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# Magnetic Resonance Imaging

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**Magnetic Resonance Imaging**

**Introduction**

In all societies and in all eras, health has been an issue of major importance. Our times are, of course, no different in this, except for one thing: the kind and amount of resources available to us are augmented. During the last couple of centuries, technology has certainly been the most important new resource made available to mankind. Thus, we have witnessed the generation of a large series of new tools and devices that have helped the field of medicine progress and enhance the services it is able to offer.

In our time, it is computers and communication technology that have this role in all aspects of human activities, including medicine. As the computer-based patient record system expands to support more clinical activities, healthcare organizations are asking physicians and nurses to interact increasingly with computer systems to perform their duties.

MRI aka magnetic resonance imaging type of scanning used in radiology to visualize detailed internal structures. MRI makes use of the property of Nuclear magnetic resonance (NMR) to image nuclei of atoms inside the body. One of the major roles of MRI is medical imaging, which is brief description of the technique and process used to create images of the human body for clinical purposes (medical procedures seeking to reveal, diagnose or examine disease) or medical science (including the study of normal anatomy and physiology). Although imaging of removed organs and tissues can be performed for medical reasons, such procedures are not usually referred to as medical imaging, but rather are a part of pathology. Up until 2010, 5 billion medical imaging studies had been conducted worldwide.

The foundations for imaging using magnetic resonance were laid in 1946 by Bloch and Purcell, Bloch at Stanford studying liquids, and Purcell at Harvard, in solids. Though they received Nobel prizes for their discovery, it was not until 1973 that nuclear magnetic resonance (NMR) was used to generate images. Magnetic resonance imaging is a relatively new technology first developed at the University of Aberdeen, UK. The first MR image was published in 1973 and the first cross-sectional image of a living mouse was published in January 1974. The
first studies performed on humans were published in 1977. By comparison, the first human X-ray image was taken in 1895. Paul Bottomley, the director of MR Research at Johns Hopkins University worked to develop the MRI machine.

**MRI architecture**

![MRI architecture diagram](image-url)
Generally there are two types of MRI, closed and open MRI.

1-closed MRI layout

1-open MRI
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This is normally used for claustrophobic patients, it has a weaker magnetic field and as a result it has a weaker resolution, but in order to fully understand how MRI works? We need to know its components, their different types, as well as the function of each.

The main components are:

1- The Primary magnet:
   The largest part of the MRI. Developing a magnetic field of adequate strength to create MRI images was an early hurdle to overcome in the Development of this technology.

2- The gradient magnet:
   The gradient magnets are the 'fine-tuning' part of the MRI machine. They allow the MRI to focus on a specific part of the body. The gradient magnets are also responsible for the 'clanging' noise in a MRI.

3- The Coil:
   Next to the part of your body being imaged is the coil. There are coils made for shoulders, knees, and other body parts. The coil will emit a radiofrequency that makes a MRI possible.

Primary magnet
A permanent magnet (like the kind you use on your refrigerator door) powerful enough to use in a MRI would be too costly to produce and too cumbersome to store. The other way to make a magnet is to coil electrical wire and run a current through the wire. This creates a magnetic field within the center of the coil. In order to create a stronger enough magnetic field to perform MRI, the coils of wire must have no resistance; therefore they are bathed in liquid helium at a temperature 450 degrees Fahrenheit below zero! This allows the coils to develop magnetic fields of 1.5 to 3 Tesla (the strength of most medical MRIs), more than 20,000 times stronger than the earth's magnetic field. There are three different types of primary magnet:
Permanent magnet which produces a vertical field magnet, such magnet is constructed of two magnets (one at each pole).
Resistive magnet which is a conventional electromagnets that depend on a high and a constant supply. It has an iron core vertically oriented magnetic field, and a limited fringe field with little Air core horizontally oriented fields, which have large fringe fields.
Resistive magnet does not require
cooling but needs a constant power supply to maintain homogenous magnetic field. The third type of primary magnet is super conducting magnet. Superconductors have effectively zero resistance below a certain very low temperature called the critical temperature. As resistance decreases, current dissipation also decreases. MR scanners are super cooled with inert gases such as helium. If these cryogens BOIL OFF either intentionally or unintentionally, a quench has occurred. The coils are wound from Niobium-titanium (NbTi) filaments embedded in a copper matrix. The copper serves to protect the NbTi wires in the event of a quench. MR scanners are super cooled with inert gases such as helium. If these cryogens BOIL OFF either intentionally or unintentionally, a quench has occurred. An INTENTIONAL quench is done in an emergency to run the magnetic field to ZERO in order to remove a projectile/patient from the scanner in extreme emergencies. If a quench occurs, remove all staff from the room immediately.
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The following table shows a comparison between different types of primary magnets.

<table>
<thead>
<tr>
<th></th>
<th>Permanent</th>
<th>Resistive</th>
<th>Superconducting</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Field Strength</strong></td>
<td>~0.3 T (limited)</td>
<td>0.02-0.2 T (limited)</td>
<td>0.15-7.0 T (high field possible)</td>
</tr>
<tr>
<td><strong>Homogeneity</strong></td>
<td>Moderate (&lt;5 ppm/40 cm dia)</td>
<td>Moderate (&lt;5 ppm/20 cm dia)</td>
<td>Good (&lt;5 ppm/50 cm dia)</td>
</tr>
<tr>
<td><strong>Stability</strong></td>
<td>Temp. Dependent</td>
<td>Moderate</td>
<td>Good</td>
</tr>
<tr>
<td><strong>Fringe Field</strong></td>
<td>Negligible [&lt;0.1 m]</td>
<td>Small [2 m]</td>
<td>Large (without shielding)[10 m]</td>
</tr>
<tr>
<td><strong>Weight</strong></td>
<td>High</td>
<td>Low</td>
<td>Moderate (without shielding)</td>
</tr>
<tr>
<td><strong>Emergency Shutdown</strong></td>
<td>Not Possible</td>
<td>Switch off</td>
<td>Quench (Expensive)</td>
</tr>
<tr>
<td><strong>Power Consumption</strong></td>
<td>None</td>
<td>High</td>
<td>Negligible</td>
</tr>
<tr>
<td><strong>Cooling Manufacturing</strong></td>
<td>None</td>
<td>Chilled water</td>
<td>Cryogen liquids</td>
</tr>
<tr>
<td><strong>Cost</strong></td>
<td>Medium</td>
<td>Low</td>
<td>High</td>
</tr>
</tbody>
</table>

The Gradient Magnets
There are three smaller magnets within a MRI machine called gradient magnets. These magnets are much smaller than the primary magnet (about 1/1000 as strong), but they allow the magnetic field to be altered very precisely. It is these gradient magnets that allow image "slices" of the body to be created. By altering the gradient magnets, the magnetic field can be specifically focused on a selected part of the body.

The Coil
MRI uses properties of hydrogen atoms to distinguish between different tissues within the human body. The human body is composed primarily of hydrogen atom (63%); other common elements are oxygen (26%), carbon (9%), nitrogen (1%), and relatively small amounts of phosphorus, calcium, and sodium. MRI uses a property of Atoms called "spin" to distinguish differences between Tissues such as muscle, fat, and tendon. With a patient in a MRI
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machine and the magnet turned on, the nuclei of the hydrogen atoms tend
to spin in one of two directions. These hydrogen atom nuclei can
transition their spin orientation, or process, to the opposite orientation.
In order to spin the other direction, the coil emits a radiofrequency
(RF) that causes this transition (the frequency of energy required
to make this transition is specific, and called the Larmour Frequency).
The signal that is used in creating MRI images is derived from
the energy released by molecules transitioning, or processing, from their
high-energy to their low-energy state. This
exchange of energy
between spin states is
called resonance, and thus
the name magnetic
resonance imaging.

Job description (how MRI works)

An MRI machine uses a
powerful magnetic field to
align the magnetization of
some atoms in the body,
and radio frequency fields to
systematically alter the
alignment of this
magnetization. This causes the
nuclei to produce a rotating
magnetic field detectable by the
scanner—and this information
is recorded to construct an image of the scanned area of the body. Strong
magnetic field gradients cause nuclei at different locations to rotate at
different speeds. 3-D spatial information can be obtained by providing
gradients in each direction. MRI provides good contrast between the
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different soft tissues of the body, which make it especially useful in imaging the brain, muscles, the heart, and cancers compared with other medical imaging techniques such as computed tomography (CT) or X-rays. Unlike CT scans or traditional X-rays, MRI uses no ionizing radiation.

The body is largely composed of water molecules. Each water molecule has two hydrogen nuclei or protons. When a person goes inside the powerful magnetic field of the scanner, the magnetic moments of some of these protons change and align with the direction of the field. A radio frequency transmitter is briefly turned on, producing a further varying electromagnetic field. The photons of this field have just the right energy, known as the resonance frequency, to be absorbed and flip the spin of the aligned protons in the body. The frequency at which the protons resonate depends on the strength of the applied magnetic field. After the field is turned off, those protons which absorbed energy revert back to the original lower-energy spin-down state. They release the difference in energy as a photon, and the released photons are detected by the scanner as an electromagnetic signal, similar to radio waves. As a result of conservation of energy, the resonance frequency also dictates the frequency of the released photons. The photons released when the field is removed have energy — and therefore a frequency — which depends on the energy absorbed while the field was active. It is this relationship between field-strength and frequency that allows the use of nuclear magnetic resonance for imaging. An image can be constructed because the protons in different tissues return to their equilibrium state at different rates, which is a difference that can be detected. Five different tissue variables — spin density, T1 and T2 relaxation times and flow and spectral shifts can be used to construct images. By changing the parameters on the scanner, this effect is used to create contrast between different types of body tissue or between other properties, as in fMRI and diffusion MRI. The 3D position from which photons were released is learned by applying additional fields during the scan. This is done by passing electric currents through specially-wound solenoids, known as gradient coils. These fields make the magnetic field strength vary depend on the position within the patient, which in turn makes the frequency of released photons dependent on their original position in a predictable manner, and the original locations can be mathematically recovered from the resulting signal by the use of inverse Fourier
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Contrast agents may be injected intravenously to enhance the appearance of blood vessels, tumors or inflammation. Contrast agents may also be directly injected into a joint in the case of arthrograms, MRI images of joints. Unlike CT, MRI uses no ionizing radiation and is generally a very safe procedure. Nevertheless the strong magnetic fields and radio pulses can affect metal implants, including cochlear implants and cardiac pacemakers. In the case of cochlear implants, the US FDA has approved some implants for MRI compatibility. In the case of cardiac pacemakers, the results can sometimes be lethal, so patients with such implants are generally not eligible for MRI.

Since the gradient coils are within the bore of the scanner, there are large forces between them and the main field coils, producing most of the noise that is heard during operation. Without efforts to damp this noise, it can approach 130 decibels (dB) with strong fields. MRI is used to image every part of the body, and is particularly useful for tissues with many hydrogen nuclei and little density contrast, such as the brain, muscle, connective tissue and most tumors.

Using an MRI scanner, it is possible to make pictures of almost all the tissue in the body. The tissue that has the least hydrogen atoms (such as bones) turns out dark, while the tissue that has many hydrogen atoms (such as fatty tissue) looks much brighter. By changing the timing of the radio wave pulses it is possible to gain information about the different types of tissues that are present.

An MRI scan is also able to provide clear pictures of parts of the body that are surrounded by bone tissue, so the technique is useful when examining the brain and spinal cord. Because the MRI scan gives very detailed pictures it is the best technique when it comes to finding tumors (benign or malignant abnormal growths) in the brain. If a tumor is present the scan can also be used to find out if it has spread into nearby brain
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tissue. The technique also allows us to focus on other details in the brain.
For example, it makes it possible to see the strands of abnormal tissue
that occur if someone has multiple sclerosis and it is possible to see
changes occurring when there is bleeding in the brain, or find out if the
brain tissue has suffered lack of oxygen after a stroke. The MRI scan is
also able to show both the heart and the large blood vessels in the
surrounding tissue. This makes it possible to detect heart defects that have
been building up since birth, as well as changes in the thickness of the
muscles around the heart following a heart attack. The method can also
be used to examine the joints, spine and sometimes the soft parts of your
body such as the liver, kidneys and spleen.

One fundamental principle required to understand MR imaging is the
concept of electromagnetic energy. Radio receiver in your car accepts
radiofrequency (RF) waves, which represent one form of electromagnetic
energy. Similarly, protons in living tissue are able to accept
electromagnetic energy in the form of RF pulse. This RF pulse "excites"
the protons to a higher energy level. As the protons "relax", energy is
emitted back to the antennas in MR machines. Unfortunately, the amount
of energy that is emitted back from the protons is very small. So a few
tricks are performed to maximize signal to noise ratio.

