1st Semester

كلية المأمون الجامعة

قســــم تقنيات الأشــــعة

المرحلة الثالثة

Equipment Techniques of Magnetic Resonance Imaging

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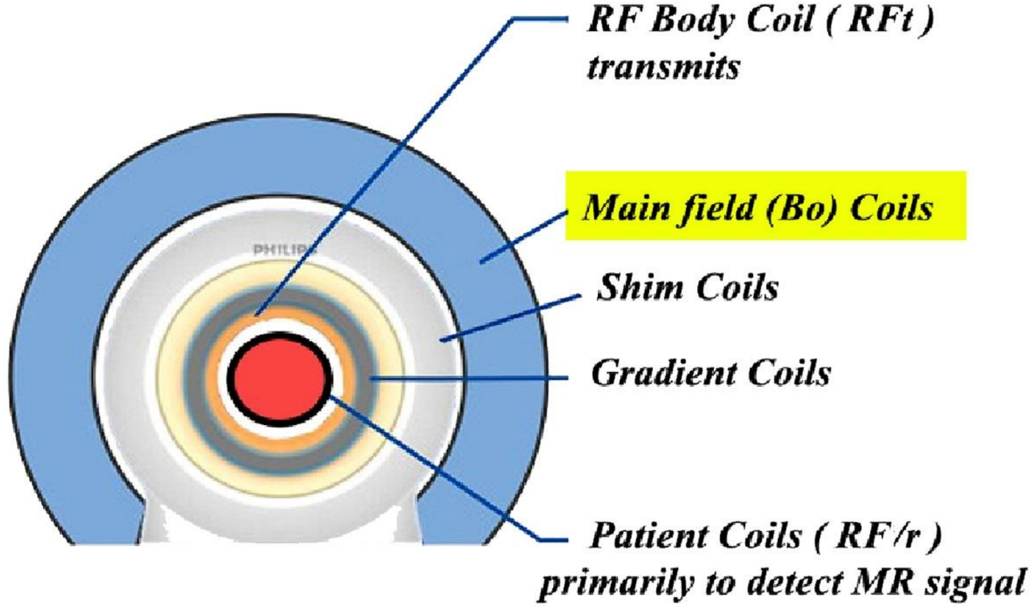
MSc Medical Imaging / MRI Applications

Lecture (2, 3)

Main Coil in MRI Device + Shimming

- Main coils: produce B_o
- Shim coils: improve homogeneity
- Gradient coils: imaging
- RF coils: transmit B_1 field
- Patient coils: receive MR signal



MRI Types :

→ *Closed MRI*

→ *Open MRI*

In MRI machines, the magnet is the main component responsible for generating a constant magnetic field, which forms the basis of the machine's physical function. The magnet creates a strong and steady magnetic field along the axis of the machine, called the primary magnetic field (B_o). This field is the main factor that affects the protons in the human body, especially hydrogen protons, which are found in large amounts in water and fat in the body.

The physical function of the magnet in MRI (Importance):

1- ***Proton Alignment***: *Normally, the protons in the human body are randomly aligned. When the body is placed in the strong magnetic field created by the machine's magnet, these protons line up with the direction of the magnetic field (B_o). This is the first step in creating the MRI image.*
2- ***Image Accuracy***: *The strength and stability of the magnetic field (B_o) directly affect the accuracy and quality of the images. The stronger the magnetic field, the clearer and more detailed the images. This is why modern MRI machines use strong magnets, with a power of up to 1.5 Tesla or 3 Tesla.*

