TITAN UNIVERSITY

MRSO Exam Prep Study Guide Module 1

Chapter 01: The Static Magnetic Field

The static magnetic field in MRI is well-known for being a safety risk. Unfortunately, MRI is not feasible without it. Depending on the MRI equipment, the static magnetic field can be generated in various methods. These units have one thing in common: they can generate a powerful magnetic field that can align hydrogen nuclei to their vector (the direction that the flux lines travel). (Figure1)

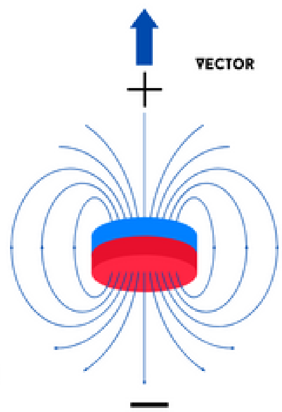


FIGURE 1

You may already know that the magnetic field has a North Pole and the South Pole. Magnetic flux lines go from the North Pole to the South Pole. These flux lines are hazardous in an MRI setting. Moving force lines are not magnetic flux lines. Instead, they are densities with varying field strengths from the North Pole to the South Pole. Magnetic fields can be measured in either Gauss or Tesla units. The magnetic field that moves a compass on Earth is around 0.5 Gauss. One Tesla has 10,000 Gauss. This means that the magnetic field in a 1.5 Tesla unit is 30,000 times stronger than the magnetic field on Earth, while a 3 T unit is 60,000 times stronger. (Figure 2)

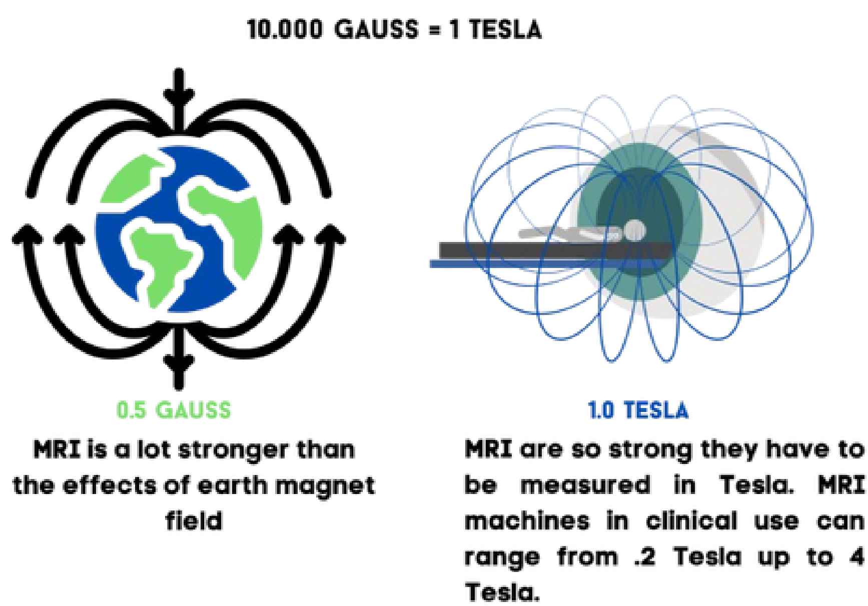


FIGURE 2

Faraday's law of induction is a key idea to learn in MRI. This term refers to the electrical current created in a conductive substance when exposed to shifting magnetic fields. It also explains the magnetic fields that are created by electrical currents. As we will see, this approach raises concerns in the MRI setting. Another key idea to understand when dealing with the static magnetic field is Lenz's force. This one-of-a-kind concept illustrates how nonmagnetic (non-ferrous) items might represent a hazard while traveling through a static magnetic field. Lenz's law states that an electrical current is created in a conductive substance as it moves through a magnetic field.

When an electrical current is created, a magnetic field is created at a 90° angle to the electrical current. This magnetic field will interact with and repel the static magnetic field. In a minute, we will talk about safety considerations with this approach. (Figure 3).

