Lecture Seven

MRI DESIGN: MR safety – bio-effects

Static magnetic field bio-effects

Current guidelines recommend a maximum limit of 8T for clinical imaging, rising to 12T for research purposes and spectroscopy. Most clinical units operate below 3T.

The following points are *fundamentally* important with regard to the potentially harmful effects of the static magnetic field. The static field is always present (24 hours a day, 365 days a year, to infinity). It is switched on even when the system is out of use (Figure 54.1). The fringe field may extend several metres beyond the examination room and therefore any harmful effects or risks may come into play at some distance from the scanner (Figure 54.2).

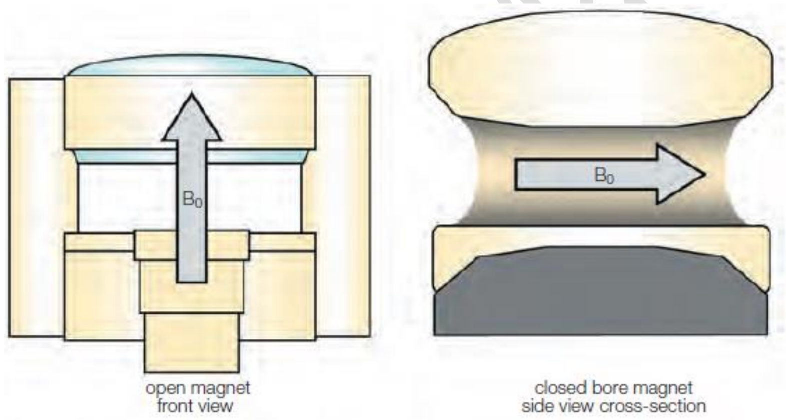

Figure 54.1 Static field in permanent and superconducting systems.

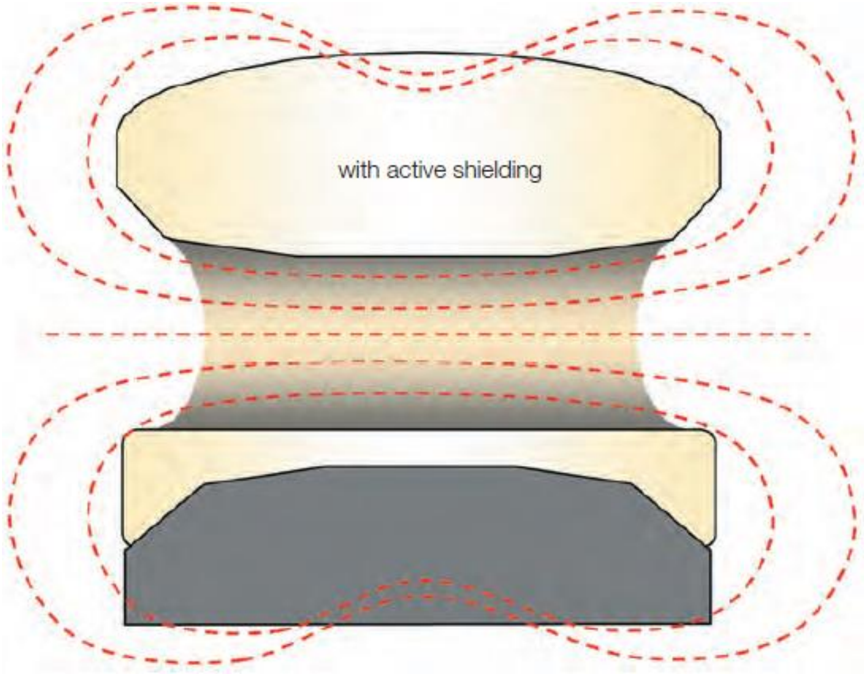

Figure 54.2 The fringe field.

There is no conclusive evidence for irreversible or harmful bio-effects in humans below 2.5 T. Reversible abnormalities may include:

- an increase in the amplitude of the T-wave that can be noted on an ECG due to the magnetic hydrodynamic effect (also known as the magnetic haemodynamic effect);
- heating of patients;
- fatigue;
- headaches;
- hypotension;
- irritability.

