Radiology

Lec 16. Magnetic Resonance Imaging (MRI)

Magnetic resonance imaging (MRI), nuclear magnetic resonance imaging (NMRI), or magnetic resonance tomography (MRT) is a medical imaging technique used in radiology to visualize internal structures of the body in detail. MRI makes use of the property of nuclear magnetic resonance (NMR) to image nuclei of atoms inside the body. MRI can create more detailed images of the human body than possible with X-rays.

An MRI scanner is a device in which the patient lies within a large, powerful magnet where the magnetic field is used to align the magnetization of some atomic nuclei in the body, and radio frequency magnetic fields are applied 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. Magnetic field gradients cause nuclei at different locations to process at different speeds, which allows spatial information to be recovered using Fourier analysis of the measured signal. By using gradients in different directions, 2D images or 3D volumes can be obtained in any arbitrary orientation.

MRI provides good contrast between the different soft tissues of the body, which makes 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 does not use ionizing radiation.

MRI 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 arthograms (MRI images of joints). Unlike CT, MRI uses no ionizing radiation and is generally a very safe procedure.
How does the procedure work?

Unlike conventional x-ray examinations and computed tomography (CT) scans, MRI does not depend on ionizing radiation. Instead, while in the magnet, radio waves redirect the axes of spinning protons, which are the nuclei of hydrogen atoms, in a strong magnetic field.

The magnetic field is produced by passing an electric current through wire coils in most MRI units. Other coils, located in the machine and in some cases, placed around the part of the body being imaged, send and receive radio waves, producing signals that are detected by the coils.

A computer then processes the signals and generates a series of images each of which shows a thin slice of the body. The images can then be studied from different angles by the interpreting physician.

Overall, the differentiation of abnormal (diseased) tissue from normal tissues is often better with MRI than with other imaging modalities such as x-ray, CT and ultrasound.

In fMRI examination, you will perform a particular task during the imaging process, causing increased metabolic activity in the area of the brain responsible for the task. This activity, which includes expanding blood vessels, chemical changes and delivery of extra oxygen, can then be recorded on MRI images.

A large proportion of the human body is made up of fat and water, both of which contain lots of hydrogen atoms. In fact, you are made up of approximately 60% hydrogen atoms. Magnetic Resonance Imaging (MRI) works by measuring the way that these hydrogen atoms absorb and then give off electromagnetic energy. When you have an MRI scan, you lie inside a machine that contains a powerful magnet. The nucleus of a hydrogen atom is like a tiny magnet so, by lying in line with the strong magnetic field inside the scanner, all your hydrogen nuclei line up too. The scanner also has several electric coils which create variations in the strength of the magnetic field at different points in your body. This means that each hydrogen nucleus experiences a slightly different magnetic field strength, which is important for detecting where exactly they are.
A pulse of radio waves is used which gives enough energy to the hydrogen nuclei for them to change direction. When the pulse is switched off the nuclei revert back to their original position and each nucleus gives off energy in the form of a radio wave. The frequency of these waves depends on the strength of the magnetic field where each nucleus is and this means that the scanner can work out the location of each nucleus.

The radio waves given off also allow the scanner to work out what type of body tissue the hydrogen nuclei are part of. This information is used to create a map of the different types of tissue in the body.

**MRI versus CT**

1. A computed tomography (CT) scanner uses X-rays (ionizing radiation) to acquire images, making it a good tool for examining tissue composed of elements of a higher atomic number than the tissue surrounding them, such as bone and calcifications (calcium based) within the body (carbon based flesh), or of structures (vessels, bowel). MRI, on the other hand, uses non-ionizing radio frequency (RF) signals to acquire its images and is best suited for soft tissue (although MRI can also be used to acquire images of bones & teeth).

2. A contrast in CT images is generated purely by X-ray attenuation, while a variety of properties may be used to generate contrast in MR images. By variation of scanning parameters, tissue contrast can be altered to enhance different features in an image. Both CT and MR images may be enhanced by the use of contrast agents. Contrast agents for CT contain elements of a high atomic number, relative to tissue, such as iodine or barium, while contrast agents for MRI have paramagnetic properties, such as gadolinium and manganese, used to alter tissue relaxation times.

3. CT and MRI scanners are able to generate multiple two-dimensional cross-sections (tomographs, or "slices") of tissue and three-dimensional reconstructions. MRI can generate cross-sectional images in any plane (including oblique planes). In the past, CT was limited to acquiring images in the axial (or near axial) plane. The scans used to be called Computed Axial Tomography scans (CAT scans). However, the development of multi-detector CT scanners with near-isotropic resolution, allows the CT scanner to produce data that can be retrospectively reconstructed in any plane with minimal loss of image quality. For purposes of tumor detection and identification in the brain, MRI is generally superior. However, in the case of solid tumors of the
abdomen and chest, CT is often preferred as it suffers less from motion artifacts. Furthermore, CT usually is more widely available, faster, and less expensive. However, CT has the disadvantage of exposing the patient to harmful ionizing radiation

**Safety with magnetic resonance imaging**

1. **Magnetic field**

Most forms of medical or bio stimulation implants are generally considered contraindications for MRI scanning. These include pacemakers, shrapnel, vagus nerve stimulators, implantable cardioverter-defibrillators, loop recorders, insulin pumps, cochlear implants, deep brain stimulators and capsules retained from capsule endoscopy.