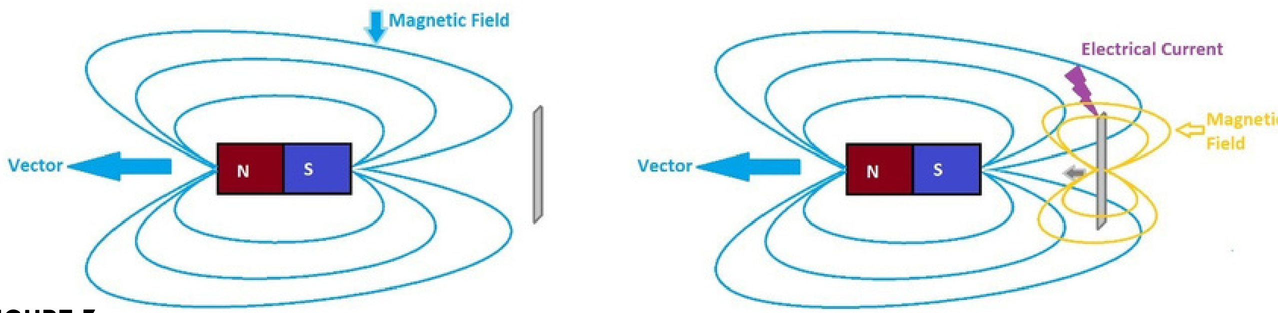


FIGURE 3

We must first recognize that there are several sorts of magnetism. When an object is put near a magnetic field, it will display magnetism. The Pauli Exclusion Principle describes this.
To comprehend this concept, we must first understand that an atom's nucleus includes one or more protons (and sometimes a neutron), and electrons circle this proton. Each orbit has its own shell or distance from the nucleus. These orbits are known as orbitals because they are not exactly circular. (Figure 4).

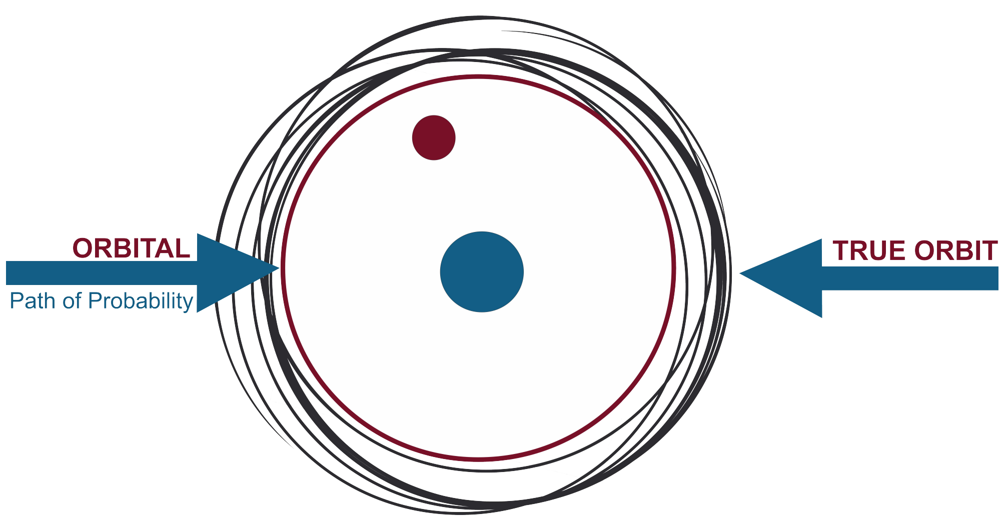
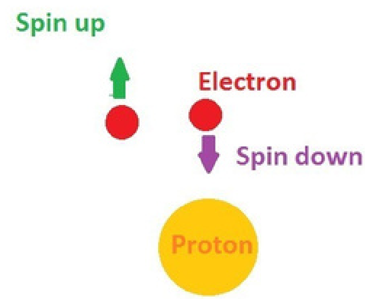
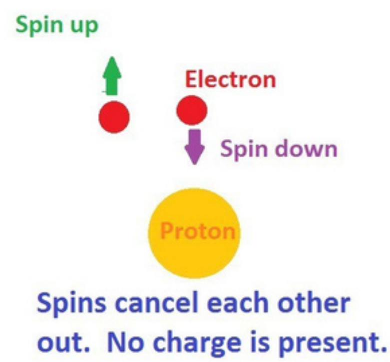


FIGURE 4

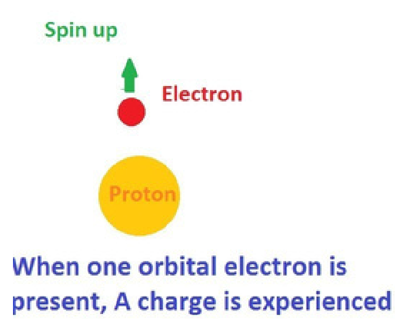
According to the Pauli Exclusion Principle, each orbital includes a minimum of one electron and a maximum of two electrons. Each electron will be charged. When put in a static magnetic field, one electron in an orbital will create a force. When two electrons are in an orbital, their charges cancel each other out, and no force is formed. It is far more intricate than this, but let us keep it simple:



When put in a static magnetic field, **diamagnetism** exhibits a repulsive force. This is because each orbital includes a pair of electrons. A diamagnetic substance is one such as oxygen. Diamagnetic substances include copper, gold, and silver.