Types of Magnets Used:

i. **Superconducting Magnets.**
ii. **Resistive Magnets.**
iii. **Permanent Magnets.**

i- Superconducting Magnets

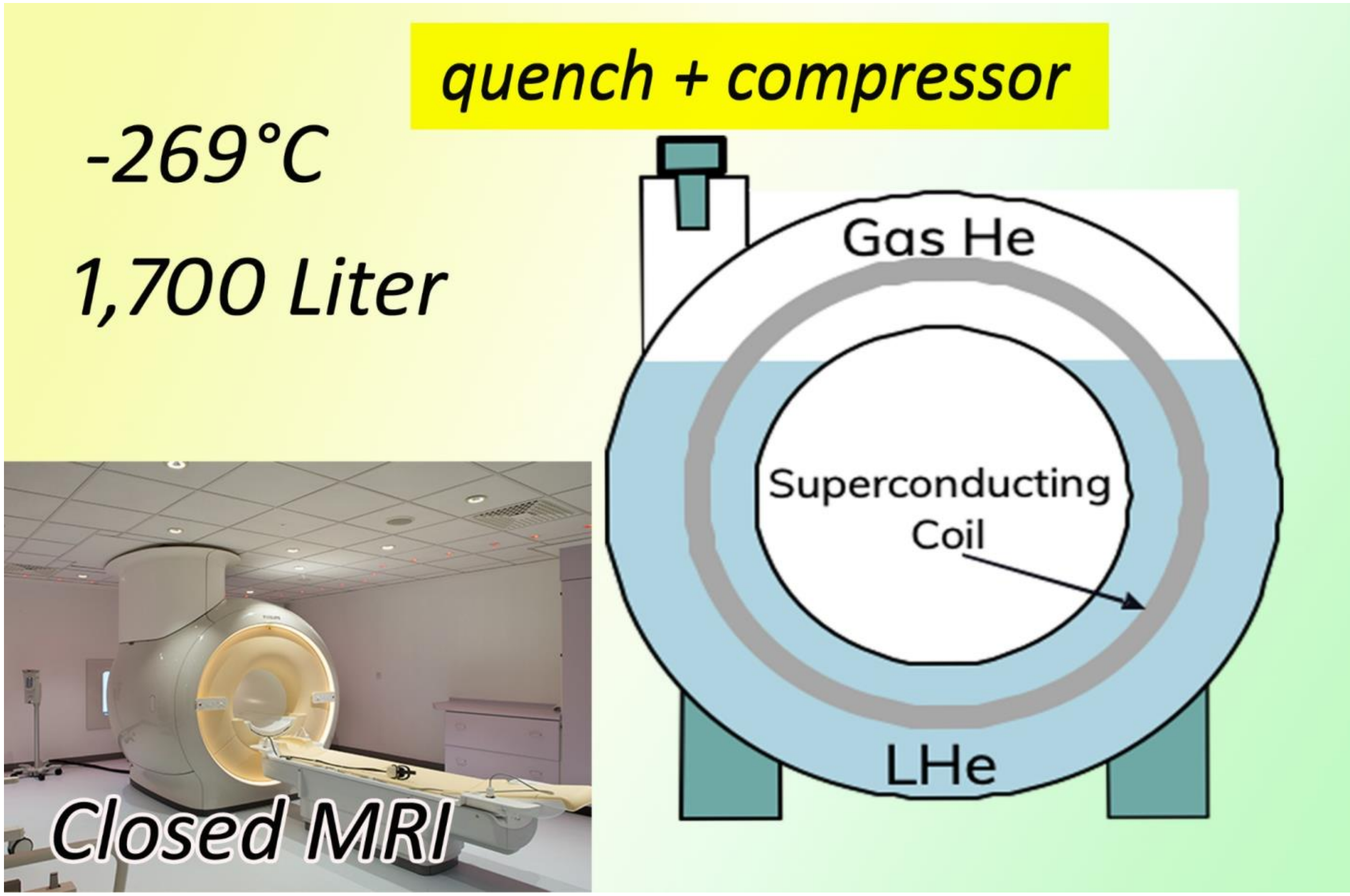
Superconducting magnet materials: That exhibit zero electrical resistance when cooled to very low temperatures. Common materials used for this purpose are niobium-titanium (NbTi) and niobium-tin (Nb_3Sn). These materials are "superconductors" because they allow electric current to flow indefinitely without losing energy, which is key for generating strong and stable magnetic fields.