2. **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.

3. **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).

4. **Contrast agents**

The most commonly used intravenous contrast agents are based on gadolinium. In general, these agents have proved safer than the iodinated contrast agents used in X-ray radiography or CT.

5. **Pregnancy**

MRI have no effects on the fetus. MRI avoids the use of ionizing radiation, to which the fetus is particularly sensitive. However, one additional concern is the use of contrast agents; gadolinium compounds are known to cross the placenta and enter the fetal blood stream, so it is recommended that their use should be avoided.
7. Heating caused by absorption of radio waves

Every MRI scanner has a powerful radio transmitter to generate the electromagnetic field which excites the spins. If the body absorbs the energy, heating occurs. For this reason, the rate at which energy is absorbed by the body has to be limited.

8. Claustrophobia and discomfort

MRI scans can be unpleasant. Older closed MRI systems have a fairly long tube or tunnel.

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
  - having a loved one in the room to hold hand, reassure them, etc.
  - holding a "panic button"
  - closing eyes as well as covering them (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.
There is medical evidence that a tattoo can cause a reaction during magnetic resonance imaging. The tattoo inks expected to cause a reaction are those containing iron oxide (some black, brown, red, flesh, yellow, orange). Not all dyes of these colors contain iron oxide. Also, some dyes of other colors may contain lesser quantities of magnetic metal. Magnetic metals can convert the radio-frequency pulses of an MRI machine into electricity.

The burning sensation that would be felt at the site of the tattoo may be a result of electricity running through the tattoo or from the 'pull' exerted on the magnetic material in the tattoo.

**Limitation of MRI**

1. High-quality images are assured only if the patient is able to remain perfectly still while the images are being recorded. (If the patient is anxious, confused or in severe pain, he may find it difficult to lie still during imaging).

2. A person who is very large (or fat) may not fit into the opening of MRI machines.

3. The presence of an implant or other metallic object sometimes makes it difficult to obtain clear images. (Patient movement can have the same effect).

4. Breathing may cause artifacts or image distortions during MRIs of the chest, abdomen and pelvis. Bowel motion is another source of motion artifacts in abdomen and pelvic MRI studies. This is less of a problem with state-of-the-art scanners and techniques.

**Pediatric MRI**

- No preparation is necessary for an MRI scan. A child can eat and drink normally.
- As a strong magnet is used, all metallic devices MUST be removed before entering the MRI room. This includes clothes with metal zips and any toys that might have a metal component.
- Radiologist can thoroughly understand the child's overall health.
Patients with cardiac pacemakers and cochlear implants cannot undergo MRI scans. Other metallic implants may prohibit patients from having an MRI scan. This includes people with certain types cerebral aneurysm clips, vascular stents, infusion pumps and neurostimulators.

The scan occurs in an enclosed space, so if the child is particularly claustrophobic or likely to feel quite anxious, must be taken in consideration.

A wide bore or 'tunnel' that is 16% wider than conventional MRI units so patients may experience less anxiety when entering the enclosed space of the MRI scanner.

Child will be required to change into and wear the examination gown. They will then be asked to lie on a movable scanning table that moves into the bore of the MRI. The body part to be scanned will be positioned in the centre of the tunnel. A coil, may be placed over the body region to be examined during the scan.

General anesthesia or deep sedation is often required for children undergoing MRI in order to obtain complete immobility of the patient. The potential complications of deep sedation include: hypoventilation, apnea, airway obstruction, laryngospasm, and cardiopulmonary impairment. Therefore, general anesthesia is often preferred for the diagnostic procedures rather than sedation, because general anesthesia is regarded as a safe, controllable, and relatively easy procedure to perform.

**Examples of fMRI Scans**

MRI scans can be used to see what parts of the brain are active when the subject is doing various different things. (used to understand how different parts of the brain respond to external stimuli or passive activity in a resting state).

1. **Joy**: MRI scan highlighting the areas of the brain involved when feeling joyful. The scan shows the regions of subject's brain that become more active when he watches his football team score a goal. Although some of these areas are related to the feeling of joy, some may be a result of different influences, such as the anticipation of a goal being scored. Deciding what the subject should do or see to isolate an emotion is perhaps the hardest part of fMRI studies.
2. **Pain**: The scan shows the regions of the brain that became more active when the subject's hand was heated to a painful level. Pain involves both sensation and emotion so different types of pain result in different areas of the brain being active. Using fMRI scientists can start to understand how pain works, and how it might be possible to reduce painful experiences.

3. **Love**: In one fMRI study the brains of people who were in love were scanned while they looked at photographs of their friends and some of their loved-ones. When they saw a picture of their loved one specific areas of the brain became active, suggesting that there is a specialized system in the brain relating to romantic love.
4. **Smell**: MRI scan images highlighting the areas of the brain activated by smell. The scan shows the brain areas that are activated by smell. Smell is a complex sense and several different parts of the brain are needed to work out what a smell is, where it's coming from and whether you like it or not.

5. **Fear**: MRI scan images highlighting the areas of the brain involved when feeling afraid. The scans show that when subject is frightened, a brain structure called the amygdale becomes more active. The amygdale is responsible for generating a range of negative emotions such as sadness, anger and disgust. It becomes less active when people perform non-emotional tasks, which is why keeping yourself busy when you're sad can make you feel better.