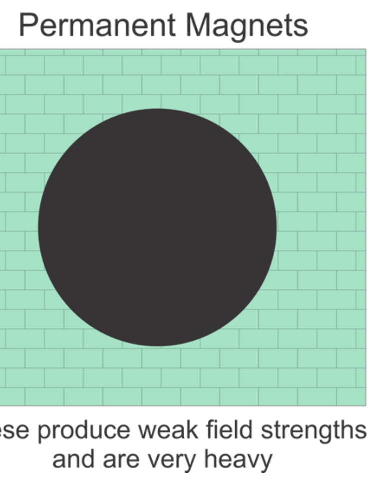
When put in a static magnetic field**, paramagnetism** can be considered a tiny attractive force. This force is so faint that it can only be measured and not seen. When one or more orbitals contain one electron, this form of magnetism is created. The attractive force created is proportional to the material's temperature and the number of orbitals containing one electron. Paramagnetic materials include gadolinium. Magnetic fields were stronger in **superparamagnetic** materials than in paramagnetic materials.



Finally, **ferromagnetic** materials are highly attracted to static magnetic fields and keep their own magnetic field after leaving the static magnetic field for a long time. Ferromagnetism is formed differently from diamagnetism or paramagnetism.

Ferromagnetic materials have directional field domains that line with the vector of a static magnetic field.

As previously stated, there are several types of MRI units. Each will generate a static magnetic field, but the distinctions are in how they do it. For example, a group of permanent magnetic bricks creates a magnetic field in a permanent MR unit. Each brick carries a modest magnetic field, which, when combined, produces a strong magnetic field. These often reach around 0.4 T. The magnetic fields generated by this unit generally have a vertical vector. The disadvantage of these devices is that the magnetic field generated cannot be switched off unless the magnet is dismantled. Furthermore, these devices are often rather hefty. On the other hand, compared to different types of units, these units are often quite affordable.



Another MRI alternative is the resistive MR unit. Using electromagnetic principles, this unit will generate a magnetic field. A coil of wire is wrapped around the gantry, and an electrical current is sent through it. This creates a magnetic field. The current quantity determines the intensity of this magnetic field passed through these wire coils.

Because of the principles indicated by Ohm's law, resistance in this wire will result in a loss of energy owing to friction, resulting in heat. The more the current passed via these wires, the greater the resistance. This indicates that there will be greater heat created. These units typically do not surpass 0.6 Tesla in strength and can be highly expensive due to the necessity for significant cooling. On the other hand, these devices may be switched on and off without causing any damage. This machine may generate a vertical or horizontal magnetic field.

Resistive Magnets

These produce medium field strengths and use electricity.

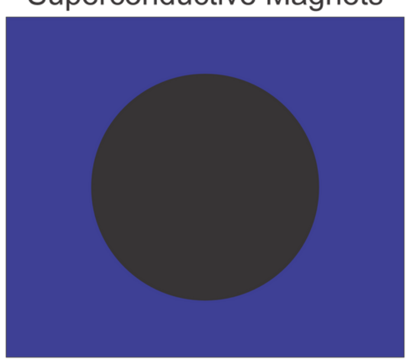
Finally, the superconducting MR unit is the most prevalent clinical application unit. This MR unit operates on the same principles as the resistive MR unit. As a result, it likewise employs coils of wire with an electrical current running through them to generate electromagnetism. The distinction here is the usage of a cryogen. Cryogen is a very cold material.

A cryogen alters the parameters of our static magnetic field in MRI. Ohm's law no longer applies when this coil of wire is immersed in a cryogen. As an electrical current flows through this wire, which is cooled to around 4.2 Kelvin, there is no current resistance in the wire. This implies that we may run massive quantities of current through these wire coils, and when we reach the necessary field strength, we can unhook the coil of wire from its electrical source.