1- **Magnetic Field Strength**: Superconducting magnets can generate very high magnetic fields, typically ranging from 1.5 Tesla to 3 Tesla, and in some research applications, up to 7 Tesla or higher. In MRI machines, stronger magnetic fields provide better image resolution and faster scan times. For example, a 3 Tesla MRI provides much more detailed images than a 1.5 Tesla system, which is important for complex diagnoses.

2- **Stability and Homogeneity**: Superconducting magnets are extremely stable and provide a highly uniform magnetic field across the scanning area. This uniformity is essential for producing high-quality MRI images. Any variations in the magnetic field can cause distortions in the image, making it difficult to diagnose medical conditions accurately.

3- **Energy Efficiency**: One of the main advantages of superconducting magnets is their efficiency. Since the materials exhibit zero electrical resistance, there is no energy loss in the form of heat, meaning they can maintain strong magnetic fields without requiring large amounts of energy. This makes them more cost-effective and supportable over time, despite the initial costs of cooling systems and cryogens like helium.

Cryogens System



Cryogens

In the context of MRI machines, cryogens play a vital role in cooling the superconducting magnets to a temperature where they exhibit zero electrical resistance, allowing them to maintain strong and stable magnetic fields without energy loss.

Cryogen system

1-Liquid Helium (He):

The most commonly used cryogen in MRI machines. Liquid helium cools the superconducting magnets to approximately (-269°C), which is necessary for the materials to reach their superconducting state. It is a key element because it is one of the coldest substances available and can maintain the extremely low temperatures required for superconductivity.

2-The compressor

In an MRI system plays a crucial role in managing the cooling process, particularly its main function is to compress and recycle helium gas that has evaporated during normal operation. This helps maintain the extremely low temperatures needed for the magnet to stay in its superconducting state.

Quench

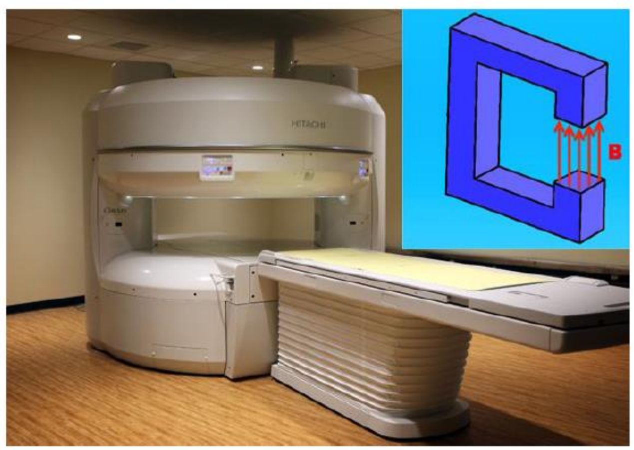
Is a term used in superconducting MRI machines to refer to the sudden loss of the magnet’s ability to remain in a superconducting state. This occurs when the magnet's resistance suddenly increases, causing the stored energy to be released as heat. As a result, the liquid helium used to cool the magnet evaporates rapidly and turns into gas, leading to a significant rise in pressure inside the cooling system. Without proper ventilation, the escaping helium gas can cause oxygen depletion in the room, posing a risk to the people inside. The magnet

Mechanism:

1- Increase in Resistance.
2- Energy Release.
3- Helium Evaporation.
4- Pressure Increase.

ii- Permanent magnets

Generate magnetic fields from their internal structure and are composed of ferromagnetic materials. In MRI, they produce magnetic fields of less than 8000 gauss, while superconducting magnets can reach up to 15000 gauss. The primary limitation of permanent magnet MRI systems is their low magnetic field strength (B_o), which restricts imaging complexity and reduces spatial and contrast resolution. Despite these drawbacks, they are appealing for low-field imaging due to minimal fringe fields, low power feeding, and open design. However, their clinical use is limited, though they are effective for specialized MRI scanners, such as extremity imaging, due to their lower cost.