Time-varying field bio-effects

Gradients create a time-varying magnetic field. This changing field occurs during the scanning sequence. It is not present at other times and therefore exposure is restricted to patients and to relatives who may be present in the scan room during the examination.

The health consequences are not related to the strength of the gradient field, but to changes in the magnetic field that cause induced currents. Nerves, blood vessels and muscles, which act as conductors in the body, may be affected. The induced current is greater in peripheral tissues, since the amplitude of the gradient is higher away from magnetic isocentre. Time-varying bio-effects from gradient coils include:

- light flashes in the eyes;
- alterations in the biochemistry of cells and fracture union;
- mild cutaneous sensations;
- involuntary muscle contractions;
- cardiac arrhythmias.

RF transmit coils also produce time-varying fields. The predominant bio-effect of RF irradiation absorption is the potential heating of tissue. As an excitation pulse is applied, some nuclei absorb the RF energy and enter the high-energy state. As they relax, nuclei give off this absorbed energy to the surrounding lattice. As excitation frequency is increased, absorbed energy is also increased, therefore heating of tissue is largely frequency dependent.

Energy dissipation can be described in terms of **specific absorption rate** or **SAR**. SAR is expressed in watts per kilogram (W/kg), a quantity that depends on:

- induced electrical field;
- pulse duty cycle;
- tissue density;
- conductivity;
- the size of the patient.

SAR is used to calculate an expected increase in body temperature during an average examination (Table 54.1). In the UK, it is recommended that this should not exceed 1°C during the examination. Studies show that patient exposure up to three times the recommended levels produces no serious adverse effects, despite elevations in skin and body temperatures. As body temperature increases, blood pressure and heart rate also increase slightly. Even though these effects seem insignificant, patients with compromised thermoregulatory systems may not be candidates for MRI.

Table 54.1 SAR limits in the USA.

Area	Dose	Time (mins)	SAR (W/kg)
Whole body	averaged over	15	4
Head	averaged over	10	3
Head or torso	per gram of tissue	5	8
Extremities	per gram of tissue	5	12

Radiofrequency fields can be responsible for significant burn hazards due to electrical currents that are produced in conductive loops. Equipment used in MRI, such as ECG leads and surface coils, should therefore be employed with extreme caution. When using a surface coil, the operator must be careful to prevent any electrically conductive material (e.g. cable of surface coil) from forming a 'conductive loop' with itself or with the patient.

Site planning

There have been a number of fatal accidents in the MR environment. It is therefore vital that access to the MRI system and the magnetic field is controlled. The American College of Radiologists has produced a White Paper that recommends that all centres define the following zones (Figure 54.3).

Zone I includes all areas that are accessible to the public. All personnel are allowed in Zone I.

Zone II is the interface between Zone I and the controlled Zone III. There must be a lock or warning signs between Zones I and II. All personnel are allowed in Zone II, but there should be a trained 'gate-keeper' to keep patients and non-MR personnel from inadvertently entering Zones III and IV.

Zone III is strictly restricted because free access by unscreened personnel and ferromagnetic objects may cause death or serious injury. This area must be strictly monitored and only MR-trained personnel and screened patients are permitted in this area.

Zone IV is only suitable for screened patients under direct and constant supervision from MR-trained personnel, as death and serious injury can occur. The patient may also experience heating, missile effects, RF antenna effects and anoxia in this zone.