Each proton in the body acts like a small magnet with its own magnetic
field. While each proton can receive and emit back the RF energy, any
sort of coherent signal generated by such experiment is promptly
cancelled out by neighbouring protons. One analogy is a room full of
people talking at the same time. While each individual person is
transmitting meaningful information, the sound of entire room makes
absolutely no sense. So, the first trick is to get the protons to talk in
unison with each other. When placed into external magnetic field, protons
align parallel to it. There is almost an equal chance that a proton orients
itself at 0 or at 180 degrees to the main magnetic field. The keyword here
is "almost," because fortunately for us, a few more protons align with the
magnetic field rather than 180 degrees to it. (Explanation for this
phenomenon requires understanding of quantum physics.) These extra
few protons (actually quite a lot of them) create a net magnetic field that
we can now manipulate. The number of protons aligned with the
magnetic field varies with strength of the magnet. Utilization of a 3T
magnet results in much better signal-to-noise ratio compared to a 0.5T
magnet.

Next point is to get the protons to emit enough energy for the MR
antennas to pick it up. Unlike static pictures on this page, each proton
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actually rotates around its axis (processes) like a wobble. Turns out that the signal generated by each rotating proton is much stronger if we make the protons process in unison with each other at 90 degrees to the main magnetic field. RF pulse does just that. The signal generated by protons processing in unison and at 90 degrees to main magnetic field is the strongest signal we get. However, 90 degree rotating frame is a high energy state, in which protons will not stay forever. There are two types of relaxation. First, there is relaxation to align back with the main magnetic field (T1 relaxation), Second, there is dephasing in the transverse plane (90 degree plane). Each individual proton precesses at slightly different speed. After a while, the signal from protons in transverse plane degenerates as protons start precessing out of phase with each other (T2 relaxation). It takes different amount of time to lose strength of the signal from T1 and T2 relaxations. By manipulating manner and frequency in which we apply RF pulses (TR), and by changing time to start of signal acquisition after RF has been applied (TE), we are able to produce T1-weighted or T2-weighted images.

We can also manipulate the strength of the magnetic field and properties of RF pulses to create predictable variations in the body so that complex signals returned to the antennas contain positional information.

A myriad of possible variations in the RF pulses and in magnetic fields results in a complex matrix of signals coming back from the tissues to the RF receiver coils. Using sophisticated mathematical manipulations, these signals are converted into variety of images. Each particular set of images contrasts specific property of the tissues to our advantage. We are not quite at the point where MRI can substitute for direct tissue evaluation. Slowly, but surely the resolution of the image is getting improved, however. Anatomical and functional information that is transformed into images is becoming crisper by the day, if not by the hour. MRIs make use of the unique property of atomic nuclei rotating in a strong magnetic field. These nuclei have a special "resonance" frequency that depends on the magnetic field. By absorbing radio waves of the same frequency, the nucleus’ energy can be increased. Radio waves are re-emitted by the nuclei as they return to the lower energy state. The time it takes for the radio wave to do this is known as the ‘relaxation time’, and the different relaxation times result in varying bright and dark spots on the image.

Before the MRI scanning process can begin, patients must remove all metal objects, such as jewellery or watches,
because they may interfere with the magnetic field. Once this has been done, the patient is instructed to lie on a bed and is placed into a magnetic field. The radio waves that are re-emitted by the nuclei in the patient’s body are detected by sensors which are placed around the body. Next, a computer uses ‘computed tomography’ techniques to assemble the slices into a three-dimensional image, allowing doctors to make a complete diagnosis.

Larmor Precession

Nuclei have an intrinsic quantum property called spin. When a magnetic field is imposed on the nucleus of an atom, this nuclear spin will orient itself according to this field, and so our z-axis can now be the direction of the magnetic field, for convenience. The spin of a nucleus can be compared to a gyroscope. The spin is represented by the arrow. Notice the tip of the arrow precesses similar to the top of the gyroscope. This spin allows absorption of a photon (a.k.a. light particle) of frequency \( \nu_L \), which is dependent on the strength of the magnetic field applied to the nucleus. This relationship is shown below:

\[
\nu_L = \gamma \times B
\]

Where \( \gamma \) (the gyro magnetic ratio) for hydrogen is 42.58
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MHz/T. This special frequency is known as the ‘Larmor’ frequency ($\nu_L$).

Different types of MRI scan (basic scans)

T1-weighted MRI

T1-weighted scans are a standard basic scan, in particular differentiating fat from water - with water darker and fat brighter. Use a gradient echo (GRE) sequence, with short TE and short TR. This is one of the basic types of MR contrast and is a commonly run clinical scan. The T1 weighting can be increased (improving contrast) with the use of an inversion pulse as in an MP-RAGE sequence. Due to the short repetition time (TR) this scan can be run very fast allowing the collection of high resolution 3D datasets. A T1 reducing gadolinium contrast agent is also commonly used, with a T1 scan being collected before and after administration of contrast agent to compare the difference. In the brain T1-weighted scans provide good gray matter/white matter contrast; in other words, T1-weighted images highlight fat deposition.

T2-weighted MRI

T2-weighted scans are another basic type. Like the T1-weighted scan,
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Fat is differentiated from water - but in this case fat shows darker, and water lighter. They are therefore particularly well suited to imaging edema, with long TE and long TR. They have long been the clinical workhorse as the spin echo sequence is less susceptible to inhomogeneities in the magnetic field. In case of cerebral and spinal study the CSF (cerebrospinal fluid) will be hyper in t2 weighted images.

T*2-weighted MRI

T*2 (pronounced "T 2 star") weighted scans use a gradient echo (GRE) sequence, with long TE and long TR. The gradient echo sequence used does not have the extra refocusing pulse used in spin echo so it is subject to additional losses above the normal T2 decay (referred to as T2’), these taken together are called T*2. This also makes it more prone to susceptibility losses at air/tissue boundaries, but can increase contrast for certain types of tissue, such as venous blood.

Spin density weighted MRI

Spin density, also called proton density, weighted scans try to have no contrast from either T2 or T1 decay, the only signal change coming from differences in the amount of available spins (hydrogen nuclei in water). It uses a spin echo or sometimes a gradient echo sequence, with short TE and long TR.

Specialized MRI scans (their types and uses)

Diffusion MRI

Diffusion MRI is a magnetic resonance imaging (MRI) method that produces in vivo images of biological tissues weighted with the local micro structural characteristics of water diffusion. The field of diffusion MRI can be understood in terms of two distinct classes of application—diffusion weighted MRI and diffusion tensor MRI. Diffusion weighted MRI can provide information about damage to parts of the nervous system. Diffusion tensor MRI can provide information about connections among brain regions. In diffusion weighted imaging (DWI), each image voxel (three dimensional pixels) has an image intensity that reflects a single best measurement of the rate of water diffusion at that location. This measurement is more sensitive to early changes after a stroke than more traditional MRI measurements such as T1 or T2 relaxation rates. DWI is most applicable when the tissue of interest is dominated by isotropic water movement e.g. grey matter in the cerebral.
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cortex and major brain nuclei—where the diffusion rate appears to be the same when measured along any axis.

Diffusion tensor imaging (DTI) is important when a tissue—such as the neural axons of white matter in the brain or muscle fibers in the heart—has an internal fibrous structure analogous to the anisotropy of some crystals. Water will then diffuse more rapidly in the direction aligned with the internal structure, and more slowly as it moves perpendicular to the preferred direction. This also means that the measured rate of diffusion will differ depending on the direction from which an observer is looking. Traditionally, in diffusion-weighted imaging (DWI), three gradient-directions are applied, sufficient to estimate the trace of the diffusion tensor or 'average diffusivity', a putative measure of edema. Clinically, trace-weighted images have proven to be very useful to diagnose vascular strokes in the brain, by early detection (within a couple of minutes) of the hypoxic edema.

More extended diffusion tensor imaging (DTI) scans derive neural tract directional information from the data using 3D or multidimensional vector algorithms based on six or more gradient directions, sufficient to compute the diffusion tensor. The diffusion model is a rather simple model of the diffusion process, assuming homogeneity and linearity of the diffusion within each image voxel. From the diffusion tensor, diffusion anisotropy measures such as the fractional anisotropy (FA), can be computed. Moreover, the principal direction of the diffusion tensor can be used to infer the white-matter connectivity of the brain (i.e. tractography; trying to see which part of the brain is connected to which other part). Recently, more advanced models of the diffusion process have been proposed that aim to overcome the weaknesses of the diffusion tensor model. Amongst others, these include q-space imaging and generalized diffusion tensor imaging.

Magnetization transfer MRI

Magnetization transfer (MT), as commonly used in
biomedical MRI, refers to the transfer of longitudinal magnetization from the hydrogen nuclei of water that have restricted motion to the hydrogen nuclei of water that moves with many degrees of freedom. The water with restricted motion is generally conceived as being bound to macromolecules, such as proteins and lipids through a series of hydrogen bonds. The free water pool is the bulk water of the cytosol. In this context, the hydrogen nuclei are typically referred to simply as protons.

In magnetic resonance imaging of molecular solutions, such as protein solutions, two types of water molecules, free (bulk) and bound (hydration), are found. Free water protons have faster average rotational frequency and hence less fixed water molecules that may cause local field inhomogeneity. Because of this uniformity, most free water protons have resonance frequencies lying narrowly around the normal proton resonance frequency of 63 MHz (at 1.5 teslas). The high rotational frequency also results in fewer interactions with the environment so that the transverse magnetization dephasing is slower and the $T_2$ is long. Conversely, hydrated water molecules are slowed down by extensive interactions with the protons in the local macromolecules and hence magnetic field inhomogeneities is created that lead to wider resonance frequency spectrum. This results in faster dephasing of the magnetization that produces the NMR signal and much shorter $T_2$ values (<200 µs). Because the $T_2$ values are so short the NMR signal from the protons of bound water is not typically observed in MRI.

However, using an off-resonance pulse excitation to saturate protons in the restricted pool can have a detectable effect on NMR signal from the mobile (free) proton pool. The transverse magnetization created is rapidly dephased and the longitudinal magnetization requires some time (approximately 5 times $T_1$) to return to equilibrium. Since the bound water may exchange magnetization with the free water, the loss of longitudinal magnetization will also be introduced into the pool of free water. This causes an increase in the $T_1$ of the free water and reduced signal from the free water in tissues in which the magnetization transfer mechanism is prevalent. Since the extent of signal decay depends on the exchange rate between free and hydration water, MT can be used to provide an alternative contrast method in addition to $T_1$, $T_2$, and proton density differences.
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MT is believed to be a nonspecific indicator of the structural integrity of the tissue being imaged. An extension of MT, the magnetization transfer ratio (MTR) has been used in neuroradiology to highlight abnormalities in brain structures.

Fluid attenuated inversion recovery (FLAIR)

Fluid Attenuated Inversion Recovery (FLAIR)[14] is an inversion-recovery pulse sequence used to null signal from fluids. For example, it can be used in brain imaging to suppress cerebrospinal fluid (CSF) so as to bring out the periventricular hyperintense lesions, such as multiple sclerosis (MS) plaques. By carefully choosing the inversion time TI (the time between the inversion and excitation pulses), the signal from any particular tissue can be suppressed.

Magnetic resonance angiography

Magnetic resonance angiography (MRA) generates pictures of the arteries to evaluate them for stenosis (abnormal narrowing) or aneurysms (vessel wall dilatations, at risk of rupture). MRA is often used to evaluate the arteries of the neck and brain, the
Magnetic resonance imaging (MRI) can be used to visualize the thoracic and abdominal aorta, the renal arteries, and the legs (called a "run-off"). A variety of techniques can be used to generate the pictures, such as administration of a paramagnetic contrast agent (gadolinium) or using a technique known as "flow-related enhancement" (e.g. 2D and 3D time-of-flight sequences), where most of the signal on an image is due to blood that recently moved into that plane, see also FLASH MRI.

Techniques involving phase accumulation (known as phase contrast angiography) can also be used to generate flow velocity maps easily and accurately. Magnetic resonance venography (MRV) is a similar procedure that is used to image veins. In this method, the tissue is now excited inferiorly, while signal is gathered in the plane immediately superior to the excitation plane—thus imaging the venous blood that recently moved from the excited plane.

Magnetic resonance gated intracranial CSF dynamics (MR-GILD)

Magnetic resonance gated intracranial cerebrospinal fluid (CSF) or liquor dynamics (MR-GILD) technique is an MR sequence based on bipolar gradient pulse used to demonstrate CSF pulsatile flow in ventricles, cisterns, aqueduct of Sylvius and entire intracranial CSF pathway. It is a method for analyzing CSF circulatory system dynamics in patients with CSF obstructive lesions such as normal pressure hydrocephalus. It also allows visualization of both arterial and venous pulsatile blood flow in vessels without use of contrast agents.