Open MRI

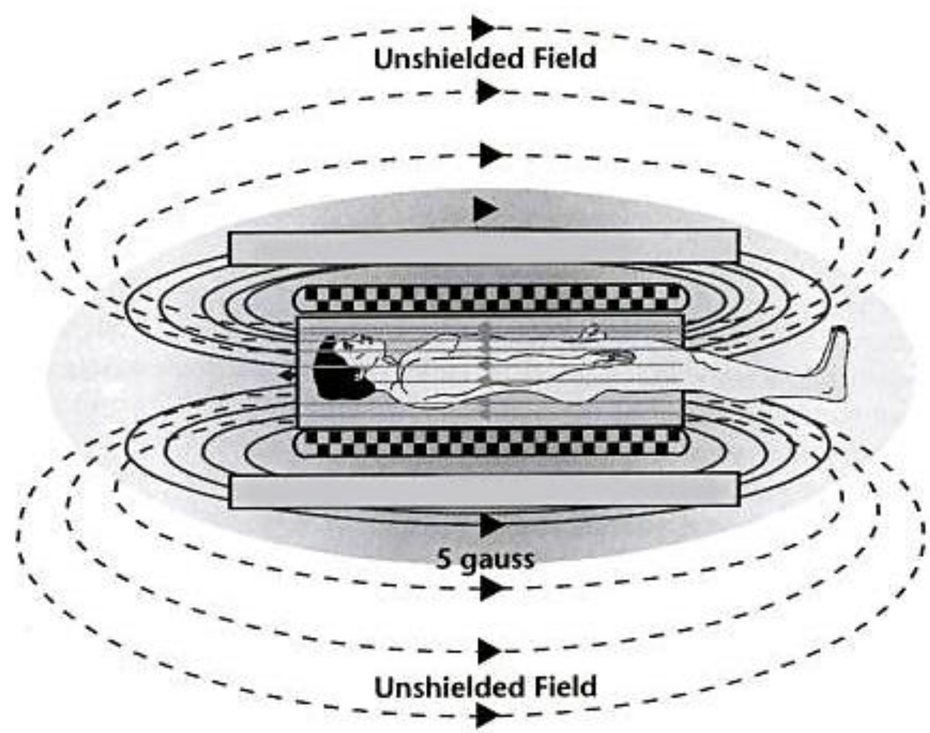
Permanent magnet is base of manufacture of open MRI. An open MRI is a type of magnetic resonance imaging (MRI) machine that has a larger opening compared to a traditional closed MRI machine.
It is designed to: set patients who may feel claustrophobic or have difficulty lying still in a confined space. The open design allows for more comfort and flexibility during the imaging process.

Headlines:

- Use permanently magnetized iron like a large bar (Ferromagnetic).
- Has been twisted into a C-shape where the two poles are close together and parallel.
- Up to 50 tons of iron in weight, restricting their placement to rooms with a strong-enough floor.
- Have low-field strength of about 0.4 T to 0.6 Tesla.