This electrical current will continue to flow through the wire coils without any energy loss if the wire coils are submerged in cryogen. The field strengths of a superconducting MR unit can exceed 10 Tesla. A titanium alloy wire coil is employed to maximize these high field strengths.

The advantage of this MR unit is that it does not use as much electricity as a resistive MR unit and has lower operating expenses. Furthermore, achieving high field strength is critical in acquiring signals in our MR picture. The disadvantages of this sort of MR unit stem from ferrous objects and the cryogen itself.

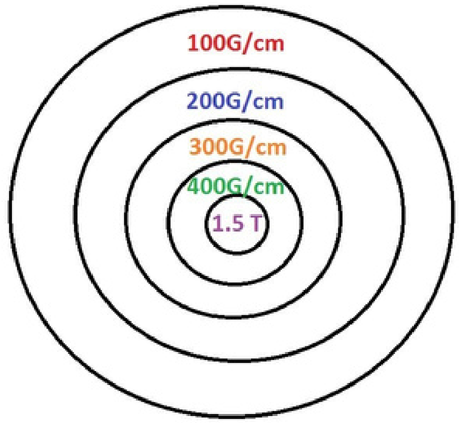
Superconductive Magnets



These produce higher field strengths and use electricity and a cryogen to function.

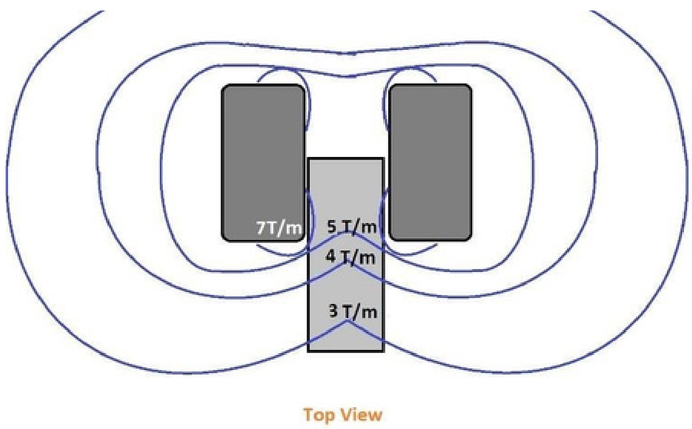
When we look at the magnetic field created by an MR unit, we see that we have directional magnetism, also known as a vector. This factor is also known as B0 (B sub-zero). We also know that magnetic flux lines, which define the B0, go from the North Pole to the South Pole. These flux lines can be compared to the layers of an onion.

Magnetic Flux Lines



This notion explains why ferrous things are drawn to the MR unit if we envision the core of the onion as our strong uniform magnetic field and each layer spreading outward as a lesser magnetic pull. This is an illustration of a spatial magnetic gradient field.

FIGURE 5



A ferrous item is not dragged to the attraction of a magnet; instead, it is drawn into the magnet by changing magnetic fields. In other words, if we position one side of our ferrous item in a layer of magnetic fields more potent than the magnetic fields sensed on the other side, it will be dragged in the direction of the stronger magnetic field. If this process continues, the ferrous item will be attracted to a region where the magnetic field experienced by the ferrous object is equal on both sides, or it will crash with the magnet. The spatial magnetic gradient field is stacking flux lines or magnetic fields of varying intensities.

The spatial magnetic gradient field is measured in **dB/dx**. The letter "d" stands for "change in," while the letter "B" stands for "field strength." The "x" stands for "distance." As a result, this unit of measurement for spatial magnetic gradient fields is defined as a change in the magnetic field divided by distance. The units of measurement used to define the spatial magnetic gradient field are gauss / centimeter **(G/cm)** or Tesla/meter **(T/m).** 1T/m is equal to 100G/cm.

To get the maximum spatial magnetic gradient field strength for a specific MR unit, multiply the spatial magnetic gradient field by the MR unit's overall strength. This is expressed as dB/dx * B. The maximum spatial gradient (Force Product) is represented in **T2/m** or **G2/cm**.

This spatial magnetic gradient field is the source of translational force. This is the force experienced by a ferrous item as it traverses the spatial magnetic gradient fields. The ferrous item will be drawn to the isocenter, or the center of the MRI unit, in MRI. This is the most consistent section of our static magnetic field. (Figure 6).

