MRSO Exam Prep Course

Module 3

Translational Force and Rotational Force

In Module 1, we discussed ferromagnetic materials, which are materials that are highly attracted to static magnetic fields and retain their magnetic field even after leaving the static magnetic field for a certain period. Ferromagnetic materials will become highly magnetized in the direction of B_0 (see Image 3.1), which causes a **translational force**.

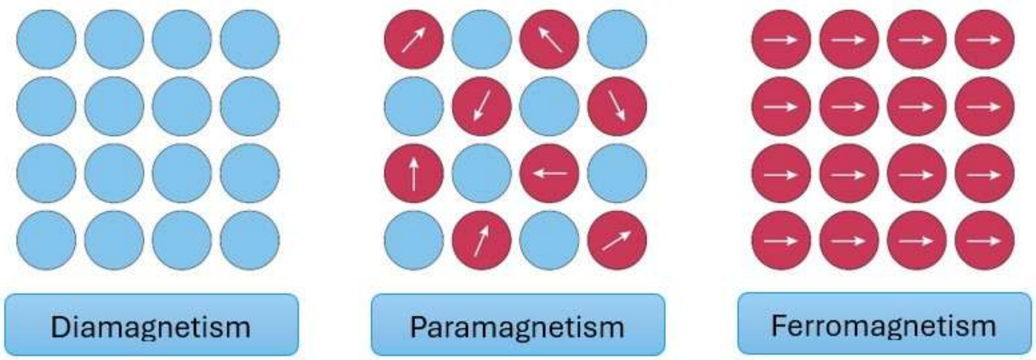

Image 3.1

The translational force pulls an object toward the isocenter of the machine, where the magnetic field is strongest. The strength of this force depends on the size, shape, distance from the isocenter, and the ferromagnetic content of the object. Rotational force, on the other hand, causes objects to rotate or spin. It is strongest at the isocenter and depends on the same factors as translational force. It is important to note that these forces can be hazardous to patients with ferromagnetic, and some paramagnetic implants, such as pacemakers or cochlear implants, which can move or rotate inside the body. Therefore, patients with such implants must be screened before MRI scans, and the MRI team must take appropriate precautions to avoid harm.

It is important to note that a magnet does not drag a ferrous item towards it. Instead, the changing magnetic fields draw the ferrous item into the magnet. This means that if one side of the ferrous item is placed in a stronger magnetic field than the other, it will be pulled toward the stronger field. This process continues until the ferrous object reaches a region where the magnetic field is equal on both sides or collides with the magnet.

If we introduce such a highly magnetized material to B_0, the magnet will exert a force on a ferromagnetic object. These forces are so strong that they can pull ferromagnetic objects, making them airborne, and will collide them into the scanner's magnet bore. This is known as the "missile effect" and can result in catastrophic consequences for individuals near the scanner and significant damage to equipment. To avoid serious or fatal injury from projectiles, MRSOs and MR personnel must understand the principles of the missile effect and properly screen individuals for ferromagnetic objects before entering the scanner room. We classify these materials as MR Unsafe.

As an MRSO, you must not only be aware of all materials entering Zone IV (the magnet room), but you must also be able to identify and possibly mitigate the materials that may have translational forces exerted on them. Because of this, you need to be able to recognize various forms of ferrous materials. These materials can be inside or outside the body. Careful consideration must be made regarding what devices and implants are present in your patient. Please do not allow a patient to enter Zone IV without finding out what their implants are made of per the manufacturer's information.

Some ferromagnetic metals consist of:

- **Iron (Fe):** A significant constituent of stainless-steel alloys that are used for fracture plates and bone screws.
- **Nickel (Ni):** Sometimes added to stainless steel to improve corrosion resistance. Nickel can be seen in orthopedic devices, compressions, screws, and plates.
- **Titanium (Ti):** Commonly alloyed with other metals to improve strength and corrosion resistance, along with having the ability to bond to bone.
- **Cobalt (Co):** Cobalt alloys are seen in surgical applications mainly related to orthopedic prostheses for the knee, shoulder, and hip and fracture-fixing devices.
- **Stainless Steel:** Stainless steel is made from iron, chromium, and nickel and is used in a variety of medical procedures including dental implants, plastic surgery, and orthopedic surgery.

  A huge amount of variation exists within the world of stainless steel, with well over 100 unique grades of stainless steel available currently. The majority of these grades fall within five general categories:
    - Ferritic stainless steel
    - Martensitic stainless steel
    - Duplex stainless steel
    - Austenitic stainless steel (paramagnetic)
    - Precipitation-hardening stainless alloys

  Ferritic stainless steels have a high amount of chromium and low amount of carbon. This allows the metal to have higher formability properties and will be less likely to crack during forming. These steels are used extensively due to their high amount of chromium (corrosion resistance) and low carbon (formability) and tend to be the least expensive to produce. Ferritic stainless steels consist of the following American Iron & Steel Institute (AISI) grades:

    - 409 stainless steel
    - 430 stainless steel
    - 430LI stainless steel
    - 434 stainless steel

- 439 stainless steel
- 442 stainless steel
- 444 stainless steel
- 446 stainless steel

Unlike ferritic stainless steel, martensitic stainless steel is hardenable by heat treatment. There is less chromium in this metal, so this material is used where corrosion is mild. Martensitic stainless steels have the following AISI grades:

- 410 stainless steel
- 416 stainless steel
- 420 stainless steel
- 431 stainless steel
- 414 stainless steel
- 440 stainless steel

Duplex stainless steels get their name from their two-phase microstructure. They are a combination of ferritic and austenitic (paramagnetic) stainless steels. While exact ratios vary by grade, most duplex steels have a structure that is roughly 50 percent austenite and 50 percent ferrite. This allows the metal to be strong, durable, corrosion-resistant, and relatively inexpensive due to not needing as much nickel to be corrosion-resistant.