<table>
<thead>
<tr>
<th>Diastolic time data acquisition (DTDA)</th>
<th>Systolic time data acquisition (STDA)</th>
</tr>
</thead>
<tbody>
<tr>
<td><img src="image1.png" alt="Diastolic image" /></td>
<td><img src="image2.png" alt="Systolic image" /></td>
</tr>
</tbody>
</table>

Magnetic resonance spectroscopy
Magnetic resonance imaging (MRI) is a non-invasive analytical technique that has been used to study metabolic changes in brain tumors, strokes, seizure disorders, Alzheimer's disease, depression and other diseases affecting the brain. It has also been used to study the metabolism of other organs such as muscles. In the case of muscles, NMR is used to measure the intramyocellular lipid content (IMCL).

Nuclear magnetic resonance (NMR) is an effect whereby magnetic nuclei in a magnetic field absorb and re-emit electromagnetic (EM) energy. This energy is at a specific resonance frequency which depends on the strength of the magnetic field and other factors. This allows the observation of specific quantum mechanical magnetic properties of an atomic nucleus. Many scientific techniques exploit NMR phenomena to study molecular physics, crystals and non-crystalline materials through NMR spectroscopy. NMR is also routinely used in advanced medical imaging techniques, such as in magnetic resonance imaging (MRI).

All stable isotopes that contain an odd number of protons and/or of neutrons (see Isotope) have an intrinsic magnetic moment and angular momentum, in other words a nonzero spin, while all nuclides with even numbers of both have spin 0. The most commonly studied nuclei are $^1$H (the most NMR-sensitive isotope after the radioactive $^3$H) and $^{13}$C, although nuclei from isotopes of many other elements (e.g. $^2$H, $^{10}$B, $^{11}$B, $^{14}$N, $^{15}$N, $^{17}$O, $^{19}$F, $^{23}$Na, $^{29}$Si, $^{31}$P, $^{35}$Cl, $^{113}$Cd, $^{129}$Xe, $^{195}$Pt) are studied by high-field NMR spectroscopy as well. A key feature of NMR is that the resonance frequency of a particular substance is directly proportional to the strength of the applied magnetic field. It is this feature that is exploited in imaging techniques; if a sample is placed in a non-uniform magnetic field then the resonance frequencies of the sample's nuclei depend on where in the field they are located. Since the resolution of the imaging technique depends on the magnitude of magnetic field gradient, many efforts are made to develop increased field strength, often using superconductors. The effectiveness of NMR can also be improved using hyperpolarization, and/or using two-dimensional, three-dimensional and higher-dimensional multi-frequency techniques.

The principle of NMR usually involves two sequential steps:
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- The alignment (polarization) of the magnetic nuclear spins in an applied, constant magnetic field $H_0$.
- The perturbation of this alignment of the nuclear spins by employing an electromagnetic, usually radio frequency (RF) pulse. The required perturbing frequency is dependent upon the static magnetic field ($H_0$) and the nuclei of observation.

The two fields are usually chosen to be perpendicular to each other as this maximizes the NMR signal strength. The resulting response by the total magnetization ($M$) of the nuclear spins is the phenomenon that is exploited in NMR spectroscopy and magnetic resonance imaging. Both use intense applied magnetic fields ($^0H$) in order to achieve dispersion and very high stability to deliver spectral resolution, the details of which are described by chemical shifts, the Zeeman effect, and Knight shifts (in metals).

NMR phenomena are also utilized in low-field NMR, NMR spectroscopy and MRI in the Earth's magnetic field (referred to as Earth's field NMR), and in several types of magnetometers.
Functional MRI

Functional magnetic resonance imaging or functional MRI (fMRI) is a type of specialized MRI scan used to measure the hemodynamic response (change in blood flow) related to neural activity in the brain or spinal cord of humans or other animals. It is one of the most recently developed forms of neuroimaging. Since the early 1990s, fMRI has come to dominate the brain mapping field due to its relatively low invasiveness, absence of radiation exposure, and relatively wide availability. Functional MRI (fMRI) measures signal changes in the brain that are due to changing neural activity. The brain is scanned at low resolution but at a rapid rate (typically once every 2–3 seconds). Increases in neural activity cause changes in the MR signal via T*2 changes, this mechanism is referred to as the BOLD (blood-oxygen-level dependent) effect. Increased neural activity causes an increased demand for oxygen, and the vascular system actually overcompensates for this, increasing the amount of oxygenated hemoglobin relative to deoxygenated hemoglobin. Because deoxygenated hemoglobin attenuates the MR signal, the vascular response leads to a signal increase that is related to the neural activity. The precise nature of the relationship between neural activity and the BOLD signal is a subject of current research. The BOLD effect also allows for the generation of high resolution 3D maps of the venous vasculature within neural tissue.

While BOLD signal is the most common method employed for neuroscience studies in human subjects, the flexible nature of MR imaging provides means to sensitize the signal to other aspects of the blood supply. Alternative techniques employ arterial spin labeling (ASL) or weight the MRI signal by cerebral blood flow (CBF) and cerebral blood volume (CBV). The CBV method requires injection of a class of MRI contrast agents that are now in human clinical trials. Because this method has been shown to be far more sensitive than the BOLD technique in preclinical studies, it may potentially expand the role of fMRI in clinical applications. The CBF method provides more
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quantitative information than the BOLD signal, albeit at a significant loss of detection sensitivity.

Real-time MRI

Real-time MRI refers to the continuous monitoring (“filming”) of moving objects in real time. While many different strategies have been developed over the past two decades, a recent development reported a real-time MRI technique based on radial FLASH that yields a temporal resolution of 20 to 30 milliseconds for images with an in-plane resolution of 1.5 to 2.0 mm. The new method promises to add important information about diseases of the joints and the heart. In many cases MRI examinations may become easier and more comfortable for patients.

Biological uses of MRI and their applications in hospitals & healthcare centers

**Brain mapping**

Brain mapping is a set of neuroscience techniques predicated on the mapping of (biological) quantities or properties onto spatial representations of the (human or non-human) brain resulting in maps.

**Overview**

All neuroimaging can be considered part of brain mapping. Brain mapping can be conceived as a higher form of neuroimaging, producing brain images supplemented by the result of additional (imaging or non-
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imaging) data processing or analysis, such as maps projecting (measures of) behaviour onto brain regions (see fMRI).

Brain Mapping techniques are constantly evolving, and rely on the development and refinement of image acquisition, representation, analysis, visualization and interpretation techniques. Functional and structural neuroimaging are at the core of the mapping aspect of Brain Mapping.

History

In the late 1980s in the United States, the Institute of Medicine of the National Academy of Science was commissioned to establish a panel to investigate the value of integrating neuroscientific information across a variety of techniques. Of specific interest is using structural and functional magnetic resonance imaging (fMRI), electroencephalography (EEG), positron emission tomography (PET) and other non-invasive scanning techniques to map anatomy, physiology, perfusion, function and phenotypes of the human brain. Both healthy and diseased brains may be mapped to study memory, learning, aging, and drug effects in various populations such as people with schizophrenia, autism, and clinical depression. This led to the establishment of the Human Brain Project. Following a series of meetings, the International Consortium for Brain Mapping (ICBM) evolved. The ultimate goal is to develop flexible computational brain atlases. On 5/5/2010 the Supreme Court in India in its historical judgment on several PIL's has declared brain mapping, lie detector test and narcoanalysis as unconstitutional as it violates Article 20 (3) of Fundamental Rights. It cannot be conducted forcefully on any individual and requires one's consent for the same. when it is conducted with one's consent the material so obtained will be regarded as evidence during trial of cases according to Section 27 of Evidence Act.
Brain imaging

Despite the close relations between both brain mapping and imaging they both vary in their function.

Brain imaging includes the use of various techniques to either directly or indirectly image the structure, function/pharmacology of the brain. It is a relatively new discipline within medicine and neuroscience/psychology.

History

In 1918 the American neurosurgeon Walter Dandy introduced the technique of ventriculography. X-ray images of the ventricular system within the brain were obtained by injection of filtered air directly into one or both lateral ventricles of the brain. Dandy also observed that air introduced into the subarachnoid space via lumbar spinal puncture could enter the cerebral ventricles and also demonstrate the cerebrospinal fluid compartments around the base of the brain and over its surface. This technique was called pneumoencephalography.

In 1927 Egas Moniz introduced cerebral angiography, whereby both normal and abnormal blood vessels in and around the brain could be visualized with great precision.

In the early 1970s, Allan McLeod Cormack and Godfrey Newbold Hounsfield introduced computerized axial tomography (CAT or CT scanning), and ever more detailed anatomic images of the brain became available for diagnostic and research purposes. Cormack and Hounsfield won the 1979 Nobel Prize for Physiology or Medicine for their work. Soon after the introduction of CAT in the early 1980s, the development of radioligands allowed single photon emission computed tomography (SPECT) and positron emission tomography (PET) of the brain.
**Magnetic Resonance Imaging**

More or less concurrently, magnetic resonance imaging (MRI or MR scanning) was developed by researchers including Peter Mansfield and Paul Lauterbur, who were awarded the Nobel Prize for Physiology or Medicine in 2003. In the early 1980s MRI was introduced clinically, and during the 1980s a veritable explosion of technical refinements and diagnostic MR applications took place. Scientists soon learned that the large blood flow changes measured by PET could also be imaged by the correct type of MRI. Functional magnetic resonance imaging (fMRI) was born, and since the 1990s, fMRI has come to dominate the brain mapping field due to its low invasiveness, lack of radiation exposure, and relatively wide availability. As noted above fMRI is also beginning to dominate the field of stroke treatment.

In early 2000s the field of neuroimaging reached the stage where limited practical applications of functional brain imaging have become feasible. The main application area is crude forms of brain-computer interface.

**Brain imaging techniques**

**Computed axial tomography**

Computed tomography (CT) or Computed Axial Tomography (CAT) scanning uses a series of x-rays of the head taken from many different directions. Typically used for quickly viewing brain injuries, CT scanning uses a computer program that performs a numerical integral calculation (the inverse Radon transform) on the measured x-ray series to estimate how much of an x-ray beam is absorbed in a small volume of the brain. Typically the information is presented as cross sections of the brain.

In approximation, the denser a material is, the whiter a volume of it will appear on the scan (just as in the more familiar "flat" X-rays). CT scans are primarily used for evaluating swelling from tissue damage in the brain and in assessment of ventricle size. Modern CT scanning can provide reasonably good images in a matter of minutes.

**Diffuse optical imaging**

Diffuse optical imaging (DOI) or diffuse optical tomography (DOT) is a medical imaging modality which uses near infrared light to generate images of the body. The technique measures the optical
absorption of hemoglobin, and relies on the absorption spectrum of hemoglobin varying with its oxygenation status.

Event-related optical signal

Event-related optical signal (EROS) is a brain-scanning technique which uses infrared light through optical fibers to measure changes in optical properties of active areas of the cerebral cortex. Whereas techniques such as diffuse optical imaging (DOT) and near infrared spectroscopy (NIRS) measure optical absorption of haemoglobin, and thus are based on blood flow, EROS takes advantage of the scattering properties of the neurons themselves, and thus provides a much more direct measure of cellular activity. EROS can pinpoint activity in the brain within millimeters (spatially) and within milliseconds (temporally). Its biggest downside is the inability to detect activity more than a few centimeters deep. EROS is a new, relatively inexpensive technique that is non-invasive to the test subject. It was developed at the University of Illinois at Urbana-Champaign where it is now used in the Cognitive Neuroimaging Laboratory of Dr. Gabriele Gratton and Dr. Monica Fabiani.

Magnetic resonance imaging

Sagittal MRI slice at the midline.

Magnetic resonance imaging (MRI) uses magnetic fields and radio waves to produce high quality two- or three-dimensional images of brain structures without use of ionizing radiation (X-rays) or radioactive tracers. During an MRI, a large cylindrical magnet creates a magnetic field around the head of the patient through which radio waves are sent. When the magnetic field is imposed, each point in space has a unique radio frequency at which the signal is received and transmitted (Preuss). Sensors read the frequencies
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and a computer uses the information to construct an image. The detection mechanisms are so precise that changes in structures over time can be detected.

Using MRI, scientists can create images of both surface and subsurface structures with a high degree of anatomical detail. MRI scans can produce cross sectional images in any direction from top to bottom, side to side, or front to back. The problem with original MRI technology was that while it provides a detailed assessment of the physical appearance, water content, and many kinds of subtle derangements of structure of the brain (such as inflammation or bleeding), it fails to provide information about the metabolism of the brain (i.e. how actively it is functioning) at the time of imaging. A distinction is therefore made between "MRI imaging" and "functional MRI imaging" (fMRI), where MRI provides only structural information on the brain while fMRI yields both structural and functional data.

Functional magnetic resonance imaging

Axial MRI slice at the level of the basal ganglia, showing fMRI BOLD signal changes overlayed in red (increase) and blue (decrease) tones.

Functional magnetic resonance imaging (fMRI) relies on the paramagnetic properties of oxygenated and deoxygenated hemoglobin to see images of changing blood flow in the brain associated with neural activity. This allows images to be generated that reflect which brain structures are activated (and how) during performance of different tasks.