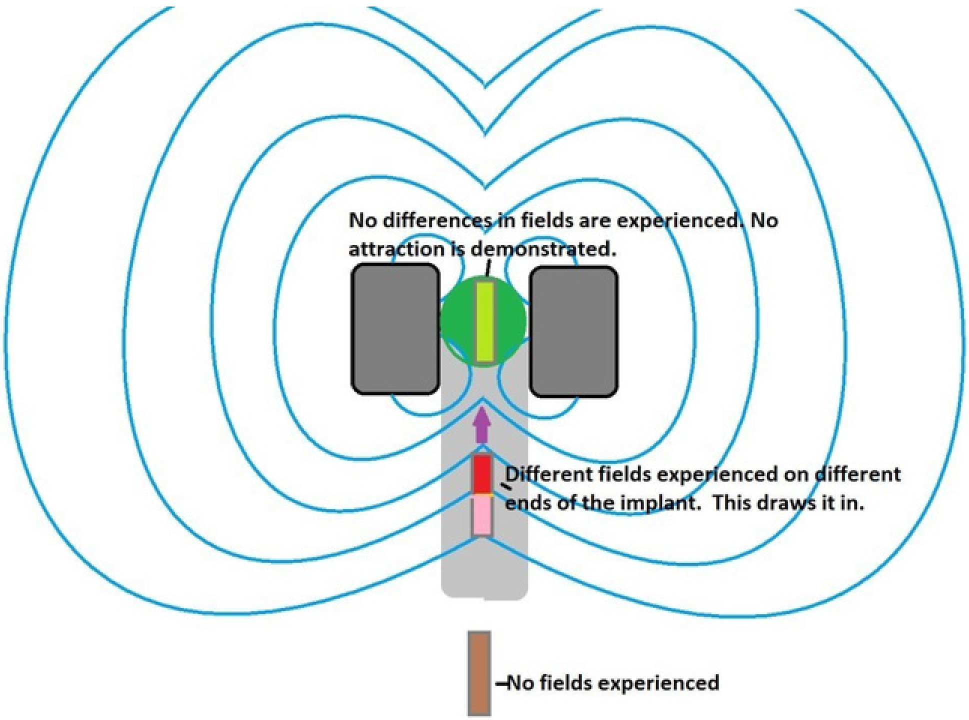


FIGURE 6

In other words, if we placed a ferrous item at the isocenter entirely immersed in a homogenous magnetic field on all sides, it would not exhibit any attractive force. Some parameters influencing the translational force exerted on an item include its size, ferrous content, static magnetic field strength, and distance from the magnetic field.

Another issue linked with the spatial magnetic gradient is the rotating force. We know that the magnetic field's flux lines formed by the MR unit flow from the North Pole to the South Pole. These magnetic fields move in a circle from one side to the other. Even if a ferrous item is positioned to the side of an MR unit, it will be drawn to the isocenter. A ferrous item does not require to travel in a straight line since it will follow the magnetic flux lines. As a result, this term may be used to explain the rotational force. Torque can be produced on implants as a ferrous item aligns to the static magnetic field. (Figure 7).