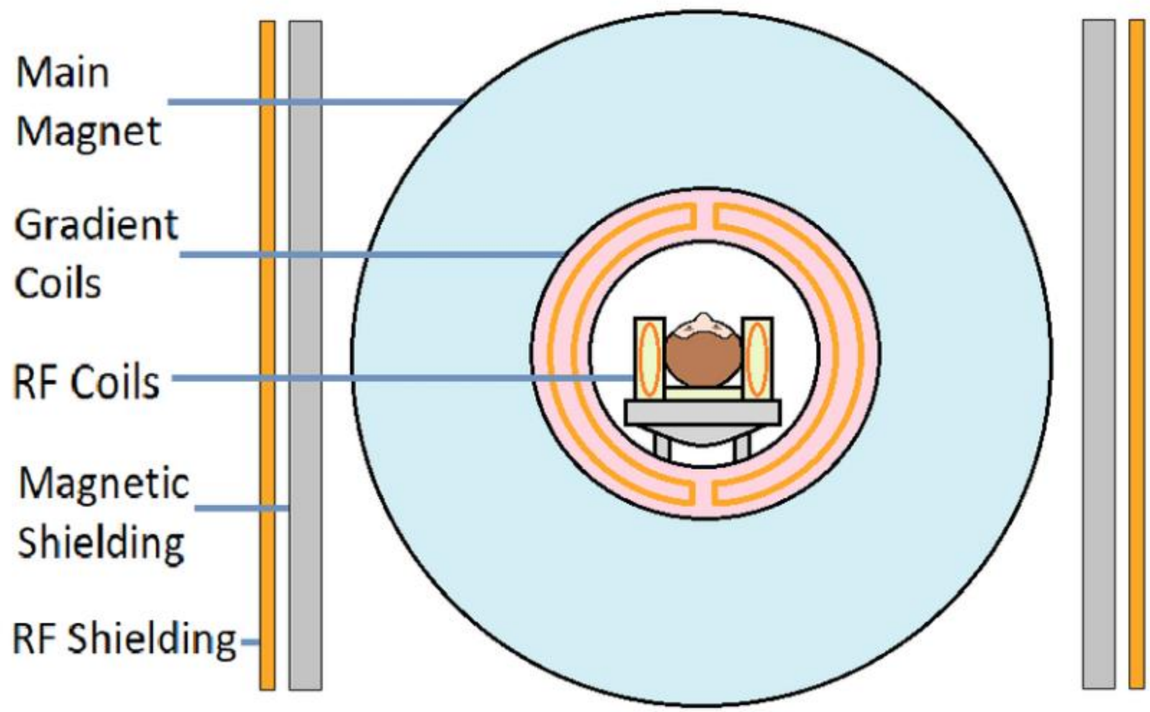
Fringe magnetic fields

Fringe magnetic fields refer to the weaker magnetic fields that extend outside the main magnet's core field (B_0). These fields can affect nearby electronic devices and pose safety concerns, particularly for patients with metallic implants or medical devices. Managing fringe fields is important to maintain a safe environment around the MRI system. High-field MRI systems use magnetic shielding to minimize these external fields, ensuring that the magnetic field remains confined to the imaging area, preventing interference with surrounding equipment and ensuring patient and staff safety.



Magnetic shielding

In MRI systems limits fringe magnetic fields, protecting sensitive electronics and ensuring safety. It includes **passive shielding** (using materials like iron to redirect fields) and **active shielding** (using coils to counteract fields), enhancing image quality and safety.



iii- Resistive Magnets:

In MRI systems are electromagnets that generate a magnetic field by passing an electric current through wire coils (cooper materials). They require constant electrical power to maintain the magnetic field. While they can be used in MRI, they are less efficient and less common than superconducting magnets because they generate heat, consume significant energy, and cannot produce the high magnetic field strengths required for high-resolution imaging. Due to these limitations, resistive magnets are not typically used in modern clinical MRI systems.

Shimming

Is the process of improving the uniformity of the static magnetic field (B_0), which is generated by the main coil in MRI devices. The goal of shimming is to minimize magnetic field inhomogeneities in the examination area, resulting in a uniform field across the entire scanning region.

Several factors can cause magnetic field inhomogeneities, including:

1- The magnetic susceptibility of the patient's tissues, metallic implants, or the anatomy, which can create variations in the magnetic field.

2- The non-uniformity of the magnetic field caused by components within the scanner or other environmental factors, which may lead to reduced image quality and inaccurate diagnoses.

By improving the magnetic field uniformity, shimming reduces these artifacts, enhancing the overall image quality.

Shimming Types

1- Passive Shimming:

This involves placing pieces of ferromagnetic materials around the main magnet to adjust the magnetic field manually.

2- Active Shimming:

Active shimming involves using small, specially designed coils to create localized magnetic fields that correct any inhomogeneities in the primary field.

Shimming Process

Shimming is performed both during the installation and calibration of the MRI machine and before each scan, depending on the requirements. It can be automated in modern systems to ensure the best possible image quality.