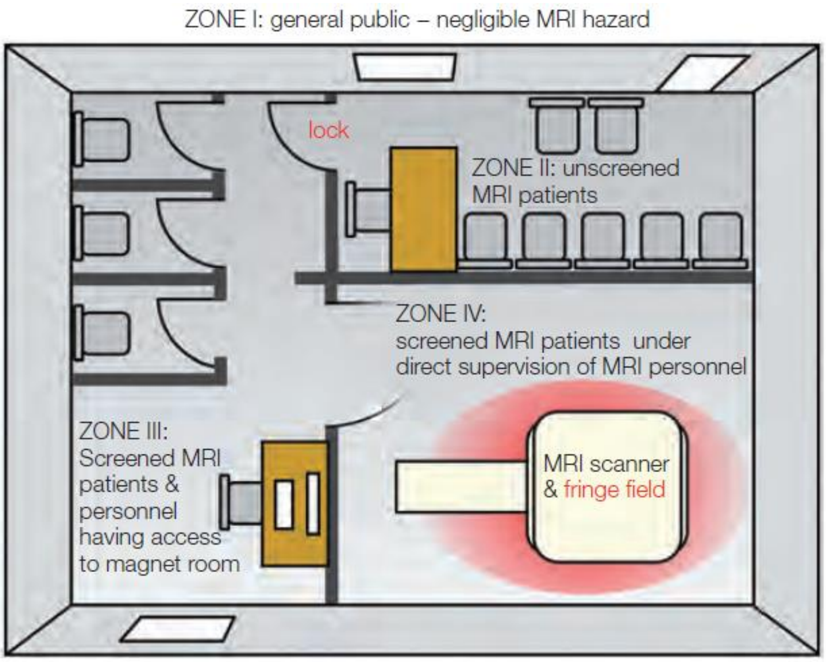

Figure 54.3 The zoning recommended by the American College of Radiology White Paper on MRI safety. Note that there has to be locked access between Zones II and III.

Key points.

- The magnetic field is present 24 hours a day, 365 days of the year.
- There is no conclusive evidence that the static magnetic field is harmful up to 2.5T.
- Time-varying fields imposed by the gradients can have effects, especially when using very fast sequences.
- RF pulses can cause heating. The SAR is a measure of how much energy the patient's tissues absorb during the scan.
- Site planning requires the establishment of clearly marked zones.

MRI DESIGN: MR safety – projectiles

The projectile effect of a metal object exposed to the field can seriously compromise the safety of anyone sited between the object and the magnet system. *The potential harm cannot be over-emphasized.* In many ways the MR scan room is the most dangerous room in a hospital or imaging facility, because it is possible to seriously injure or even kill someone in a second. Even small objects such as paperclips and hairpins have a terminal velocity of 40 mph when pulled into a 1.5 T magnet, and therefore pose a serious risk to the patient and anyone else present in the scan room. Larger objects such as scissors travel at much higher velocities and may be fatal to any person in their path (Figure 55.1).

Figure 55.1 The pulling power of a pair of scissors in a 1.5 T system.

Many types of clinical equipment are ferromagnetic and should **never** be brought into the scan room. These include surgical tools, scissors, clamps and oxygen tanks.

Quenching

If an accident occurs where a patient or other person in the scan room is pinned to the magnet by a projectile that cannot be removed by hand, the magnetic field must be immediately quenched. Quenching is the process whereby there is a sudden loss of absolute zero of temperature in the magnet coils, so that they cease to be superconducting and become resistive. The magnetic field is therefore lost. Quenching can be initiated on purpose, usually by pressing a quench button in the control room, or it may happen accidently. Quenching causes helium to escape from the cryogen bath extremely rapidly. Quenching may cause severe and irreparable damage to the superconducting coils, and so all systems should have helium-venting equipment, which removes the helium to the outside environment in the event of a quench. However, if this fails, helium vents into the room and replaces oxygen. For this reason, all scan rooms should contain an oxygen monitor that sounds an alarm if the oxygen falls below a certain level.

Metallic implants and prostheses

Devices are tested on an ongoing basis for MR safety and many manufacturers have developed MR-safe devices. It is therefore vital to check the type of device or implant and whether it is safe before booking the appointment. Metallic implants and prostheses produce serious effects, which include torque or twisting in the field, heating effects and artefacts on MR images. The type of metal used in such implants is one factor that determines the force exerted on them in magnetic fields. While non-ferrous metallic implants may show little or no deflection to the field, they could cause significant heating due to their inability to dissipate the heat caused by radiofrequency absorption. Devices that might need to be taken into the scan room must be tested beforehand. There are standard labels depending on whether the device is safe, unsafe or conditional on the field strength (Figure 55.2).