QUESTION: Which of the following stainless steels are non-ferrous?

a. Austenitic
b. Ferritic
c. Duplex
d. Martensitic

ANSWER: a

- Austenitic is a non-ferrous stainless steel that is the most commonly used. It is durable and widely used in implant and joint replacements.
- Ferritic is a ferrous metal.
- Duplex is a stainless steel combination of ferritic and austenitic steel.
- Martensitic is a ferrous metal that is used in medicine. It can be heat-tempered, unlike ferritic steel.

Per our discussion on the translational force, we know how ferrous objects are attracted to B_0 based on the changing magnetic field in the scanner room. This environment can cause a ferrous object to act as a projectile and approach the primary magnet at a potentially fast speed and great force.

Rotational force, also known as torque, is a force that is applied to an object, which will result in the object turning (or rotating) to align with the vector of B_0. Like translational forces, rotational forces are at their strongest at the isocenter. When we look at Image 3.2 below and consider these ions to be ferrous, we can see their behavior on the left before entering the MR environment and then being introduced to the MR environment on the right. We can see that the ferrous object's ions will begin to align to the vector of B_0. This is how torque is applied to the object.

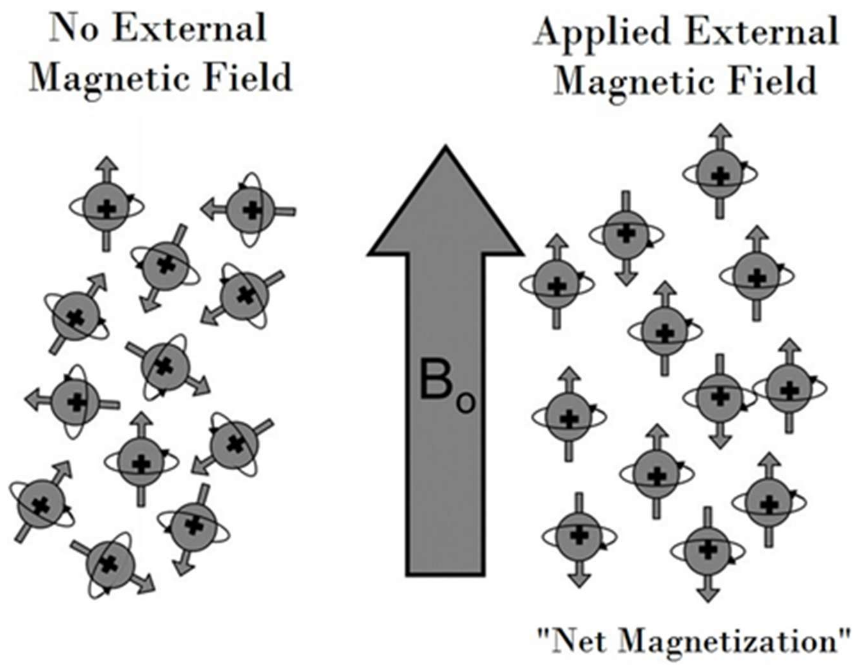

Image 3.2

Like translational force, rotational force can be dangerous to people and equipment. With proper screening of your patient in Zones II and III, external ferrous and MR Conditional objects can be removed from this environment. However, we must also consider objects like implants that may be present inside our patients before they enter the fringe field. Rotational and translational forces applied to patient implants can result in severe injury or even death to the patient.

Consider the following example scenario:

A patient needs to have a head scan. The patient currently has a heart valve implant. After pulling her medical files, you learn the implant is a Carpentier-Edwards PERIMOUNT Magna Mitral Ease valve. You then pull the manufacturer information and find the following data on the implant (Image 3.3):

> **MR Conditional**
>
> Non-clinical testing has demonstrated that the Carpentier-Edwards PERIMOUNT Magna Mitral Ease pericardial bioprosthesis is MR Conditional. A patient with the PERIMOUNT Magna Mitral Ease bioprosthesis can be scanned safely immediately after placement of this implant under the following conditions:
>
> - Static magnetic field of 3 tesla or less.
> - Maximum spatial gradient field of 720 gauss/cm.
> - Maximum MR system-reported whole-body-averaged specific absorption rate (SAR) of 3W/kg for 15 minutes of scanning.

Image 3.3

With this data, you have now determined the limitations of patient exposure to the MR environment. You will then need to check the spatial magnetic gradient graph provided by the MRI manufacturer. The current environment is a 3.0T scanner. We know that the heart stent is in the patient's chest, and you can determine her height per her patient file. We know she needs a head scan, so we will place her head at isocenter. We can see that her chest will encounter a magnetic spatial gradient of 1 T/m during the scan but will experience up to 17 T/m as she enters the bore of the MRI unit.

According to the data on the implant in Image 4.2, the maximum allowable spatial gradient is 720 G/cm. We need to convert this to T/m by taking the following steps:

1. 1T = 10,000G, therefore 1G = 0.0001T
2. 1 m = 100 cm, therefore 1 cm = 0.01m
3. 720 G/cm = 0.0720T/0.01m = 7.2 T/m

Based on our findings, we can say that this MR environment is unsafe for this patient. Though she will experience only 1 T/m during the scan, she will undergo a spatial gradient of up to 17 T/m as she enters the bore, which is more than the allowable 7.2 T/m. This could lead to severe injury or death. The team should consider reviewing the MR environment for a 1.5T scanner instead of a 3T scanner.