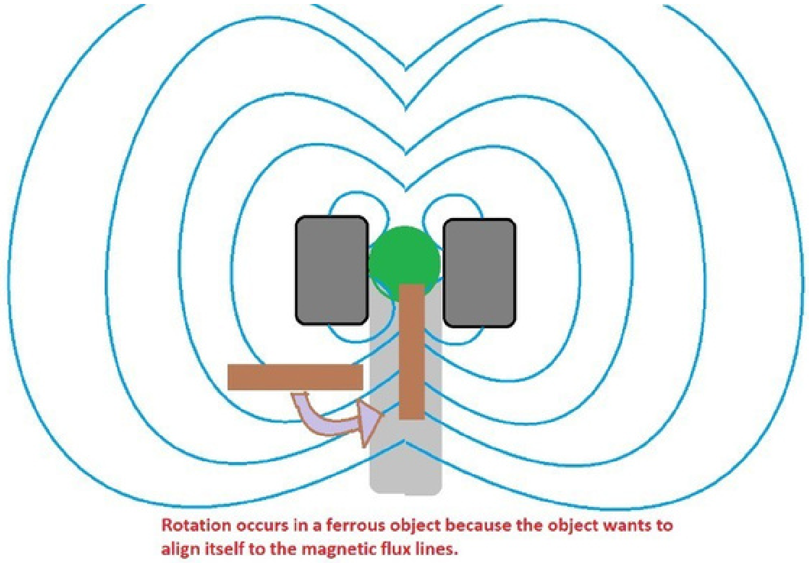


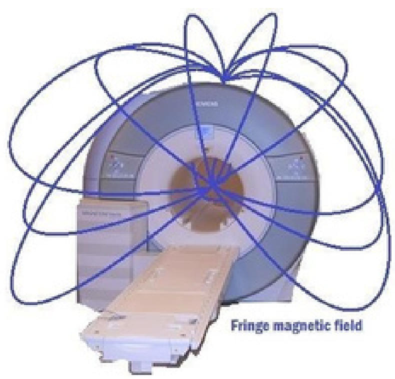
FIGURE 7

The elements that determine rotating force are the same as those that control translational force. We already know that translational force is weakest at the isocenter. On the other hand, the rotational force is most significant in the isocenter. This means that ferrous objects will exhibit the greatest torque in the isocenter.

The effects of translational and rotational force on magnets with different vectors must be described. For example, along the longitudinal vector, a horizontal vector produces a larger gradient of spatial magnetic fields. However, a vertical MRI machine will provide a shorter gradient of the spatial magnetic field. In other words, the amplitude of the spatial magnetic gradient increases as one moves away from the MR unit.

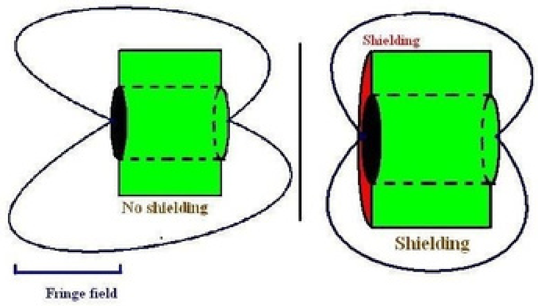
It is time to address some of the safety issues raised by the static magnetic field. The fringe field is the spatial magnetic gradient that extends beyond the MR unit. This fringe field is responsible for the translational force experienced by ferrous objects. The missile effect occurs when an item is drawn to the MR unit.

The Fringe Field Illustration



Magnetic shielding is used to lessen the missile effect. This can be accomplished either passively or actively. If passive magnetic shielding is utilized, a steel cage is built around the MRI machine to modify and concentrate the magnetic field in certain places. Active magnetic shielding employs coils of wire that run in the opposite direction as the coil of wire is used to generate the static magnetic field. This extra magnetic field will oppose the static magnetic field, canceling some magnetism. However, the peripheral field will be reduced because of this. (Figure 8)

FIGURE 8



Another source of concern in the MRI environment is Lenz's force. As we know, this defines magnetic fields created by electrically conductive and nonferrous things. We know electrical current is created when electrically conductive materials are moved through a magnetic field. Faraday's law of induction describes this. This material generates an electrical current and a magnetic field at 90° to the current. The produced magnetic field opposes the static magnetic field. This becomes a risk when a patient with a nonferrous but electrically conductive implant is placed in the MRI equipment. The static magnetic field may reject the implant as a result.

Moving the electrically conducting material quicker across our spatial magnetic gradient produces a more significant current. As a result, greater magnetic fields will be generated. As a result, moving patients with these implants slowly into the scanner reduces the likelihood of Lenz's force occurring.

Faraday's Law of Induction principles causes another issue discovered in the MRI environment. Moving electrically conductive materials over the spatial magnetic gradient produces an electrical current. As a result, a patient or caregiver traveling swiftly along the spatial magnetic gradient may generate an electrical current in the nerves and muscles.

Magnetophosphenes are flashing lights visible from stimulation in the eye caused by this form of induction. Rapid movements over spatial magnetic gradients have also been documented to produce dizziness, nausea, and nystagmus.

Nystagmus is an involuntary eye movement caused by movement in a static magnetic field.

Many studies have assessed the dangers of intense static magnetic fields on patients and MRI technicians. Teratogenesis in MRI refers to the impact of the MRI environment on the fetus of pregnant women. There is no proof that these difficulties exist, according to research. Pregnancy-related concerns have also been investigated in pregnant MRI technicians. There has been research on spontaneous abortion, pre-term delivery, offspring gender, low birth weight, and infertility. There have been no major findings to support any of these assertions.
Implants can cause significant anxiety during an MRI. This is because some implants are neither safe nor necessary in an MRI setting. These implants are tested scientifically by organizations.