Most fMRI scanners allow subjects to be presented with different visual images, sounds and touch stimuli, and to make different actions such as pressing a button or moving a joystick. Consequently, fMRI can be used to reveal brain structures and processes associated with perception, thought and action. The resolution of fMRI is about 2-3 millimeters at present, limited by the spatial spread of the hemodynamic response to
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neural activity. It has largely superseded PET for the study of brain activation patterns. PET, however, retains the significant advantage of being able to identify specific brain receptors (or transporters) associated with particular neurotransmitters through its ability to image radiolabelled receptor "ligands" (receptor ligands are any chemicals that stick to receptors).

As well as research on healthy subjects, fMRI is increasingly used for the medical diagnosis of disease. Because fMRI is exquisitely sensitive to blood flow, it is extremely sensitive to early changes in the brain resulting from ischemia (abnormally low blood flow), such as the changes which follow stroke. Early diagnosis of certain types of stroke is increasingly important in neurology, since substances which dissolve blood clots may be used in the first few hours after certain types of stroke occur, but are dangerous to use afterwards. Brain changes seen on fMRI may help to make the decision to treat with these agents. With between 72% and 90% accuracy where chance would achieve 0.8%, fMRI techniques can decide which of a set of known images the subject is viewing.

Electroencephalography

Electroencephalography (EEG) is an imaging technique used to measure the electric fields in the brain via electrodes placed on the scalp of a human. EEG offers a very direct measurement of neural electrical activity with very high temporal resolution but relatively low spatial resolution.

Magnetoencephalography

Magnetoencephalography (MEG) is an imaging technique used to measure the magnetic fields produced by electrical activity in the brain via extremely sensitive devices such as super conducting quantum interference devices (SQUIDs). MEG offers a very direct measurement neural electrical activity (compared to fMRI for example) with very high temporal resolution but relatively low spatial resolution. The advantage of measuring the magnetic fields produced by neural activity is that they are not distorted by surrounding tissue, unlike the electric fields measured by EEG (particularly the skull and scalp).
There are many uses for the MEG, including assisting surgeons in localizing pathology, assisting researchers in determining the function of various parts of the brain, neurofeedback, and others.

Positron emission tomography

PET scan of a normal 20-year-old brain.

Positron emission tomography (PET) measures emissions from radioactively labeled metabolically active chemicals that have been injected into the bloodstream. The emission data are computer-processed to produce 2- or 3-dimensional images of the distribution of the chemicals throughout the brain. The positron emitting radioisotopes used are produced by a cyclotron, and chemicals are labeled with these radioactive atoms. The labeled compound, called a radiotracer, is injected into the bloodstream and eventually makes its way to the brain. Sensors in the PET scanner detect the radioactivity as the compound accumulates in various regions of the brain. A computer uses the data gathered by the sensors to create multicolored 2- or 3-dimensional images that show where the compound acts in the brain. Especially useful are a wide array of ligands used to map different aspects of neurotransmitter activity, with by far the most commonly used PET tracer being a labeled form of glucose (see Fluodeoxyglucose (18F)(FDG)).

The greatest benefit of PET scanning is that different compounds can show blood flow and oxygen and glucose metabolism in the tissues of the working brain. These measurements reflect the amount of brain activity in the various regions of the brain and allow to learn more about how the brain works. PET scans were superior to all other metabolic imaging methods in terms of resolution and speed of completion (as little as 30 seconds), when they first became available. The improved resolution permitted better study to be made as to the area of the brain activated by a particular task. The biggest drawback of PET scanning is that because the radioactivity decays rapidly, it is limited to monitoring short
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tasks. Before fMRI technology came online, PET scanning was the preferred method of functional (as opposed to structural) brain imaging, and it still continues to make large contributions to neuroscience.

PET scanning is also used for diagnosis of brain disease, most notably because brain tumors, strokes, and neuron-damaging diseases which cause dementia (such as Alzheimer's disease) all cause great changes in brain metabolism, which in turn causes easily detectable changes in PET scans. PET is probably most useful in early cases of certain dementias (with classic examples being Alzheimer's disease and Pick's disease) where the early damage is too diffuse and makes too little difference in brain volume and gross structure to change CT and standard MRI images enough to be able to reliably differentiate it from the "normal" range of cortical atrophy which occurs with aging (in many but not all) persons, and which does not cause clinical dementia.

Single photon emission computed tomography

Single photon emission computed tomography (SPECT) is similar to PET and uses gamma ray emitting radioisotopes and a gamma camera to record data that a computer uses to construct two- or three-dimensional images of active brain regions. SPECT relies on an injection of radioactive tracer, which is rapidly taken up by the brain but does not redistribute. Uptake of SPECT agent is nearly 100% complete within 30 – 60s, reflecting cerebral blood flow (CBF) at the time of injection. These properties of SPECT make it particularly well suited for epilepsy imaging, which is usually made difficult by problems with patient movement and variable seizure types. SPECT provides a "snapshot" of cerebral blood flow since scans can be acquired after seizure termination (so long as the radioactive tracer was injected at the time of the seizure). A significant limitation of SPECT is its poor resolution (about 1 cm) compared to that of MRI.

Like PET, SPECT also can be used to differentiate different kinds of disease processes which produce dementia, and it is increasingly used for this purpose. Neuro-PET has a disadvantage of requiring use of tracers with half-lives of at most 110 minutes, such as FDG. These must be made in a cyclotron, and are expensive or even unavailable if necessary transport times are prolonged more than a few half-lives. SPECT,
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however, is able to make use of tracers with much longer half-lives, such as technetium-99m, and as a result, is far more widely available.

Neuroimaging

History

The history of neuroimaging, began in the early 1900s with a technique called pneumoencephalography. This process involved draining the cerebrospinal fluid from around the brain and replacing it with air, altering the relative density of the brain and its surroundings, to cause it to show up better on an x-ray. It was considered to be incredibly unsafe for patients (Beaumont 8). A form of magnetic resonance imaging (MRI) and computed tomography (CT) were developed in the 1970s and 1980s. The new MRI and CT technologies were considerably less harmful and are explained in greater detail below. Next came SPECT and PET scans, which allowed scientists to map brain function because, unlike MRI and CT, these scans could create more than just static images of the brain's structure. Learning from MRI, PET and SPECT scanning, scientists were able to develop functional MRI (fMRI) with abilities that opened the door to direct observation of cognitive activities.

Early uses of brain imaging

The desire to understand the human mind has been one of the main desires of philosophers throughout the ages. Questions about thoughts, desires, etcetera have drawn psychologists, computer, philosophers, sociologists and the like together into the new discipline of cognitive science. Non-invasive imaging of the human brain has proven invaluable in this context.

Structural imaging began with early radiographic techniques to image the human brain. Unfortunately, because the brain is almost entirely composed of soft tissue that is not radio-opaque, it remains essentially invisible to ordinary or plain x-ray examination. This is also true of most brain abnormalities, though there are exceptions such as a calcified tumour (e.g.meningioma, craniopharyngioma, some types of glioma); whilst calcification in such normal structures as the pineal body, the choroid plexuses, or large brain arteries may indirectly give important clues to the presence of structural disease in the brain itself.
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In 1918 the American neurosurgeon Walter Dandy introduced the technique of ventriculography whereby images of the ventricular system within the brain were obtained by injection of filtered air directly into one or both lateral ventricles of the brain via one or more small trephine holes drilled in the skull under local anaesthesia. Though not usually a painful procedure, ventriculography carried significant risks to the patient under investigation, such as haemorrhage, infection, and dangerous changes in intracranial pressure. Nevertheless the surgical information given by this method was often remarkably precise and greatly enlarged the capabilities and accuracy of neurosurgical treatment. Dandy also observed that air introduced into the subarachnoid space via lumbar spinal puncture could enter the cerebral ventricles and also demonstrate the cerebrospinal fluid compartments around the base of the brain and over its surface. This technique was called pneumoencephalography. It further extended the scope for precise intracranial diagnosis, but at a similar cost of risks to the patient as well as being, in itself, a most unpleasant and often painful ordeal.

Development in modern techniques

In 1927 Egas Moniz, professor of neurology in Lisbon and Nobel Prize for Physiology or Medicine in 1949, introduced cerebral angiography, whereby both normal and abnormal blood vessels in and around the brain could be visualized with great accuracy. In its early days this technique likewise carried both immediate and long-term risks, many of them referable to deleterious effects of the positive-contrast substances that were used for injection into the circulation. Techniques have become very refined in the past few decades, with one in 200 patients or less experiencing ischemic sequelae from the procedure. As a result, cerebral angiography remains an essential part of the neurosurgeon's diagnostic imaging armamentarium and, increasingly, of the therapeutic armamentarium as well, in the neurointerventional management of cerebral aneurysms and other blood-vessel lesions and in some varieties of brain tumor.
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Different types of neuroimaging techniques

Computerized tomography

With the advent of computerized axial tomography (CAT or CT scanning), ever more detailed anatomic images of the brain became available for diagnostic and research purposes. The names of Oldendorf (in 1961) Godfrey Newbold Hounsfield and Allan McLeod Cormack (in 1973) are associated with this revolutionary innovation, which enabled much easier, safer, non-invasive, painless and (to a reasonable extent) repeatable neuro-investigation. Cormack and Hounsfield won the Nobel Prize in Physiology or Medicine in 1979 for this work.

Radioactive neuroimaging

Early techniques such as xenon inhalation provided the first blood flow maps of the brain. Developed in the early 1960s by Niels A. Lassen, David H. Ingvar and Erik Skinhøj in southern Scandinavia it used the isotope xenon-133. Later versions would have 254 scintillators so a two-dimensional image could be produced on a color monitor. It allowed them to construct images reflecting brain activation from speaking, reading, visual or auditory perception and voluntary movement.[2]

Soon after the invention of CAT, the development of radioligands started the functional imaging revolution. Radioligands either remain within the bloodstream or enter the brain and bind to receptors. Radioligands are either single photon or positron emitters. This is how single photon emission computed tomography (SPECT) and positron emission tomography (PET) got their names. Edward J. Hoffman and Michael Phelps developed the first human PET scanner in 1973.

Functional imaging took a large step forward with the development of oxygen-15 labelled water (H215O, or H2O-15) imaging. H2O-15 emits positrons and creates images based on regional blood flow within the brain. Since active neurons recruit a robust blood supply, H2O-15 PET allowed investigators to make regional maps of brain activity during various cognitive tasks. Later, a more common sort of functional imaging based on PET scans used FDG, a positron-emitting sugar-derivative which is distributed in the brain according to local metabolic activity. Unlike the short half-life of oxygen-15 (2.25 minutes), the 110 minute half-life of FDG allowed PET scans by machines physically distant from the cyclotron producing the isotope (in this case fluorine-18).
Magnetic resonance imaging

More or less concurrently, magnetic resonance imaging (MRI or MR scanning) was developed. Rather than using ionizing or x-radiation, MRI uses the variation in signals produced by protons in the body when the head is placed in a strong magnetic field. Associated with early application of the basic technique to the human body are the names of Jackson (in 1968), Damadian (in 1972), and Abe and Paul Lauterbur (in 1973). Lauterbur and Sir Peter Mansfield were awarded the 2003 Nobel Prize in Physiology or Medicine for their discoveries concerning MRI. At first, structural imaging benefited more than functional imaging from the introduction of MRI. During the 1980s a veritable explosion of technical refinements and diagnostic MR applications took place, enabling even neurological tyros to diagnose brain pathology that would have been elusive or incapable of demonstration in a living person only a decade or two earlier.\[1\]

Scientists soon learned that the large blood flow changes measured by H20-15 PET were also imaged by MRI. Functional magnetic resonance imaging (fMRI) was born. Since the 1990s, fMRI has come to dominate the brain mapping field due to its low invasiveness, lack of radiation exposure, and relatively wide availability.

Physicists have also developed other MRI-based techniques such as magnetic resonance spectroscopy (for measuring some key metabolites such as N-acetylaspartate and lactate within the living brain) and diffusion tensor imaging (for mapping white matter tracts within the living brain). Whereas structural MRI and CAT scanning have a large place in medicine, fMRI and its brethren techniques are still largely devoted to neuroscience research. However, very recently neurologists have started to use fMRI to begin to answer clinical questions, such as how long after thrombotic stroke is it safe and effective to give clot-dissolving drug like tissue plasminogen activator (TPA). Similarly, PET and SPECT have moved out of neuro-research and are increasingly being used clinically to help diagnose and differentiate types of dementing illnesses (dementia).

Multimodal neuroimaging

Multimodal imaging combines existing brain imaging techniques in synergistic ways which facilitate the improved interpretation of data.
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Besides fMRI, another example of technology allowing relatively older brain imaging techniques to be even more helpful is the ability to combine different techniques to get one brain map. This happens quite frequently with MRI and EEG scans. The electrical diagram of the EEG provides split-second timing while the MRI provides high levels of spatial accuracy.

