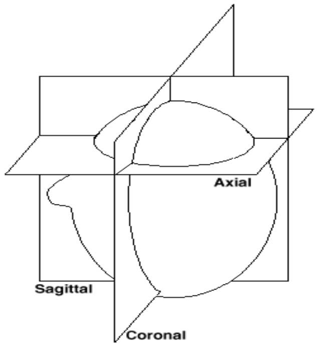


Figure 8: MRI plane orientation
*(Source: http://electronics.howstuffworks.com/mri9.htm)*

## Disadvantages

The disadvantages of MRI can be summarised as follows:

1) MRI scan times are relatively long and require the patient to remain still for periods that range anywhere from fifteen (15) to thirty (30) minutes. Movement of the body part being scanned can cause artefacts or the image to be distorted.
2) Patients with implanted devices such as pacemakers or aneurysm clips cannot be scanned.
3) Patients with orthopaedic implants (e.g., screws, plates, artificial joints, etc.) can be scanned, since the implants are usually firmly attached to the bone, but if the implant is in the area being scanned it can alter the magnetic field and cause the image to be distorted.
4) MRI systems are very expensive relative to CT scanners and therefore exams/ procedures are also very costly. On the positive side however, MRI scans are covered by OHIP

## The Future of MRI Technology

MRI is a relatively new technology that is progressing in many different directions. Significant research is being done in the following areas: functional MRI, clinical spectroscopy, imaging of elements other than Hydrogen, multi-channel imaging, fetal imaging, and imaging on the cellular level.

**Functional MRI:** Functional MRI (fMRI) can be used to determine which parts of an organ are functioning. Oxygen rich areas of the brain are an indication that the section is in use, deoxygenated areas indicate the non-functioning areas. Deoxyhemoglobin (cells devoid of oxygen) in the brain have a small magnetic field which can be used to differentiate between the functioning and non-functioning areas. The clinical use would be to scan the patient both prior to surgery and following the removal of the malignant growth. The post operative scan would reveal if any of the functioning areas were damaged by the surgery or if a particular function moved from one area of the brain to another.

**Clinical Spectroscopy:** Clinical spectroscopy is one research area that is in its infancy but the future appears limitless especially for: a) the diagnoses of mental illnesses such as depression (which currently is very subjective); and b) the determination of the efficacy of cancer treatments. The technique screens and maps the chemical composition of specific tissue samples as a series of peaks. Using the knowledge that the peaks are proportional to the amount of chemical in that tissue, one could diagnose disorders by comparing the sample tissue with a database of known "healthy" tissue. The presence or absence of certain chemicals could lead to a much more scientific diagnosis of psychological disorders. However, since the chemical composition within a tissue will change with age and other variables/ environmental factors, research is underway to determine how some of these variables can be base-lined to help diagnose brain deficiencies. This technique could also be used to determine if a specific treatment of chemotherapy was effective. A pre-treatment image could be taken, followed by an image a few days into the treatment and finally an image at the conclusion of the treatment. Based on the findings, the physician could alter the course of treatment to improve the patient's chances of survival.

**Imaging of Carbon, Fluorine and Sodium:** Current clinical MRIs only look at water content or Hydrogen but research is underway to image, sodium, carbon, and fluorine. This area is still in the development stages since each element would need its own coils and its own sequences to account for the different spins. The practical uses of imaging different elements could help diagnose brain damage or various types of mental illness. In London, Ontario, research is already ongoing to image Sodium in the brain.

**Multi-Channel Imaging:** Multi-Channel Imaging is a technique used to detect multiple elements, such as Hydrogen and Phosphorus. Hydrogen is a measure of the water content. Phosphorus is a measure of the energy level. Scanning for both variables simultaneously will significantly improve the efficiency and accuracy of the MR images. Today, the patient is scanned for Hydrogen, removed from the magnet, and then scanned for Phosphorus using a different coil. With multi-channel scans both images can be acquired at the same time with the patient in the same position.

**Fetal Imaging:** Fetal imaging is presently only performed when there is a significant concern for the patients health or the health of the developing fetus. Fetal imaging requires a slow moving gradient field. A rapid moving gradient field can cause nerve stimulation, which has an unknown effect on the fetus. Therefore, efforts are underway to develop faster imaging techniques with slow gradients.

**Imaging on the Cellular Level:** A clinical image's three dimensional (3D) voxel is a space that is 3mm by 0.9mm by 0.9mm and is an average of the cellular information at that location. This area contains thousands of cells and if the problem were at a cellular level it could be completely missed by the clinician. Improvements to the MRI acquisition techniques, coils, and magnets will allow images to be produced at a cellular level and allow the clinician to view many cellular abnormalities.

The aforementioned topics are just a few of the areas of research in MRI. Constant improvements to coils and high field magnets; improvements in data acquisition; and the filling of k-space using spiral techniques are other areas not formally discussed. Patient comfort is also not being over looked by research facilities. Open system MRI machines exist and are being improved upon to treat patients who are claustrophobic. Work is also being done to eliminate the sounds produced by the gradient coils.

## Conclusion

As Magnetic Resonance Imaging develops and its availability increases, its applications will grow and eventually replace many of the conventional diagnostics methods used today. MRI is a new technology, with seemingly limitless potential. One should expect great things from MRI in the future.

## Acknowledgements

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