The degree of attraction to the static magnetic field that an item shows at a certain spatial magnetic gradient field is referred to as deflection. This is determined by suspending the object under test from a string and moving it into a static magnetic field.

The amount of magnetic field deflection or attraction is measured and recorded. The assumption underlying the deflection is that if an object deflects 45°, gravity equals the translational force exerted on the item by the MR unit.

As a result, as long as the deviation is less than 45°, implants represent no significant risk to the patient. As deflection rises, so do the risks to the patient. If we have a deflection of 90°, we must realize that we cannot forecast how much force this item will exert on our patient because 90° is the most considerable deflection that is feasible. (Figure 9).

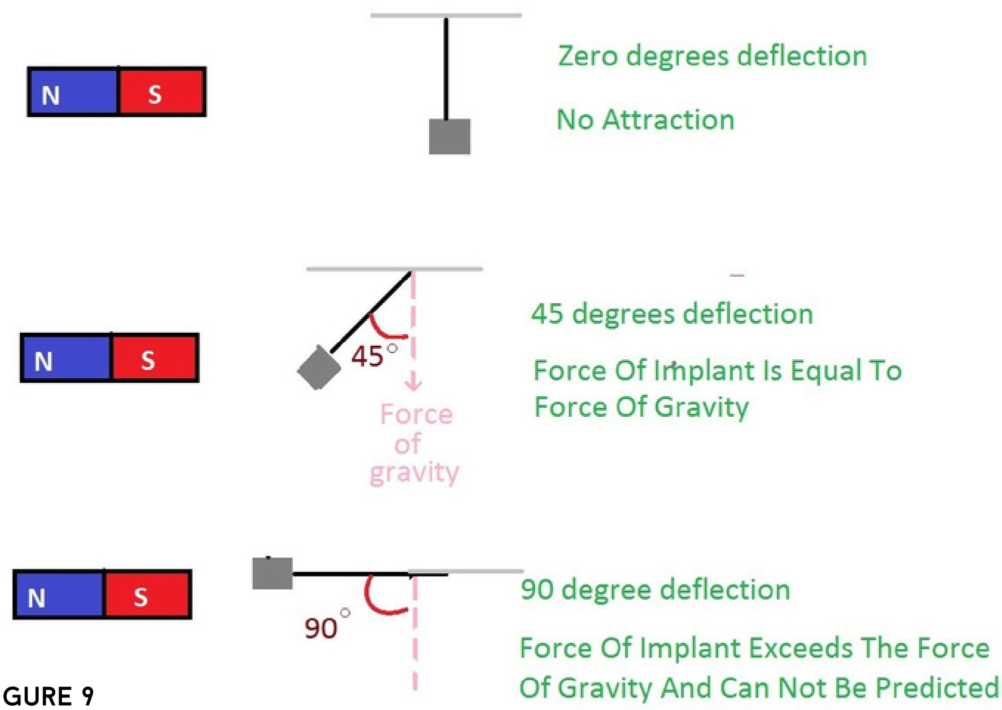


FIGURE 9

A conditional implant may claim that an item deflected 44° in a 400 Gauss/centimeter magnetic field. This indicates that scanning the patient is safe if the implant does not enter a magnetic field stronger than 400 Gauss/centimeter. Therefore, receiving a spatial magnetic gradient map from the MRI unit's manufacturer is critical to identify the safe zones of spatial magnetic gradients. This will aid in determining the various magnetic field strengths a patient will be exposed to.

It is also critical to recognize that implants might generate artifacts in our picture. The severity of these artifacts is determined by whether the implant contains ferrous or nonferrous material.
In an MRI scan, a ferrous item will show more artifacts than a nonferrous one. The dimensions of these objects vary greatly. Steel is the most prevalent ferrous metal, followed by nickel and cobalt. Gold is an example of nonferrous material. Stainless steel is more difficult to comprehend; some stainless steel is nonferrous, while others are ferrous. Nonferrous austenitic stainless steel Ferrous stainless steel includes ferritic and Martensitic stainless steel.

When examining the safety issues linked with the static magnetic field and implants, it is critical to ask the correct questions. It is critical to understand the distance between the implant and the MR unit and any restrictions on the highest magnetic field that the implant may be in.

These are available from the manufacturer. Another factor to consider is that implants implanted in the heart, such as cardiac stents, are subjected to significant stress due to the heart's pounding. This produces higher torque and force on a cardiac stent than on a static magnetic field. As a result, many, if not all, of these cardiac stents are MRI-safe.