Anatomically-constrained Magnetoencephalography (aMEG) is a relatively new technique which was first employed in 2000. It combines the spatial resolution of a structural MRI scan with the temporal resolution of the MEG. Often the non-uniqueness of the MEG source estimation problem (inverse problem) can be alleviated by incorporating information from other imaging modalities as an a priori constraint. aMEG uses anatomical MRI data as a geometrical or location constraint and as a medium for visualization of MEG results. MEG does not provide structural or anatomical information. Therefore, MEG data is often combined with MR data into a composite image whereby functional information is overlaid on the corresponding anatomy to produce an activation map.

Recent breakthroughs

Recent breakthroughs in non-invasive brain imaging have been somewhat limited because most of them have not been completely novel; rather, they are simply refining existing brain imaging techniques. fMRI is a perfect example of this from the early 1990s, and it still remains the most popular brain imaging technique available today.

Advances have been made in a number of ways regarding neuroimaging, and this section will cover some of the more prominent improvements including computational advances, transcranial magnetic stimulation, and nuclear magnetic resonance.

To begin with, much of the recent progress has had to do not with the actual brain imaging methods themselves but with our ability to utilize computers in analyzing the data. For example, substantial discoveries in the growth of human brains from age three months to the age of fifteen have been made due to the creation of high-resolution brain maps and computer technology to analyze these maps over various periods of time and growth (Thompson, UCLA). This type of breakthrough represents the nature of most breakthroughs in neuroscience today. With fMRI
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technology mapping brains beyond what we are already understanding, most innovators time is being spent trying to make sense of the data we already have rather than probing into other realms of brain imaging and mapping.

This can be seen more clearly in the fact that brain imaging archives are catching on and neuroinformatics is allowing researchers to examine thousands of brains rather than just a few (Lynch). Also, these archives are universalizing and standardizing formats and descriptions so that they are more searchable for everyone. For the past decade we have been able to get data and now our technology allows us to share findings and research much easier. This has also allowed for "brain atlases" to be made. Brain atlases are simply maps of what normal functioning brains look like (Thompson, Bioinformatics).

Transcranial magnetic stimulation (TMS) is a recent innovation in brain imaging. In TMS, a coil is held near a person's head to generate magnetic field impulses that stimulate underlying brain cells to make someone perform a specific action. Using this in combination with MRI, the researcher can generate maps of the brain performing very specific functions. Instead of asking a patient to tap his or her finger, the TMS coil can simply "tell" his or her brain to tap his or her finger. This eliminates many of the false positives received from traditional MRI and fMRI testing. The images received from this technology are slightly different from the typical MRI results, and they can be used to map any subject's brain by monitoring up to 120 different stimulations. This technology has been used to map both motor processes and visual processes (Potts link at bottom of TMS). In addition to fMRI, the activation of TMS can be measured using electroencephalography (EEG) or near infrared spectroscopy (NIRS).

Nuclear magnetic resonance (NMR) is what MRI and fMRI technologies were derived from, but recent advances have been made by going back to the original NMR technology and revamping some of its aspects. NMR traditionally has two steps, signal encoding and detection, and these steps are normally carried out in the same instrument. The new discovery, however, suggests that using laser-polarized xenon gas for "remembering" encoded information and transporting that information to a remote detection site could prove far more effective (Preuss). Separating the encoding and detection allows researchers to gain data
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about chemical, physical, and biological processes that they have been unable to gain until now. The end result allows researchers to map things as big as geological core samples or as small as single cells.

It is interesting to see how advances are split between those seeking a completely mapped brain by utilizing single neuron imaging and those utilizing images of brains as subjects perform various high-level tasks. Single neuron imaging (SNI) uses a combination of genetic engineering and optical imaging techniques to insert tiny electrodes into the brain for the purpose of measuring a single neuron's firing. Due to its damaging repercussions, this technique has only been used on animals, but it has shed a lot of light on basic emotional and motivational processes. The goal of studies in higher-level activities is to determine how a network of brain areas collaborates to perform each task. This higher-level imaging is much easier to do because researchers can easily use subjects who have a disease such as Alzheimer's. The SNI technology seems to be going after the possibility for AI while the network-probing technology seems to be more for medical purposes.

Medical imaging

A general world used to describe one of the uses of MRI, however itself can be considered as a biological use or one of the multi applications of MRI done in healthcare centers and in hospitals. Medical imaging is the technique and process used to create images of the human body (or parts and function thereof) for clinical purposes (medical procedures seeking to reveal, diagnose or examine disease) or medical science (including the study of normal anatomy and physiology). Although imaging of removed organs and tissues can be performed for medical reasons, such procedures are not usually referred to as medical imaging, but rather are a part of pathology.

As a discipline and in its widest sense, it is part of biological imaging and incorporates radiology (in the wider sense), nuclear medicine, investigative radiological sciences, endoscopy, (medical) thermography, medical photography and microscopy (e.g. for human pathological investigations).

Measurement and recording techniques which are not primarily designed to produce images, such as electroencephalography (EEG), magnetoencephalography (MEG), Elec
trocardiography (EKG) and others, but which produce data susceptible to be represented as maps (i.e. containing positional information), can be seen as forms of medical imaging.

Up until 2010, 5 billion medical imaging studies had been conducted worldwide.[1] Radiation exposure from medical imaging in 2006 made up about 50% of total ionizing radiation exposure in the United States.

**Overview**

In the clinical context, "invisible light" medical imaging is generally equated to radiology or "clinical imaging" and the medical practitioner responsible for interpreting (and sometimes acquiring) the images is a radiologist. "Visible light" medical imaging involves digital video or still pictures that can be seen without special equipment. Dermatology and wound care are two modalities that utilize visible light imagery. Diagnostic radiography designates the technical aspects of medical imaging and in particular the acquisition of medical images. Theradiographer or radiologic technologist is usually responsible for acquiring medical images of diagnostic quality, although some radiological interventions are performed by radiologists. While radiology is an evaluation of anatomy, nuclear medicine provides functional assessment.

As a field of scientific investigation, medical imaging constitutes a sub-discipline of biomedical engineering, medical physics or medicine depending on the context: Research and development in the area of instrumentation, image acquisition (e.g. radiography), modelling and quantification are usually the preserve of biomedical engineering, medical physics and computer science; Research into the application and interpretation of medical images is usually the preserve of radiology and the medical sub-discipline relevant to medical condition or area of medical science (neuroscience, cardiology, psychiatry, psychology, etc.) under investigation. Many of the techniques developed for medical imaging also have scientific and industrial applications.

Medical imaging is often perceived to designate the set of techniques that noninvasively produce images of the internal aspect of the body. In this restricted sense, medical imaging can be seen as the solution
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of mathematical inverse problems. This means that cause (the properties of living tissue) is inferred from effect (the observed signal). In the case of ultrasonography the probe consists of ultrasonic pressure waves and echoes inside the tissue show the internal structure. In the case of projection radiography, the probe is X-ray radiation which is absorbed at different rates in different tissue types such as bone, muscle and fat.

The term noninvasive is a term based on the fact that following medical imaging modalities do not penetrate the skin physically. But on the electromagnetic and radiation level, they are quite invasive. From the high energy photons in X-Ray Computed Tomography, to the 2+ Tesla coils of an MRI device, these modalities alter the physical and chemical environment of the body in order to obtain data.

Available technologies

Radiography

Two forms of radiographic images are in use in medical imaging; projection radiography and fluoroscopy, with the latter being useful for catheter guidance. These 2D techniques are still in wide use despite the advance of 3D tomography due to the low cost, high resolution, and depending on application, lower radiation dosages. This imaging modality utilizes a wide beam of x rays for image acquisition and is the first imaging technique available in modern medicine.

Fluoroscopy produces real-time images of internal structures of the body in a similar fashion to radiography, but employs a constant input of x-rays, at a lower dose rate. Contrast media, such as barium, iodine, and air are used to visualize internal organs as they work. Fluoroscopy is also used in image-guided procedures when constant feedback during a procedure is required. An image receptor is required to convert the radiation into an image after it has passed through the area of interest. Early on this was a fluorescent screen, which gave way to an Image Amplifier (IA) which was a large vacuum tube that had the receiving end coated with cesium iodide, and a mirror at the opposite end. Eventually the mirror was replaced with a TV camera.

Projectional radiographs, more commonly known as x-rays, are often used to determine the type and extent of a fracture as well as for detecting pathological changes in the lungs. With the use of radio-
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opaque contrast media, such as barium, they can also be used to visualize the structure of the stomach and intestines - this can help diagnose ulcers or certain types of colon cancer.

Magnetic resonance imaging (MRI)

A magnetic resonance imaging instrument (MRI scanner), or "nuclear magnetic resonance (NMR) imaging" scanner as it was originally known, uses powerful magnets to polarise and excite hydrogen nuclei (single proton) in water molecules in human tissue, producing a detectable signal which is spatially encoded, resulting in images of the body. The MRI machine emits an RF (radio frequency) pulse that specifically binds only to hydrogen. The system sends the pulse to the area of the body to be examined. The pulse makes the protons in that area absorb the energy needed to make them spin in a different direction. This is the "resonance" part of MRI. The RF pulse makes them (only the one or two extra unmatched protons per million) spin at a specific frequency, in a specific direction. The particular frequency of resonance is called the Larmour frequency and is calculated based on the particular tissue being imaged and the strength of the main magnetic field. MRI uses three electromagnetic fields: a very strong (on the order of units of teslas) static magnetic field to polarize the hydrogen nuclei, called the static field; a weaker time-varying (on the order of 1 kHz) field(s) for spatial encoding, called the gradient field(s); and a weak radio-frequency (RF) field for manipulation of the hydrogen nuclei to produce measurable signals, collected through an RF antenna.
Magnetic Resonance Imaging

Like CT, MRI traditionally creates a two dimensional image of a thin "slice" of the body and is therefore considered a tomographic imaging technique. Modern MRI instruments are capable of producing images in the form of 3D blocks, which may be considered a generalisation of the single-slice, tomographic, concept. Unlike CT, MRI does not involve the use of ionizing radiation and is therefore not associated with the same health hazards. For example, because MRI has only been in use since the early 1980s, there are no known long-term effects of exposure to strong static fields (this is the subject of some debate; see 'Safety' in MRI) and therefore there is no limit to the number of scans to which an individual can be subjected, in contrast with X-ray and CT. However, there are well-identified health risks associated with tissue heating from exposure to the RF field and the presence of implanted devices in the body, such as pacemakers. These risks are strictly controlled as part of the design of the instrument and the scanning protocols used.

Because CT and MRI are sensitive to different tissue properties, the appearance of the images obtained with the two techniques differ markedly. In CT, X-rays must be blocked by some form of dense tissue to create an image, so the image quality when looking at soft tissues will be poor. In MRI, while any nucleus with a net nuclear spin can be used, the proton of the hydrogen atom remains the most widely used, especially in the clinical setting, because it is so ubiquitous and returns a large signal. This nucleus, present in water molecules, allows the excellent soft-tissue contrast achievable with MRI.

Nuclear medicine

Nuclear medicine encompasses both diagnostic imaging and treatment of disease, and may also be referred to as molecular medicine or molecular imaging & therapeutics. Nuclear medicine uses certain properties of isotopes and the energetic particles emitted from radioactive material to diagnose or treat various pathology. Different from the typical concept of anatomic radiology, nuclear medicine enables assessment of physiology. This function-based approach to medical evaluation has useful applications in most subspecialties, notably oncology, neurology, and cardiology. Gamma cameras are used in e.g. scintigraphy, SPECT and PET to detect regions of biologic activity that may be associated with disease. Relatively short lived isotope, such as 123I is administered to the
**Magnetic Resonance Imaging**

patient. Isotopes are often preferentially absorbed by biologically active tissue in the body, and can be used to identify tumors or fracture points in bone. Images are acquired after collimated photons are detected by a crystal that gives off a light signal, which is in turn amplified and converted into count data.

- **Scintigraphy** ("scint") is a form of diagnostic test wherein radioisotopes are taken internally, for example intravenously or orally. Then, gamma cameras capture and form two-dimensional[4] images from the radiation emitted by the radiopharmaceuticals.

- **SPECT** is a 3D tomographic technique that uses gamma camera data from many projections and can be reconstructed in different planes. A dual detector head gamma camera combined with a CT scanner, which provides localization of functional SPECT data, is termed a SPECT/CT camera, and has shown utility in advancing the field of molecular imaging. In most other medical imaging modalities, energy is passed through the body and the reaction or result is read by detectors. In SPECT imaging, the patient is injected with a radioisotope, most commonly Thallium 201TI, Technetium 99mTC, Iodine 123I, and Gallium 67Ga.

