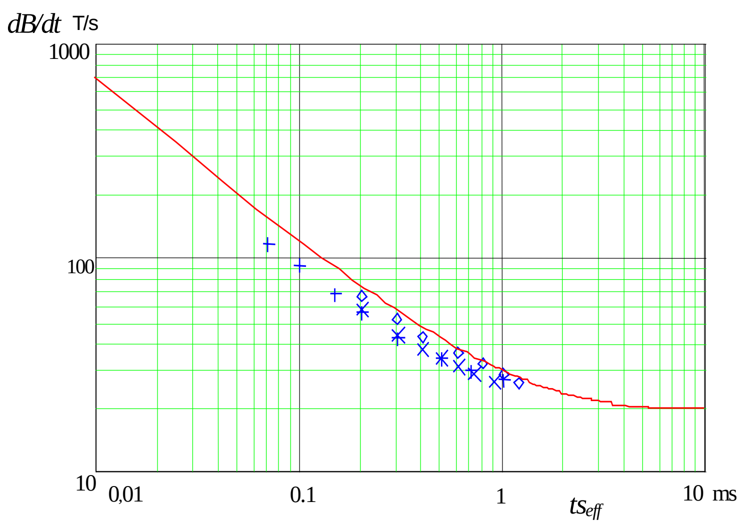
Introduction to MR Safety Dick J. Drost

Three EM fields with associated safety issues are required for MR imaging.

1. A static homogenous magnetic field, which typically ranges from 0.2 to 3.0 Tesla, often referred to as the Bo field, is required to polarize the hydrogen nuclei into two energy levels. One of the safety hazards associated with this field includes the "projectile hazard" where ferromagnetic objects, for example oxygen cylinders are rapidly accelerated towards the magnet center. Another hazard is the pull or torque on ferromagnetic particles within the patient as the patient is inserted or removed from the center of the magnet. Imbedded ferromagnetic materials can include brain aneurysm clips used during surgery or iron particles in the eye from machining accidents. Magnetic fields also alter the function of implanted electronic devices such as cardiac pacemakers. Therefore, cardiac pacemakers are a contraindication for an MR scan. Since most MR magnets are superconducting and therefore require that the superconducting windings are in a liquid helium filled container, there are some additional hazards associated with the cryogen liquid. If a magnet quenches (a small fraction of a winding becomes resistive and rapidly expands resulting in a collapse of the magnetic field with its energy converted to heat) approximately a 1000 l of liquid helium is converted to a gas, which can asphyxiate anyone in the magnet room if not vented. Some magnets also have active shielding. With this technology additional superconducting windings have been added to the ends of the magnet, which oppose the main static field. This design reduces the stray magnetic fields making the magnet easier to site, but increases the magnetic field gradient at the magnet opening which provides less warning for an impending projectile hazard. Therefore a shielded magnet is not a safer magnet.
2. A radio frequency (RF) field is used for exciting the H nuclei from their low to high energy levels and for recording the RF emitted when the H nuclei fall back to their low energy level. These RF signals are used to reconstruct the MR image. The RF fields are generated with a near field antenna usually referred to as a RF coil. These coils, normally cylindrical, surround the patient and are magnetically closely coupled to the body, but optimally designed to have very little electric field coupling to the body. For a 1.5 T static magnetic field the operating RF frequency, referred to as the Larmor frequency, is 63 Mhz. The magnetic component of the RF field induces current loops within the conductive tissues of the body, which in turn generate heat. The amount of heat deposited in the body is referred to as the Specific Absorption Rate (SAR) and has units of Watts/kg. SAR varies with the particular type of MR imaging sequence, body size, and as the square of the static magnetic field strength (everything else being equal, SAR increases by 4 when imaging at 3 T as compared to 1.5 T). The FDA and the International Electrotechnical Commission (IEC) have set specific SAR limits during MR imaging to prevent overheating the patient. A second hazard, a RF burn, can occur if a metallic conductor is present within or on the surface of the

patient. The mechanism of a RF burn is thought to be the following: the metal conductor forms a resonant circuit with the surrounding tissue at or very near the operating (Larmor) frequency of the MR system. As a result there is a very efficient transfer of power from the RF coil (instantaneous power up to 10 kilowatts) to the resonant metal conductor/tissue circuit causing an almost instantaneous RF burn. The resulting tissue damage is similar to an electrical burn.

3. The third type of field required for MR imaging are the 3 orthogonal time changing gradient magnetic fields. Since these are gradients rather than a uniform magnetic field they alter the Larmor frequency of the H nuclei as a function of spatial location. This alteration in frequency as a function of spatial location is used for image reconstruction through a Fourier Transform. MR imaging requires that these gradients be switched on and off rapidly (under a few hundred usec) which can cause peripheral nerve stimulation. This does not permanently injure the patient, but can become painful. The mechanism for this is that the time changing magnetic field, often referred to as dB/dt, induces an electric field within the patient which if large enough can stimulate nerves. Experimentally it has been found that both the dB/dt magnitude and the switching duration determine whether a subject will experience peripheral nerve stimulation. This is best illustrated in the following figure taken from the IEC MR safety guidelines.



As gradient switching becomes more rapid, ts_{eff} decreases, and higher values of dB/dt are required to reach peripheral nerve stimulation.

A short aside on units: gradients are usually specified in mT/m or gauss/cm. A gradient strength of 40 mT/m would mean that the magnetic field from this gradient is an additional 8 mT in the same direction as the main static magnetic field at a point 20 cm from the center of the magnet. If this gradient switched from 0 to this value in 200 usec the dB/dt value at this location would be 40 T/s. Since this value is well below the red line on the graph at a value of ts_{eff} = 0.2 ms, peripheral nerve stimulation should not occur for these gradient values.

A second hazard associated with the gradient fields is acoustic noise. The time switching gradient magnetic fields interact with the main static field creating a very loud drumming sound that can lead to hearing loss. Again the FDA and IEC have guidelines to protect patients from both peripheral nerve stimulation and hearing loss.

All the above MR fields have well understood mechanisms for causing patient discomfort and harm; therefore hardware and software limits along with proper MR technologist safety training can be implemented to protect the patient. There are also possible biological effects where there is no understood or accepted mechanism. For example, repeated epidemiological studies have shown a very small increase in childhood leukemia from exposure to magnetic fields from power lines. Currently there is no accepted mechanism to explain this result, leaving open the question of whether the magnetic fields from a MR scan can have any long-term effects. This last topic will also be discussed in this CE course.

References

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