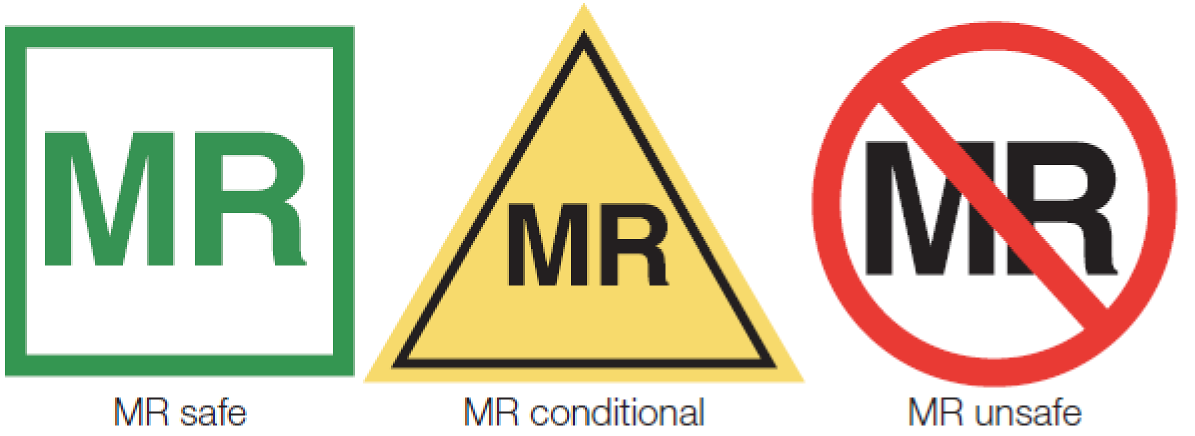

Figure 55.2 Standard labels associated with MR device testing.

What is not safe to scan?

Cochlear implants are attracted to the magnetic field and are magnetically or electronically activated. They are therefore unsafe to scan. It is not uncommon for patients who have worked with sheet metal to have metal fragments or slivers located in and around the eye. Since the magnetic field exerts a force on ferromagnetic objects, a metal fragment in the eye could move or be displaced and cause injury to the eye or surrounding tissue. Therefore, all patients with a suspected eye injury must be X-rayed before the MR examination.

Aneurysm clip motion may damage the vessel, resulting in haemorrhage, ischaemia or death. Currently, many intracranial clips are made of a non-ferromagnetic substance such as titanium. However, some of these may still deflect in a magnetic field. It is therefore recommended that imaging of patients with aneurysm clips is delayed, until the type of clip is emphatically identified as non-ferrous and non-deflectable. Intracranial clips also cause severe magnetic susceptibility artefact, especially in gradient echo sequences (Figure 55.3).

Although MR-safe pacemakers have been developed, it is important to assume that most patients do not have this kind of pacemaker. Even field strengths as low as 10 gauss may be sufficient to cause deflection, programming changes and closure of the reed switch that converts a pacemaker to asynchronous mode. Patients who have had their pacemaker removed may have pacer wires left within the body that could act as an antenna and (by induced currents) cause cardiac fibrillation.

What is probably safe to scan?

Prosthetic heart valves are deflected by the static magnetic field, but this is minimal compared to normal pulsatile cardiac motion. Although patients with most valvular implants are considered safe for MR, careful screening for valve type is advised.

Most orthopaedic implants show no deflection within the main magnetic field. A large metallic implant such as a hip prosthesis can become heated by currents induced in the metal by the magnetic and radiofrequency fields. It appears, however, that such heating is relatively low. The majority of orthopaedic implants have been imaged with MR without incident.

Abdominal surgical clips are generally safe for MR because they become anchored by fibrous tissue, but produce artefacts in proportion to their size and can distort the image.

Key points.

- The MR scan room can be considered the most dangerous room in the hospital or imaging facility.
- Objects are accelerated towards the magnet at very high velocity depending on their mass, the strength of the magnetic field and what they are made of.
- Anyone entering the scan room must have been thoroughly screened and checked by a trained MR practitioner.
- Implants and any devices being taken into the scan room must be checked beforehand.

Q: The heating of tissue is largely frequency dependent. Discuss!!!