The radioactive gamma rays are emitted through the body as the natural decaying process of these isotopes takes place. The emissions of the gamma rays are captured by detectors that surround the body. This essentially means that the human is now the source of the radioactivity, rather than the medical imaging devices such as X-Ray, CT, or Ultrasound.

- **Positron emission tomography (PET)** uses coincidence detection to image functional processes. Short-lived positron emitting isotope, such as 18F, is incorporated with an organic substance such as glucose, creating F18-fluorodeoxyglucose, which can be used as a marker of metabolic utilization. Images of activity distribution throughout the body can show rapidly growing tissue, like tumor, metastasis, or infection. PET images can be viewed in comparison to computed tomography scans to determine an anatomic correlate. Modern scanners combine PET with a CT, or even MRI, to optimize the image reconstruction involved with positron imaging. This is
Magnetic Resonance Imaging

performed on the same equipment without physically moving the patient off of the gantry. The resultant hybrid of functional and anatomic imaging information is a useful tool in non-invasive diagnosis and patient management.

Photo acoustic imaging

Photoacoustic imaging is a recently developed hybrid biomedical imaging modality based on the photoacoustic effect. It combines the advantages of optical absorption contrast with ultrasonic spatial resolution for deep imaging in (optical) diffusive or quasi-diffusive regime. Recent studies have shown that photoacoustic imaging can be used in vivo for tumor angiogenesis monitoring, blood oxygenation mapping, functional brain imaging, and skin melanoma detection, etc.

Tomography

Tomography is the method of imaging a single plane, or slice, of an object resulting in a tomogram. There are several forms of tomography:

- **Linear tomography:** This is the most basic form of tomography. The X-ray tube moved from point "A" to point "B" above the patient, while the cassette holder (or "bucky") moves simultaneously under the patient from point "B" to point "A." The fulcrum, or pivot point, is set to the area of interest. In this manner, the points above and below the focal plane are blurred out, just as the background is blurred when panning a camera during exposure. No longer carried out and replaced by computed tomography.

- **Poly tomography:** This was a complex form of tomography. With this technique, a number of geometrical movements were programmed, such as hypocycloidal, circular, figure 8, and elliptical. Philips Medical Systems [1] produced one such device called the 'Polytome.' This unit was still in use into the 1990s, as its resulting images for small or difficult physiology, such as the inner ear, was still difficult to image with CTs at that time. As the resolution of CTs got better, this procedure was taken over by the CT.
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Zonography: This is a variant of linear tomography, where a limited arc of movement is used. It is still used in some centres for visualising the kidney during an intravenous urogram (IVU).

Orthopantomography (OPT or OPG): The only common tomographic examination in use. This makes use of a complex movement to allow the radiographic examination of the mandible, as if it were a flat bone. It is often referred to as a "Panorex", but this is incorrect, as it is a trademark of a specific company.

Computed Tomography (CT), or Computed Axial Tomography (CAT: A CT scan, also known as a CAT scan), is a helical tomography (latest generation), which traditionally produces a 2D image of the structures in a thin section of the body. It uses X-rays. It has a greater ionizing radiation dose burden than projection radiography; repeated scans must be limited to avoid health effects. CT is based on the same principles as X-Ray projections but in this case, the patient is enclosed in a surrounding ring of detectors assigned with 500-1000 scintillation detectors. This being the fourth-generation X-Ray CT scanner geometry. Previously in older generation scanners, the X-Ray beam was paired by a translating source and detector.

Ultrasound

Ultrasound representation of Urinary bladder (black butterfly-like shape) and hyperplastic prostate

Medical ultrasonography uses high frequency broadband sound waves in the megahertz range that are reflected by tissue to varying degrees to produce (up to 3D) images. This is commonly associated with imaging the fetus in pregnant women. Uses of ultrasound are much broader, however. Other important uses include imaging the abdominal organs, heart, breast, muscles, tendons, arteries and veins. While it may provide less anatomical detail than
Magnetic Resonance Imaging

techniques such as CT or MRI, it has several advantages which make it ideal in numerous situations, in particular that it studies the function of moving structures in real-time, emits no ionizing radiation, and contains speckle that can be used inelastography. Ultrasound is also used as a popular research tool for capturing raw data, that can be made available through an Ultrasound research interface, for the purpose of tissue characterization and implementation of new image processing techniques. The concepts of ultrasound differ from other medical imaging modalities in the fact that it is operated by the transmission and receipt of sound waves. The high frequency sound waves are sent into the tissue and depending on the composition of the different tissues; the signal will be attenuated and returned at separate intervals. A path of reflected sound waves in a multilayered structure can be defined by an input acoustic impedance( Ultrasound sound wave) and the Reflection and transmission coefficients of the relative structures[5] . It is very safe to use and does not appear to cause any adverse effects, although information on this is not well documented. It is also relatively inexpensive and quick to perform. Ultrasound scanners can be taken to critically ill patients in intensive care units, avoiding the danger caused while moving the patient to the radiology department. The real time moving image obtained can be used to guide drainage and biopsy procedures. Doppler capabilities on modern scanners allow the blood flow in arteries and veins to be assessed.

Cardiac PET

Brief description

Cardiac PET (or cardiac positron emission tomography) is a form of diagnostic imaging in which patients are evaluated using a PET scanner after intravenously injected with a radioisotope. Although several isotopes have been used for Cardiac PET imaging, the most widely employed in clinical practice are Rubidium-82 and Nitrogen-13 ammonia.

The requirements to perform Cardiac PET imaging include:

Facility: taking into consideration clinical workflow, as well as regulatory requirements such as requisite shielding from radiation exposure
Capital equipment: PET or PET/CT scanner
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Radiopharmaceutical: Rubidium-82 generator system or close access to cyclotron produced isotopes such as Nitrogen-13 ammonia

Personnel: including specialty trained physician, radiation safety, physics, nursing, and technologist support

Operations: stress test monitoring, as well as emergency response equipment, processing and review workstations, administrative and support personnel are additional considerations

This form of diagnostic imaging has traditionally been perceived as cost-prohibitive in comparison to general nuclear medicine cardiac stress testing using single photon emission computed tomography (SPECT). However, due to significant gains in access to scanners, related to the widely accepted role of PET/CT in clinical oncology, cardiac PET is likely to become more widely available, particularly given various clinical and technical advantages that might make this a potential test of choice in the diagnosis of coronary artery/heart disease.

Cardiac PET imaging has now been expanded to mobile services to facilitate rural areas by a company called Nuclear Imaging Services located in Houston, TX. They now have the first Medicare approved mobile Cardiac PET scanner available for patient use.

SAFETY

There are no known dangers or side effects connected to an MRI scan. The test is not painful; you cannot feel it. Since radiation is not used, the procedure can be repeated without problems. There is a small theoretical risk to the fetus in.

The first 12 weeks of pregnancy, and therefore scans are not performed on pregnant women during this time. There are risks and benefits. Those pieces of technology in wide use generally have a high benefit to risk ratio, while those with a low benefit to risk ratio are generally used more sparingly. Although MRI does not use ionizing radiation to produce images there are still some important safety considerations which one should be familiar with. These concern the use of strong magnetic fields, radio frequency energy, time varying magnetic fields, cryogenic liquids, and magnetic field gradients.
In 1982 the US FDA set guidelines for MRI exams that covered the maximum Bo field, change in magnetic field with respect to time (dB/dt), the absorption of radio frequency energy, and acoustic noise levels. These are summarized in the animation window table. In 1997, the US FDA revised these guidelines due to the accumulated data on MRI.

Because patients have to lie inside a large cylinder while the scans are being made some people get claustrophobic during the test. Patients who are afraid this might happen should talk to the doctor beforehand, who may give them some medication to help them relax.

The machine also makes a banging noise while it is working, which might be unpleasant.
Although MRI is completely safe, it is instructive to consider how the scanner interacts with the patient. To put this section into historical context, in 1980 there were concerns about using field strengths as little as 0.35 T but within 6 years this 'safe' limit had moved up to 2.0 T. Similarly, gradient performances were limited to 3 T/s in the mid-1980s whereas today MRI is routinely performed with gradients exceeding 50 T/s. What follows is a summary of each particular safety issue associated with MRI. It is intended to be educational and certainly should not be misconstrued.

A number of features of MRI scanning can give rise to risks. These include:

- Powerful magnetic fields
- Cryogenic liquids
- Noise

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- Claustrophobia

In addition, in cases where MRI contrast agents are used, these also typically have associated risks.

Magnetic field

Most forms of medical or biostimulation implants are generally considered contraindications for MRI scanning. These include pacemakers, vague nerve stimulators, implantable cardioverter-defibrillators, loop recorders, insulin pumps, cochlear implants, deep brain stimulators and capsules retained from capsule endoscopy. Patients are therefore always asked for complete information about all implants before entering the room for an MRI scan. Several deaths have been reported in patients with pacemakers who have undergone MRI scanning without appropriate precautions.[citation needed] To reduce such risks, implants are increasingly being developed to make them able to be safely scanned,[36] and specialized protocols have been developed to permit the safe scanning of selected implants and pacing devices. Cardiovascular stents are considered safe, however.

Ferromagnetic foreign bodies such as shell fragments, or metallic implants such as surgical prostheses and aneurysm clips are also potential risks. Interaction of the magnetic and radio frequency fields with such objects can lead to trauma due to movement of the object in the magnetic field or thermal injury from radio-frequency induction heating of the object.

Titanium and its alloys are safe from movement from the magnetic field.

In the United States a classification system for implants and ancillary clinical devices has been developed by ASTM International and is now the standard supported by the US Food and Drug Administration:
**MR Safe sign**

MR-Safe — The device or implant is completely non-magnetic, non-electrically conductive, and non-RF reactive, eliminating all of the primary potential threats during an MRI procedure.

**MR Conditional sign**

MR-Conditional — A device or implant that may contain magnetic, electrically conductive or RF-reactive components that is safe for operations in proximity to the MRI, provided the conditions for safe operation are defined and observed (such as 'tested safe to 1.5 teslas' or 'safe in magnetic fields below 500 gauss in strength').

**MR Unsafe sign**

MR-Unsafe — nearly self-explanatory, reserved for objects that are significantly ferromagnetic and pose a clear and direct threat to persons and equipment within the magnet room.
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The very high strength of the magnetic field can also cause "missile-effect" accidents, where ferromagnetic objects are attracted to the center of the magnet, and there have been incidences of injury and death. To reduce the risks of projectile accidents, ferromagnetic objects and devices are typically prohibited in proximity to the MRI scanner and patients undergoing MRI examinations are required to remove all metallic objects, often by changing into a gown or scrubs and ferromagnetic detection devices are used by some sites.

There is no evidence for biological harm from even very powerful static magnetic fields

Radio frequency energy

A powerful radio transmitter is needed for excitation of proton spins. This can heat the body to the point of risk of hyperthermia in patients, particularly in obese patients or those with thermoregulation disorders[citation needed]. Several countries have issued restrictions on the maximum specific absorption rate that a scanner may produce.

Peripheral nerve stimulation (PNS)

The rapid switching on and off of the magnetic field gradients is capable of causing nerve stimulation. Volunteers report a twitching sensation when exposed to rapidly switched fields, particularly in their extremities[citation needed]. The reason the peripheral nerves are stimulated is that the changing field increases with distance from the center of the gradient coils (which more or less coincides with the center of the magnet).[citation needed] Note however that when imaging the head, the heart is far off-center and induction of even a tiny current into the heart must be avoided at all costs.[citation needed] Although PNS was not a problem for the slow, weak gradients used in the early days of MRI, the strong, rapidly switched gradients used in techniques such as EPI, fMRI, diffusion MRI, etc. are indeed capable of inducing PNS. American and European regulatory agencies insist that manufacturers stay below specified dB/dt limits (dB/dt is the change in field per unit time) or else prove that no PNS is induced for any imaging sequence. As a result of dB/dt limitation, commercial MRI systems cannot use the full rated power of their gradient amplifiers.
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Acoustic noise
Switching of field gradients causes a change in the Lorentz force experienced by the gradient coils, producing minute expansions and contractions of the coil itself. As the switching is typically in the audible frequency range, the resulting vibration produces loud noises (clicking or beeping). This is most marked with high-field machines[43] and rapid-imaging techniques in which sound intensity can reach 120 dB(A)(equivalent to a jet engine at take-off)[44] and therefore appropriate ear protection is essential for anyone inside the MRI scanner room during the examination.[45]

Cryogens
As described in Physics of Magnetic Resonance Imaging, many MRI scanners rely on cryogenic liquids to enable superconducting capabilities of the electromagnetic coils within. Though the cryogenic liquids used are non-toxic, their physical properties present specific hazards.

An unintentional shut-down of a superconducting electromagnet, an event known as "quench", involves the rapid boiling of liquid helium from the device. If the rapidly expanding helium cannot be dissipated through an external vent, sometimes referred to as 'quench pipe', it may be released into the scanner room where it may cause displacement of the oxygen and present a risk of asphyxiation.

Oxygen deficiency monitors are usually used as a safety precaution. Liquid helium, the most commonly used cryogen in MRI, undergoes near explosive expansion as it changes from liquid to a gaseous state. The use of an Oxygen monitor is important for two reasons: 1. Keeping the O2 levels safe for patient/physicians and; 2. Making sure the MRI Scanner is working properly. Rooms built in support of superconducting MRI equipment should be equipped with pressure relief mechanisms[47] and an exhaust fan, in addition to the required quench pipe.

Since a quench results in rapid loss of all cryogens in the magnet, recommissioning the magnet is expensive and time-consuming. Spontaneous quenches are uncommon, but may also be triggered by equipment malfunction, improper cryogen fill technique, contaminants inside the cryostat, or extreme magnetic or vibrational disturbances.
Contrast agents
The most commonly used intravenous contrast agents are based on chelates of gadolinium. In general, these agents have proved safer than the iodinated contrast agents used in X-ray radiography or CT. Anaphylactoid reactions are rare, occurring in approx. 0.03–0.1%. Of particular interest is the lower incidence of nephrotoxicity, compared with iodinated agents, when given at usual doses—this has made contrast-enhanced MRI scanning an option for patients with renal impairment, who would otherwise not be able to undergo contrast-enhanced CT.

Although gadolinium agents have proved useful for patients with renal impairment, in patients with severe renal failure requiring dialysis there is a risk of a rare but serious illness, nephrogenic systemic fibrosis that may be linked to the use of certain gadolinium-containing agents. The most frequently linked is gadodiamide, but other agents have been linked too. Although a causal link has not been definitively established, current guidelines in the United States are that dialysis patients should only receive gadolinium agents where essential, and that dialysis should be performed as soon as possible after the scan to remove the agent from the body promptly. In Europe, where more gadolinium-containing agents are available, a classification of agents according to potential risks has been released. Recently a new contrast agent named gadoxetate, brand name Eovist (US) or Primovist (EU) was approved for diagnostic use: this has the theoretical benefit of a dual excretion path.

Pregnancy
No effects of MRI on the fetus have been demonstrated. In particular, MRI avoids the use of ionizing radiation, to which the fetus is particularly sensitive. However, as a precaution, current guidelines recommend that pregnant women undergo MRI only when essential. This is particularly the case during the first trimester of pregnancy, as organogenesis takes place during this period. The concerns in pregnancy are the same as for MRI in general, but the fetus may be more sensitive to the effects—particularly to heating and to noise. However, one additional concern is the use of contrast agents; gadolinium compounds are known to cross the placenta and enter the fetal bloodstream, and it is recommended that their use be avoided.

Despite these concerns, MRI is rapidly growing in importance as a way of diagnosing and monitoring congenital defects of the fetus because it
**Magnetic Resonance Imaging**

can provide more diagnostic information than ultrasound and it lacks the ionizing radiation of CT. MRI without contrast agents is the imaging mode of choice for pre-surgical, in-utero diagnosis and evaluation of fetal tumors, primarily teratomas, facilitating open fetal surgery, other fetal interventions, and planning for procedures (such as the EXIT procedure) to safely deliver and treat babies whose defects would otherwise be fatal.

Claustrophobia and discomfort

Due to the construction of some MRI scanners, they can be potentially unpleasant to lie in. Older models of closed bore MRI systems feature a fairly long tube or tunnel. The part of the body being imaged must lie at the center of the magnet, which is at the absolute center of the tunnel. Because scan times on these older scanners may be long (occasionally up to 40 minutes for the entire procedure), people with even mild claustrophobia are sometimes unable to tolerate an MRI scan without management. Modern scanners may have larger bores (up to 70 cm) and scan times are shorter. This means that claustrophobia is less of an issue, and many patients now find MRI an innocuous and easily tolerated procedure.[citation needed]

Nervous patients may still find the following strategies helpful:

- Advance preparation
  - visiting the scanner to see the room and practice lying on the table
  - visualization techniques
  - chemical sedation
  - general anesthesia
- Coping while inside the scanner
  - holding a "panic button"
  - closing eyes as well as covering them (e.g. washcloth, eye mask)
  - listening to music on headphones or watching a movie, using mirror-glasses and a projection screen or via a Head-mounted display, while in the machine.
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Alternative scanner designs, such as open or upright systems, can also be helpful where these are available. Though open scanners have increased in popularity, they produce inferior scan quality because they operate at lower magnetic fields than closed scanners. However, commercial 1.5 tesla open systems have recently become available, providing much better image quality than previous lower field strength open models.[57]

For babies and young children chemical sedation or general anesthesia are the norm, as these subjects cannot be instructed to hold still during the scanning session. Obese patients and pregnant women may find the MRI machine to be a tight fit. Pregnant women may also have difficulty lying on their backs for an hour or more without moving.

Guidance

Safety issues, including the potential for biostimulation device interference, movement of ferromagnetic bodies, and incidental localized heating, have been addressed in the American College of Radiology's White Paper on MR Safety, which was originally published in 2002 and expanded in 2004. The ACR White Paper on MR Safety has been rewritten and was released early in 2007 under the new title ACR Guidance Document for Safe MR Practices.

In December 2007, the Medicines in Healthcare product Regulation Agency (MHRA), a UK healthcare regulatory body, issued their Safety Guidelines for Magnetic Resonance Imaging Equipment in Clinical Use. In February 2008, the Joint Commission, a US healthcare accrediting organization, issued a Sentinel Event Alert #38, their highest patient safety advisory, on MRI safety issues.

In July 2008, the United States Veterans Administration, a federal governmental agency serving the healthcare needs of former military personnel, issued a substantial revision to their MRI Design Guide, which includes physical or facility safety considerations.
Physiological effects of electricity

Figure 14.1  Physiological effects of electricity  Threshold or estimated mean values are given for each effect in a 70-kg human for a 1- to 3-s exposure to 60-Hz current applied via copper wires grasped by the hands.

Macroshock hazard

Figure 14.6  Macroshock due to a ground fault from hot line to equipment case for (a) ungrounded cases and (b) grounded chassis.
Recent development

As technology takes one step further toward new inventions we with our own eyes witness a new era of MRI, not just basic immobile MRI, but ones that can be used anywhere everywhere even right outside your home, as it fits perfectly in a truck, which is typical to that used in hospitals.
One of the companies which had a significant role in developing the normal MRI

Creating the future of MRI

Healthcare is changing at an almost incalculable rate. The demands of patients are altering expectations while the demands of business require new responses. It’s an exciting time filled with great opportunity. That’s how we see it at Siemens MRI. This is why we relentlessly drive innovation and transformation. Our focus is on helping our customers deliver superb care, more efficiently than ever. We measure ourselves by our ability to have a leading solution for each business need. This
Mobile MRI means the newest, most innovative technology in Magnetic Resonance delivered right to your doorstep in one complete package. A complete MRI solution in a mobile environment can address individual business needs and clinical requirements. Whether to meet growing capacity demands for MR scanning in your hospital or facility or to provide a temporary solution while your current MR system is being upgraded or replaced, Mobile MR solutions from Siemens will provide the answer.

You need access to the latest technology but have insufficient demand or budget to support your own system? Then Mobile MRI solutions from Siemens can help you build shared ownership models with your partners, providing access while reducing the cost. Or you may be a service provider, operating a single unit or fleet of mobile units delivering Mobile MRI solutions to your customers. You may need to add more capacity or upgrade your technology to provide more services. Whatever your business need, Siemens offers the leading solutions in Mobile MRI.
Leading technology

You have the choice between four Siemens solutions at 1.5T to meet your business need. MAGNETOM Avanto, delivering MRI excellence in 1.5T and incorporating the revolutionary Tim™ (Total imaging matrix) technology. MAGNETOM Espree, the first Open-Bore MRI System, which combines a 70 cm open bore with the world-wide shortest system length of 125 cm and Tim. MAGNETOM Symphony with a top performance at a great value. Or MAGNETOM ESSENZA, which was developed from the ground up to be an affordable, reliable powerhouse that will support both your clinical and financial success. Future security. And with the syngo EVOLVE Package – a unique offering to regularly participate in technological advances – you remain constantly up-to-date with upgrades to the latest Syngo software and hardware platforms. Syngo software support and two upgrades of the whole computer system within 6 years round out a most comprehensive obsolescence protection.
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Comparison

MRI VS. CAT scan

The CT scan, or computerized axial tomography, is a specialized x-ray (therefore, it uses ionized radiation) whereby the patient is placed in a tube and the x-ray source rotates 360 degrees around the patient directing a precise narrow x-ray beam through the body. A computer then interprets the information to construct an image that is a cross section of the body part to be examined. By moving the patient up or down in the scanner, the radiologist can get serial “cuts” or “slices”, and basically get a picture of what is inside the body. As a general rule, whereas the typical x-ray is good for highlighting dense structures like bone, the CT is good for soft tissues such as the chest or abdomen.

Magnetic resonance imaging (MRI) was developed later than CT scanning. An MRI machine uses computer-controlled radio waves and very big magnets, which create a magnetic field roughly 25,000 times stronger than the earth's magnetic field. After the machine creates a magnetic field, it sends radio waves into the body and then measures the response of its cells (how much energy they release) with a computer. From these responses, the computer is able to create a three dimensional picture of the inside of the body. MRI makes use of the fact that all living cells have a certain magnetic quality to them; because of this, MRI can provide a look at the biochemistry of living cells. The MRI has become the preferred imaging modality to diagnose disease of the brain or central nervous system.

Both the CT scan and the MRI have their strong points and their differences. The CT scan does use radiation, whereas the MRI does not. The CT scan is a quicker test, and is more accessible in less metropolitan
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areas. The CT scan is less costly than the MRI. Both tests provide detailed pictures of areas of the body that used to be inaccessible by conventional x-rays. CT scans give us excellent information on anatomical features and tissue density (this allows for the detection of tumors, and sometimes the ability to distinguish between malignant and benign tumors). CT scans can also detect calcium deposits, cysts, and abscesses. They are often used in place of ultrasound for obese patients because fat deposits often hinder ultrasonic waves. CT scanning does carry with it the risks associated with x-ray exposure, although it is significantly less than that from ordinary x-rays.

One of the more common questions about MRI vs CT scan asked by patients is what's the difference between CT and MRI? Why should I have a CT instead of an MRI? Or why should I have an MRI instead of a CT?

These are very common questions and imaging professionals like us have the answers. The answers come from 2 other very important questions....

1. What part of the body does your doctor want to see? AND

2. What's the reason for the exam?

CT Scan does not show you tendons and ligaments very well at all; at least not yet. MRI is the best choice for that. Tendons and ligaments around the shoulder and knee are best seen by the physics used in MRI. This is due to the density of the tissues that compose the tendons and ligaments.

Spinal cord is best seen by MRI for the same reason. The density of the spinal cord and the composition of it is such that MRI physics can show it to us much better than CT.

There are also reasons why CT is the exam of choice over MRI. It is the preferred modality for cancer, pneumonia, and abnormal chest x-rays. Bleeding in the brain, especially from injury, is better seen on CT than MRI. But a tumor in the brain is better seen on MRI. Many people suffer from ringing in the ears; CT displays the inner auditory canals well and there are natural remedies available to relieve it.

If you've been in an accident, organs can get torn or damaged. CT shows organ tear and organ injury quickly and efficiently. Broken bones and vertebral bodies of the spine are better seen on CT but injury to the spinal cord itself is displayed on MRI far better than CT.
Magnetic Resonance Imaging

CT is far superior at visualizing the lungs and organs in the chest cavity between the lungs. MRI is not a good tool for visualizing the chest or lungs at all.

MRI vs CT scan depends on what needs to be visualized and the reason you need the test. Radiologists are the doctors that specialize in reading images of the body and therefore know which test is best for showing anatomy according to the reason for the exam. Very experienced CT and MRI technologists will also know from working with Radiologists.

The difference in the way the images are produced in MRI vs CT is the physics involved. CT scan uses an x-ray beam that slices through you like a knife carving a spiral ham.

MRI (magnetic resonance imaging) uses a magnetic field with radio frequencies introduced into it. When your body is placed inside the magnetic field, the molecules of water in your body (hydrogen molecules) will start to spin like a kid's top when he spins it. The top will begin to wobble as it slows down.

Your hydrogen molecules will start to wobble just like the top does at a certain rate of speed; the stronger the magnetic field, the faster they will wobble and the weaker the magnetic field, the slower they will wobble; it depends on the strength of the magnetic field.

Then a radio frequency is introduced into the magnetic field at the same rate of speed at which the "tops wobble" causing the wobbling tops and radio frequency to sing out together sharing the same signal frequency. (Thus the term resonance) That signal is used by the MRI computer to produce the image.

Differences between CT scan and MRI:

- In CT scans images are created by using x-rays while MRI uses magnetic waves to create images.
- CT scans can't help much in seeing clearly very fine soft tissue details as in the knee or shoulder compared to MRI. Also MRI provide more details of bony structures compared to CT scan.
- MRI scanners are best suited for imaging soft tissue.
- CT scan is more costly and needs long time (30min) to be completed as compared to MRI that is almost done in 5min.
- Pregnant women and patients having surgical clips, metallic fragments, cardiac monitors and pace makers cannot have CT scan.
Magnetic Resonance Imaging

- MRI machines can produce images in any plane without moving the patient and has got the ability to change the contrast of the images making them more clear than CT scan.

Is MRI Better Than CT?

MRI and CT are very different and used for different needs and reasons; both are valuable and both have specific applications; they are not interchangeable and one is not a better test than the other for all things.

The decision whether to use one or the other is based according to the density of the body tissue that needs to be seen. Softer tissues that have more water molecules or hydrogen atoms in them are better seen by MRI because of the physics used.

This is what an MRI image of the brain looks like.

![MRI Image of Brain](image)

Body tissue that is composed of a greater number of hydrogen atoms are seen well using MRI. Thus, MRI shows us the spinal cord, and tendons and ligaments in the knee and shoulder and brain tissue well but not the skull bone.

Brain tissue that is dying from loss of blood supply and tumors of the brain are best seen on MRI. Neurological diseases of the brain, like Multiple Sclerosis, are detectable on MRI and present as plaque deposits on the brain surface.

This makes MRI the modality used to look for neurological conditions
Magnetic Resonance Imaging

and abnormalities. It’s also used to look at bone marrow (inside the femur bone for example) but not the dense outer layer of bone; CT is used for that.

MRI is also used to evaluate internal organs and arteries in the neck and brain. IV contrast, different than what is used in CT, can also be used to fill the arteries for further evaluation when needed.

MRI does not use an x-ray beam; instead, you’re placed in a magnetic field instead of passing through a spinning X-ray beam like CT. This is why MRI scanners often make people feel claustrophobic. The design is such that the magnetic field needs to surround the part being imaged for the best resolution.

The image on the left is a CT Brain image that shows bleeding (white areas) in the brain. The image on the right is an MRI of the same brain. CT is far superior than MRI at visualizing bleeding in the brain from a head injury or a ruptured artery.

This side by side comparison shows how both CT and MRI are often used to help in evaluation and diagnoses.
What is the Difference Between Ultrasound and MRI?

Ultrasound and magnetic resonance imaging (MRI) are two types of medical imaging which are used to give doctors a glimpse of the inside of the body. They work in different ways, and each has some distinctive advantages and disadvantages which must be considered. Sometimes, a doctor may request imaging studies using both techniques to get a more complete view of what is going on inside a patient's body.

These imaging techniques have a number of similarities, starting with the fact that either method can be used to produce both still and moving pictures of the inside of the body. Both procedures are performed without the use of radiation, which is a distinct advantage of these types of medical imaging. In the case of a patient who needs multiple imaging studies, ultrasound and MRI are preferable because the patient's body is not at risk of damage from accumulated radiation. The techniques are also noninvasive to minimally invasive, depending on the specifics of the testing. In some cases, it may be necessary to inject contrast material, or to insert an ultrasound transducer into the body for the purpose of getting a better image.

In the case of ultrasound, the image is acquired by bouncing high frequency sound waves off the body cavity. The sound waves are collected upon their return, and the changes in frequency and angle are used to generate a picture of the patient's insides. With an MRI study, the
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patient is inserted into a large chamber which generates a magnetic field, agitating hydrogen atoms in the patient's body. The MRI machine reads the changes in the body's magnetic field and uses these changes to build a picture.

One major disadvantage of ultrasound is that it often has difficulty with obstructions. Certain parts of the body are difficult to image because thick bones or organs are in the way. By contrast, MRI images are very clear and crisp, and they can be taken along any plane of the body. In both cases, the image quality can be very high with a good machine, and the use of a contrast agent may improve visibility even more, allowing a doctor to see specific structures in detail.

The primary issue with magnetic resonance imaging is that the MRI machine will interact with magnetic objects in the room, and these objects can cause damage to the machine. The patient must remove all magnetic objects on his or her person, but in the case of patients with implanted medical devices, the MRI machine could cause a problem. MRI studies are especially dangerous for people with devices implanted in or around their hearts. In a case where MRI is not feasible, it may be necessary to use ultrasound.

MRI technician

An MRI technician is someone who operates, adjusts, and maintains MRI equipment. They are responsible for administering MRI procedures and doing purely technical analysis of the images obtained. The actual diagnoses based on the images are handled by a physician.
Magnetic Resonance Imaging

MRI technology is considered a branch of radiology in general, which includes other imaging techniques such as x-ray technology, CT scans, and mammography.

MRI Applications

MRI scans are used to detect differences between tissue types or different chemical compounds in the body. Since these different types respond to the electromagnetic fields being produced differently, they can be differentiated from each other by the scanning equipment. This creates a very effective MRI image. Mainly the advantage of this type of images over other techniques such as ultrasound and x-rays is its accuracy and clarity in certain imaging situations.

Brain Scanning

One of the main areas where MRI scans are used is in scanning the brain. These scans can accurately image what is going on in the grey matter. It tends to be used in cases of head trauma, aneurysms, stroke, and brain tumors. These various conditions appear with clarity in the images that are created.
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Spinal Cord

MRI scans also prove useful in investigating injuries and conditions of the spinal cord. It accurately images both the interior spinal cord itself and the vertebrae and disks of the spine. This is often done after accidents in which patients have received trauma to the spinal column.

Heart

The heart can also be accurately imaged by an MRI scan and thus used to diagnose cardiac problems. It’s main advantages here is that it is noninvasive and may give better imaging than echocardiography (discussed a bit below) and some other techniques.

MRI technicians are responsible for administering these and other types of MRI scans. They often discuss the procedure with patients before hand, handle the actual procedure, adjust equipment, and reposition patients as the process continues. Afterwards they make various technical analyses of the images taken in order to assist physicians in interpreting them.

Ultrasound Technicians

Modern diagnostic ultrasound is used as a noninvasive, non-ion radiating method of imaging internal body structures without the side effects that x-ray has on the body. Diagnostic ultrasound gives us a near perfect, real-
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time view of the body and its operations. More powerful computer processors and integrated circuits allow ultrasound to perform functions that were previously impossible. The improved image quality and new capabilities gained over the past few years have given rise to its popularity in diagnosis and make this modality one of the fastest growing methods of medical imaging.

Ultrasound is used for the detection of boundaries between different types of tissue. Standard, 2-dimensional gray scale ultrasound is used to detect changes in organs due to disease. Such changes include the build-up of atherosclerotic plaques in arteries and the development of tumors in the liver and other organs. Ultrasound is also used to monitor fetal development and provide a reference for the calculation of the fetal growth rate and expectancy date. Some ultrasound transducers are mounted on the tips of catheters that can be inserted into blood vessels to obtain images of the insides of arteries. Other transducers are designed to go into the esophagus to image the heart. Ultrasound is also used to calculate the velocity of blood flow. This is accomplished by using the principles of Doppler. The calculated Doppler signal is displayed either in a spectral format, for accurate calculations, or in a color format for ease in locating problem areas.

Rapid advances improving the function of ultrasound are directly attributable to improvement in the speed and reduction in size of the integrated circuits used in ultrasound equipment. These improvements allow the use of more complex software, thus utilizing information that was always present, but unattainable.

Ultrasound is an entirely different type of technology. It sends high frequency sound waves toward the body of the patient. These waves penetrate and strike various parts of the interior of the body, then bounce off. What is basically occurring is that this sound is echoing. Though this is not audible to the human ear, these echoes can be gathered by the imaging equipment and used to create an image.

An ultrasound technician, like an MRI technician, is responsible for handling the entire technical end of the ultrasound imaging process. They explain the procedure to patients, run the actual ultrasound procedure, adjust equipment, positions patients, and perform technical analyses after the images are taken.
Ultrasound Applications

This kind of imaging is considered quite accurate in many situations. It may be used for some of the following applications:

Obstetrics/Gynecology

Ultrasound can be used to create images of the fetus in the womb and a woman’s reproductive system in general.

Cardiology

The use of ultrasound in cardiology is known as echocardiography. This is an accurate and relatively safe technique that produce clear images of the heart.

Musculoskeletal Imaging

Ultrasound can clearly show muscles, bones, tendons, ligaments, connective tissue, and so on. This is especially useful in situations of traumatic injury such as breaks and sprains.
Therapeutic Ultrasound

Ultrasound technicians do not solely deal with imaging for diagnostic purposes. There is also a whole branch of the field that deals with the therapeutic effects of ultrasound. It may be used, for instance, to break through blood clots, dissolve cysts or tumors, or treat cataracts.

The main difference between these modalities then is the technology used and its resulting applications. This just depends on the specifics of a given medical and imaging situation. It’s also important to note that MRI and radiology in general is considered more dangerous than ultrasound, so MRI technicians usually must be licensed in order to practice, while with sonography this is not a requirement. Either of these professionals may also deal with other imaging techniques, but it is perhaps a bit more common for MRI technicians to perform other radiology techniques such as X-rays or CT scans.

**MRI VS. X-ray**

Difference Between MRI & X Ray (for Back Pain)

Having chronic back pain can be a debilitating experience. Diagnosing and treating its cause can alleviate some, if not all, of that pain. Most doctors use magnetic resonance imaging (MRI) or X-rays during diagnosis. While it's the doctor's preference which she wants to use, some differences exist between the two tools.

**X-ray for Back Pain**

- Two types of X-rays are used on the back: discography and myelogram. A discography requires injections into the discs and is used if the source of pain is believed to be a disc. A myelogram requires a spinal injection and is used when the patient has back pain when moving and standing.

**MRI for Back Pain**

- An MRI is not usually the first choice for diagnosing back pain problems when they appear. As a result, an MRI exam may not be covered by insurance.

When to Use X-ray
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- When back pain is thought to be due to disease, an X-ray is preferred. It can illustrate the progression of degenerative conditions such as arthritis.

When to Use MRI

- Some factors may lead a doctor to choose an MRI to find the cause of back pain. They include the patient being more than 50 years old, having congenital spine problems, signs of fracture or tumor, spine arthritis, a previous spinal injury or surgery, steroid or drug abuse, a shooting pain down a leg and the condition not improving after four weeks of at-home treatment.

Picture Quality

- MRIs have the ability to take 3-D images of the back and other parts of the body, and they provide a more precise picture of the soft tissue surrounding the vertebrae than X-rays. X-rays do a good job showing the alignment of the spine and vertebrae as a whole.

Comfort

- The MRI machine is similar to a tube. The patient lays on a table that slides into the tube, and the MRI machine then rotates around the table. This setup can cause problems for claustrophobic patients and people who get headaches from the machine's loud noise. To have an X-ray taken, the patient lays on a table or stands, and the X-ray machine is positioned around him. A X-ray taken while the patient stands may be more comfortable for someone with serious back pain.

X-Ray vs. MRI (in general)

Advancement in medical technology has made it possible for doctors to look at what is happening inside our bodies without the need to operate. This makes it possible to have a diagnosis at a low cost and very minimal intrusion to the
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patients. X-Rays are the oldest of these technologies, having been developed in the late 1900. It uses the radiation from a vacuum tube. The radiation can pass through soft tissue but not bones. The radiation that passes through is deposited into a photographic plate that is then developed to present the final image.

An MRI can do the same thing but it is more advanced, understandably so since it was made almost a century after X-Rays. The name Magnetic Resonance Imaging gives you a hint that it uses magnetic fields to produce the image. In the simplest sense, an MRI uses a huge magnetic source like a fixed magnet or an electromagnet to align the magnetic moments of protons that is in the water in our bodies. For a short period of time, an electromagnetic field via RF is introduced. This causes the molecules to realign then slowly return to their original orientation. The rate at which these molecules returns to their original alignment is then detected by the scanner and plotted in a computer. To improve the image, contrast material is often injected to the patient.

The primary problem with X-Rays is the danger associated with prolonged exposure. The radiation that passes through the soft tissue can lead to damage. This is why we cannot take a lot of X-Rays at a single time. MRIs do not have these problems as it does not introduce anything to the body. During a single MRI session, it is common practice to take a lot of cross sectional images of the body so that doctors have a lot more materials to work with. With the advancement of computers, these images can be reconstructed into a 3D image. It is almost like opening up the body and looking directly at the organs within and make their diagnosis a little bit easier and more accurate.

Summary:
1. X-Rays utilize radiation to get an internal view of the body while the MRI uses magnetic fields
2. X-Rays are quite old and almost a century older than MRI
3. X-Rays are more dangerous than an MRI
4. MRIs are able to create a 3D representation of the body, something X-Rays cannot do
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